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Contents

The Vine

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There are over a thousand known grape varieties in the world, but the vast majority of these varieties belong to one species, *Vitis vinifera*. This species is indigenous to Eurasia. North American vine species are also used in wine production in some regions (e.g. New York State), but their main function globally is as rootstocks (see Planting Materials) onto which *V. vinifera* is grafted. The most important North American species are *Vitis labrusca*, *Vitis riparia*, *Vitis berlandieri* and *Vitis rupestris*.

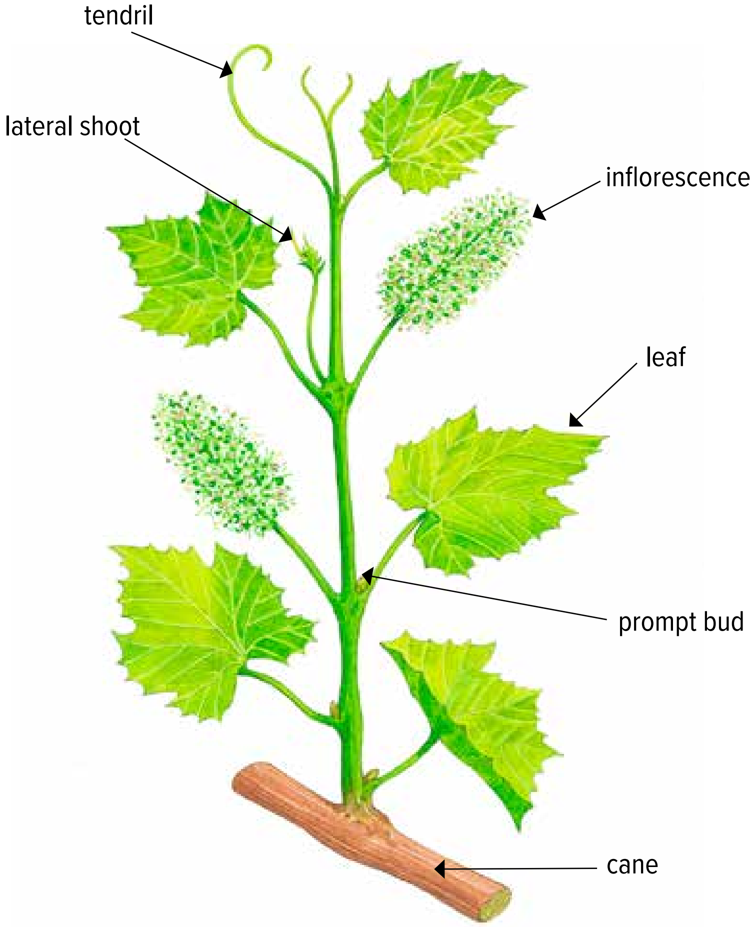
1.1. The Anatomy of the Vine

All vines have a similar structure. This structure can be divided into four sections: the shoots, one-year-old wood, permanent wood and the roots. The shoots and all of their major structures – buds, leaves, lateral shoots, tendrils and inflorescences/grape bunches – are collectively called the canopy.

THE STRUCTURE OF THE SHOOTS

The shoots on the vine grow in spring from buds retained from the previous year. The major structures of the shoots are the buds, leaves, tendrils, lateral shoots and inflorescences or grape bunches. The main axis of the shoot transports water and solutes to and from the different structures (solutes are substances that dissolve in a liquid to form a solution and in this instance include sugars and minerals). It is also a store of carbohydrates. The little swellings along the shoot, where the other structures are attached, are called nodes. The lengths in between the nodes are called internodes.

In late summer, the leaves fall from the vine and the green shoots lignify (become woody, rigid and brown); from this point they are called canes. During the winter the vine will be pruned to leave the necessary structures for the next growing season (see Vine Pruning in Canopy Management Techniques).



A vine shoot at flowering

A bud before budburst

Buds

Buds form between the leaf stalk (petiole) and the stem. As they mature they contain all the structures in miniature that will become green parts of the vine, including the stem, buds, tendrils, leaves and often inflorescences. There are two main types of buds:

- **Compound buds** (also called latent buds) form in one growing season and break open in the next growing season (provided they are retained during winter pruning). They produce the shoots in the next growing season.
  Within a compound bud, there is typically a primary bud (the main growing point) and smaller secondary and tertiary buds. The secondary and tertiary buds usually only grow if damage has occurred to the primary bud (e.g. spring frost).
- **Prompt buds** form and break open in the same growing season. They form on the primary shoot (that has just grown from a compound bud) and produce lateral shoots.

Lateral Shoots

Lateral shoots grow from buds formed in the current year (prompt buds). They are smaller and thinner than the primary shoots. Lateral shoots have a stem, leaves, buds, tendrils and sometimes inflorescences. Their main function is to allow the plant to carry on growing if the tip of the primary shoot has been damaged or eaten. Lateral shoots can provide an additional source of leaves for photosynthesis (the process by which green plants use sunlight to produce sugars from carbon dioxide and water), which can be useful if the laterals are near the ends of the primary shoots and able to benefit from sunlight. Growth of laterals nearer the base of the primary shoot can be undesirable as they impede air flow and can shade the fruit too much. They may be removed in summer pruning (see Canopy Management Techniques).

Lateral shoots often produce inflorescences, which can be known as a 'second crop'. However, this can depend on the grape variety and canopy management techniques. Pinot Noir is a grape variety that often forms inflorescences on lateral shoots. These inflorescences become bunches of grapes later than those on the main stem and hence ripen later. If harvested at the same time as the main crop, the bunches in the second crop will be higher in acidity, lower in sugar and may have unripe tannins and aromas/flavours and, in black grapes, less colour development. The second crop may be removed during the growing season by green harvesting (see Summer Pruning in Canopy Management Techniques); this technique is thought to enhance the ripening process and improve the uniformity of ripeness of the remaining bunches. Alternatively, if fruit is hand-harvested, the ability to be selective means the second crop need not be picked or can be separated. However, this is not possible when fruit is machine harvested, and the second crop may therefore have an impact on the must (the substance that is fermented to make wine) and finished wine.

Tendrils

The shoot cannot support itself, therefore vines have tendrils. In the wild, these tendrils would have enabled the vine to attach itself to other plants or trees, providing support. In viticulture, grape growers can use a trellis to position the vine canopy (for more details see Trellising in Canopy Management Techniques). The tendrils curl around trellis wires and keep the canopy in place. However, grape growers typically do not trust the tendrils to hold the vine to the trellis on their own and therefore they tie in canes and shoots as necessary.

Leaves

The leaves are the main site of photosynthesis in the vine. The sugars produced in photosynthesis are used for vine growth and metabolism. Stomata (pores) open on the underside of the leaves, letting water diffuse out and carbon dioxide for photosynthesis to enter. As water diffuses from the leaf, a process called transpiration draws water and nutrients from the soil up through the vine to the leaves. These stomata partially close if the vine is water stressed. This can help conserve water, but limits photosynthesis by preventing carbon dioxide from entering the vine (see The Effects of Water).

Inflorescences

The inflorescence is a cluster of flowers on a stem, which becomes a bunch of grapes at fruit set (see Flowering and Fruit Set for more details). The number of inflorescences on each shoot can depend on the grape variety but is usually between one and three.

An inflorescence

Bunches

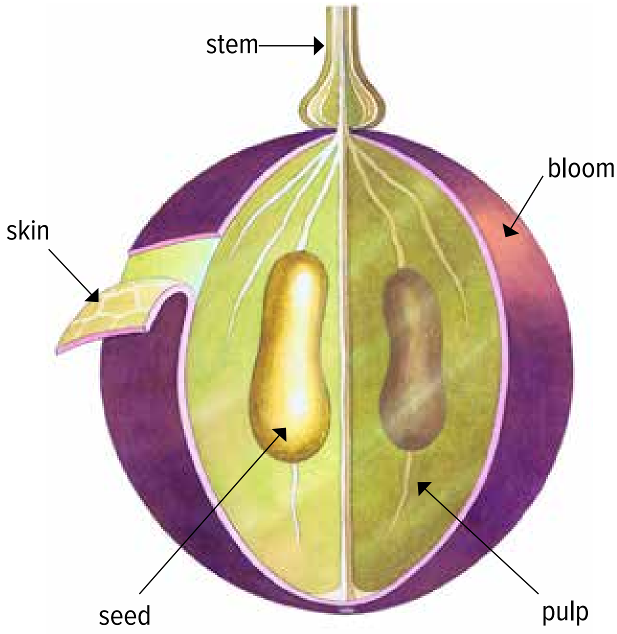
A bunch of grapes is a fertilised inflorescence. Usually, not all the flowers in the inflorescence will successfully become grapes. The characteristics of the individual grapes, as well as the size and shape of the bunch, varies between grape varieties and even between different clones of the same grape variety.

Some grape varieties can have very tight bunches (e.g. Pinot Noir) and are more prone to fungal diseases due to the increased likelihood of grape-skin splitting during growth and lack of air flow through the bunch.

Grapes

A grape is a type of berry. In broad terms, a grape is made up of pulp, skin and seeds.

- **Pulp** – The pulp makes up the majority of the grape's weight and volume. It contains water, sugars, acids and some aroma compounds and aroma precursors (see Wine Components). The pulp of most grapes is colourless. Exceptions include *teinturier* varieties, which have red-coloured pulp (e.g. Alicante Bouschet); however, these are not common.
- **Skin** – The skin of the grape contains a high concentration of aroma compounds and aroma precursors, tannins and colour compounds. The amount of tannins and colour in black grapes is significantly higher than in white grapes.
- **Seeds** – Seeds mature inside the grape, turning yellow to dark brown. Seeds contain oils, tannins and the embryo, which can grow into a new plant.



Parts of the grape

A powdery waxy coating, called the bloom, covers the surface of the grape. The grape is attached to the vine by a stem, which contains tannins. The development and ripening of the grape is covered in Grape Development.

ONE-YEAR-OLD WOOD

One-year-old wood refers to the shoots from the previous growing season that were not removed at pruning. The amount of one-year-old wood will depend on the pruning and training decisions made by the grape grower. Importantly, the one-year-old wood supports the compound buds that will break to release the shoots for the upcoming growing season. Depending on how the vine is pruned the one-year-old wood will either be a cane or a spur (for more details see Vine Training in Canopy Management Techniques).

A cane-pruned vine. The canes are one-year-old wood.

PERMANENT WOOD

These are the woody parts of the vine that are older than one year, including the trunk. Depending on pruning and training decisions, some vines also have one or more horizontal arms of permanent wood, typically called cordons. The trunk and cordons provide support for the other parts of the vine. They transport water and solutes to and from different parts of the vine and store carbohydrates and nutrients.

The trunk and cordons of this vine are permanent wood.

ROOTS

The roots are important for anchoring the vine and also for the uptake of water and nutrients. The roots are also a store of carbohydrates and produce hormones that have important functions within vine growth and grape ripening. In most cases, vines are grafted onto a rootstock (for more details on choice of rootstock see Planting Materials).

Most of the vine's roots are found in the top 50 cm of the soil, although vine roots have been found that reach over six metres down into the soil. Distribution of the main framework of roots is influenced by the soil properties, irrigation, cultivation and the type of rootstock. The water and nutrients are absorbed at the root tips, where the roots are actively growing.

1.2. Vine Propagation

In modern viticulture, vines are propagated by cuttings or layering. A cutting is a section of a vine shoot that can be planted and will then grow as a new plant. It is by far the most common propagation technique as many small cuttings can be taken from a vine and propagated at the same time. Importantly, it also permits the use of rootstocks, onto which the vine cutting can be grafted before it is planted. In addition, nurseries are able to treat vine cuttings to avoid spread of diseases.

Layering is a method of filling gaps in a vineyard (e.g. due to the death of a vine) by using shoots from an established neighbouring vine to produce a new vine. A cane is bent down and a section of it is buried in the ground. The tip of the cane points up out of the ground. The section that is buried takes root and, once these roots are established, the cane linking the new growth to the original plant is cut. The new vine grows on its own roots, not those of a rootstock, and this method is therefore not always suitable. The new vine will have no protection against phylloxera or have the qualities (such as the desired yield) that a choice of rootstocks offers (for more details see Planting Materials).

A cane buried in the ground as part of the layering process.

These two methods create new plants that are usually genetically identical to the parent plant, and therefore have the same characteristics. Importantly, in viticulture, vines are not propagated through seeds (although see New Grape Varieties). Vines that grow through seeds are not genetically identical to the parent vines and although they can show similar characteristics to their parents, more often they are notably different.

CLONES

As stated above, the methods of cutting and layering usually produce vines that are genetically identical to the parent vine. However, at each cell division during plant growth there is the risk that random mutations in the genetic code will occur. Many of these mutations have no effect on the vine; however, some will cause the new vine to have slightly different characteristics (e.g. smaller or larger grapes, thicker or thinner grape skins, more or less disease resistance, etc.). This causes diversity within the vines of the same grape variety.

Vines with particularly favourable characteristics are selected by vine nurseries or grape growers for propagation by cuttings in order to grow new vines with these favourable characteristics. This is known as clonal selection. The process of clonal selection has given rise to different 'clones' within a grape variety. Plants of the same clone have the same characteristics as each other and are slightly different from vines of a different clone.

Pinot Noir is a grape variety with many clones:

- Pinot Noir Clone 115 has low yields of small grapes, making it suited to high quality red wine production.
- By comparison, Pinot Noir Clone 521 has higher yields of bigger grapes, making it better suited to sparkling wine production. This is because high concentrations of tannins and colour from the skins are not needed in these wines.

(For more information on the choices involved in the selection of grape varieties and clones see Planting Materials).

On rare occasions, a mutation might be so significant that the new vine is classified as a new grape variety. For example, the grape varieties Pinot Noir, Meunier, Pinot Blanc and Pinot Gris are all mutations of the grape variety Pinot.

The most common way of obtaining new planting material is to buy young vines from a nursery, which will typically offer particular clones of grape varieties. One of the reasons for this is that young vines purchased from nurseries have been tested to be free from virus infection. However, depending on the region and the grape variety, only a very limited number of clones may be available from nurseries. The limited supply of clones means that the vines planted across a vineyard or even a region can be relatively uniform, especially if natural factors are consistent across the region. This may have some benefits: if all of the vines grow in a similar way and ripen grapes at the same time as each other, management of the vineyard becomes simpler. However, it can also be disadvantageous, meaning there is less diversity in the fruit and hence potentially producing a wine with less complexity and balance (if that is desired for the style and quality of the wine). It also makes the vineyard more susceptible to disease (the identical vines are likely to all be equally susceptible to a disease or pest). For these reasons, where available, a grape grower will often buy and plant a number of different clones of the same grape variety.

MASS SELECTION

Clonal selection is a relatively recent practice that became common within the last 40–50 years. Before this, grape growers would propagate their vines through the process of mass selection (also termed *Selection Massale*), a technique regaining popularity with some vineyard owners. The technique requires vineyard owners to take cuttings from the vines in their own vineyard(s) and cultivate these cuttings. (The cuttings can be sent to a nursery for grafting onto rootstock where necessary.) Cuttings are taken from several different vines. Generally, the best-performing vines are selected (e.g. those that consistently yield fruit with the desired characteristics). These vines are selected after several years of monitoring and recording their performance.

An advantage of mass selection is that it increases the diversity of planting material in the vineyard and throughout the region. Another advantage is that the vineyard owner is using their own unique planting material (different from that being bought from the local nursery), which can enhance fruit quality and/or yield (and can be used as a marketing asset). However, the selection and monitoring of vines to ensure the propagation of the best vines is costly in terms of time and labour. Further, if the parent vine is infected by disease (e.g. a virus), this is likely to be passed onto the new vines, and therefore this technique can increase the spread of vine diseases.

NEW GRAPE VARIETIES

New grape varieties are typically produced from seeds. The pollen from the stamens of the flowers of one vine is transferred to the stigmas of the flowers of another vine and fertilisation occurs; this is called cross fertilisation. Grapes develop and the seeds from these vines are planted and grown. The new vines that grow from the seeds will all have different characteristics, in the way that siblings in a family are not identical to each other or their parents. If one of the new vines has desirable characteristics, it may be propagated by cuttings to create identical vines.

The performance of the new vine will be assessed over a long period. If there is thought to be value in making this new variety available commercially, it will need to be registered on the OIV catalogue as a new grape variety. When the two parent vines are from the same species, the offspring is called a cross. For example, Pinotage is a cross of Pinot Noir and Cinsaut. When the two parent vines are from different species, the offspring is called a hybrid. Possibly the best-known hybrid for wine production is Vidal Blanc, often simply called Vidal, from Ugni Blanc (*V. vinifera*) and a member of the Seibel family (American parentage).

It is thought that many grape varieties with a long history of cultivation were created through cross fertilisation that happened by chance in the wild. For example, it is likely that Cabernet Sauvignon was formed by a chance cross fertilisation of Sauvignon Blanc and Cabernet Franc. In modern viticulture, scientists actively try to create useful new grape varieties by carrying out cross fertilisation in a laboratory environment. The aim is usually to create an offspring that has the favourable characteristics of the two parent vines, but in reality, this often does not happen. For example, Müller-Thurgau, a cross between Riesling and Madeleine Royale, was created to have the fruit quality of Riesling and the high yield of Madeleine Royale. However, while it has proved to be a variety valuable for its yields, very few would claim it has the same quality potential as Riesling.

> Read about the five Pierce's Disease-resistant grape varieties that UC Davis recently released here.

Various hybrid varieties were bred in an attempt to combine the resistance of non-*vinifera* species (to diseases, pests or climatic extremes) and the quality of fruit from *V. vinifera*. Unfortunately, many hybrids do not produce fruit that matches the quality of most *V. vinifera* (although there are notable exceptions), but their other characteristics make them useful as rootstocks. Resistance against disease (e.g. Pierce's Disease in California), pest and climatic extremes (e.g. drought) are still important aims of current vine breeding programmes.

As knowledge of grapevine genetics has increased, it has become easier for scientists to use genetic markers to select the offspring with the characteristics they want without having to wait for the vine to grow and bear fruit, speeding up vine breeding programmes considerably. However, still, new grape varieties rarely come to market; the main reason is consumer resistance.

2 The Vine Growth Cycle

The Vine Growth Cycle

The grape grower's aim is to produce the largest possible crop of grapes that are of suitable ripeness and quality for the style of wine being produced. However, a vine left to grow without human intervention has different aims. In the wild, vines are woodland climbers. They grow quickly, clinging to trees for support and when they reach sunlight at the top of the woodland canopy, they flower and produce fruit. The key purpose of the grapes is to attract birds and other animals, which eat them and disseminate the seeds. These grapes may be palatable for the birds, but they would not be suitable for producing wine. The grape grower therefore needs to manipulate the vine into producing grapes with adequate ripeness of sugar, acids, tannins and aromas/flavours for the wine style being produced.

Given their natural habitat in woodland locations, with high competition from other plants, vines are able to survive on limited natural resources. However, the vine does require access to adequate water, sunlight and warmth for photosynthesis. (Carbon dioxide is also required for photosynthesis. It becomes the limiting factor for photosynthesis if the vine has sufficient water, temperature, sunlight and nitrogen, but is outside the control of the grape grower.) Warmth is also needed for other essential reactions such as respiration, the process in which energy is released from food substances, in this case, sugar. The vine also requires certain nutrients, which are important for cell structure and function and therefore vine growth and reproduction.

The amount of heat, sunlight, water and nutrients, and the timings of these key resources within the growth cycle, are important if the vine is to produce grapes suitable for making wine. The grape grower will manage the vineyard to try to compensate for any shortfall or excess in the provision of these resources by the growing environment.

This chapter will focus on each stage of the vine growth cycle and the conditions that are beneficial or detrimental for the production of grapes for wine.

2.1. Dormancy

November–March in the Northern Hemisphere, May–September in the Southern Hemisphere

What the vine needs during this stage:
Temperatures below 10°C (50°)

Adverse conditions:
- Extremely cold temperatures
- Unusually mild temperatures

Pruned vines in late winter in Tuscany

Average air temperatures below 10°C (50°F) are too cold for the vine to grow and therefore in winter the vine is dormant. Winter dormancy typically starts with leaf fall in the autumn and ends with budburst in the spring. Without leaves, the vine cannot photosynthesise. Therefore, until it has grown new leaves, the vine sustains itself by using stores of carbohydrates, mostly starch, accumulated during the previous growing season in the roots, trunk and branches.

Extremely low temperatures, such as those found in the winter in Canada, New York State and China, can be harmful to the vine even when it is dormant. Vines can be severely damaged or killed by temperatures below −20°C (–4°F). Temperatures below −25°C (−13°F) will kill most *V. vinifera*. There are vineyard management techniques that can be used to protect the vine in areas of winter freeze (see Hazards).

Winter pruning is carried out during this dormant period (for more details see Vine Pruning in Canopy Management Techniques).

2.2. Budburst

March–April in the Northern Hemisphere, September–October in the Southern Hemisphere

What the vine needs during this stage:
- Average air and soil temperatures above 10°C (50°F)

Adverse conditions:
- Frost
- Cold soils

Budburst

Budburst, also called budbreak, marks the end of winter dormancy. In this process, buds swell and open, and green shoots start to emerge. The timing of budburst depends on a number of factors.

AIR TEMPERATURE

Compound buds form and begin to develop in the previous growing season. For buds to burst, sufficiently high temperatures are needed (average air temperature approximately 10°C / 50°F). Compound buds therefore generally remain dormant over winter and burst when temperatures rise in the spring.

Regions that have marked differences in temperature between the various seasons (for example, continental climates – see Climate Classifications) can be advantageous for successful budburst. In these places, the rapidly increasing temperatures in the spring mean that budburst can be relatively uniform and this has positive implications for the homogeneity of later stages in the growing season, potentially eventually leading to a crop of grapes with even ripeness.

In regions where there is often less contrast between winter and spring temperatures (for example, maritime climates – see Climate Classifications), budburst can be less synchronised. Furthermore, problems can occur when a few unusually mild winter days cause early budburst; any cold days and frosts that follow can potentially harm the newly burst buds, leading to lower yields. Grape growers can protect new buds from frost using a number of strategies (see Hazards for more details).

SOIL TEMPERATURE

Higher soil temperatures around the roots encourage earlier budburst. Dry, free-draining soils, such as sandy soils, tend to warm up more quickly than water-storing soils, such as clay-rich soils, and therefore can be advantageous in cool climates where an early start to the growing season improves the chance of ripening.

GRAPE VARIETY

The average temperature required for budburst depends on the grape variety. For example, buds on Merlot vines open at temperatures slightly lower than 10°C (50°F), whereas Ugni Blanc buds open at temperatures slightly higher than 10°C (50°F). Grape varieties that require relatively low temperatures at budburst are referred to as 'early budding'. They include Chardonnay, Pinot Noir, Merlot and Grenache. Grape varieties that require higher temperatures are referred to as 'late budding' and include Sauvignon Blanc, Cabernet Sauvignon and Syrah. Because the buds of late-budding varieties need higher temperatures to burst, they are less at risk of spring frosts. (Please note that time of budding is not always linked to time of ripening and hence a grape variety that is early budding is not necessarily also early ripening. For example, Grenache buds early and ripens late.)

HUMAN FACTORS

Some grape growing practices can also advance or delay budburst. For example, carrying out winter pruning late in the dormant period can postpone budburst, and this technique can be used in areas where spring frost is a known problem.

2.3. Shoot and Leaf Growth

March–July in the Northern Hemisphere, September–January in the Southern Hemisphere

What the vine needs during this stage:
- Stored Carbohydrates
- Warmth, sunlight, nutrients and water

Adverse conditions:
- Low carbohydrate levels (caused by conditions in the previous growing season)
- Water stress

During spring and early summer, the shoots continue to grow, and leaves and inflorescences (a cluster of flowers on a stem) mature. The fastest rate of growth generally occurs between budburst and flowering. The speed of shoot growth can vary between vines and even within different parts of the same vine.

The term 'vigour' is often used to describe vegetative vine growth, which includes the growth of the shoots, leaves and lateral shoots, and has implications on the yield and ripening of the grapes. Hence, vines with high vigour can grow long shoots with large leaves

A very young shoot, showing an inflorescence in early development

A young shoot

and lots of lateral shoots. The vigour of the vine depends on a number of factors including the natural resources available to the vine (particularly temperature, water and nutrients), the planting material (grape variety, clone and rootstock) and the presence of any disease (e.g. viruses can lower vigour). Many grape growing choices, particularly within the field of canopy management, are made with consideration of the vine's vigour and how this can best be managed to provide the yield and quality of grapes desired. This is explained further in Canopy Management.

Carbohydrates stored in the roots, trunk and branches of the vine support initial shoot growth. If these carbohydrate levels are low (for example, caused by excessive leaf removal, water stress, mildew infections or excessively high yields in the previous growing season), shoot growth can be negatively affected. As leaves develop and mature, they provide energy for further growth via photosynthesis, and therefore need adequate warmth and sunlight for this to take place. Most of the vine's energy is directed towards shoot growth until flowering starts.

As the vine grows, so does the vine's need for nutrients (principally nitrogen, potassium and phosphorus). It is important that vines do not suffer from water stress in this time as this can limit photosynthesis and shoot growth. Nutrient uptake through the roots is also impaired in very dry soils.

Stunted shoot growth can lead to small, weak shoots, a reduction in leaf number or smaller leaves, inflorescences that do not flower properly and/or grape bunches that do not ripen fully. This can lead to poor quality and lower yields.

As shoots grow longer they may be tucked within a trellis (if used) to ensure the canopy remains upright and to avoid shading.

2.4. Flowering and Fruit Set

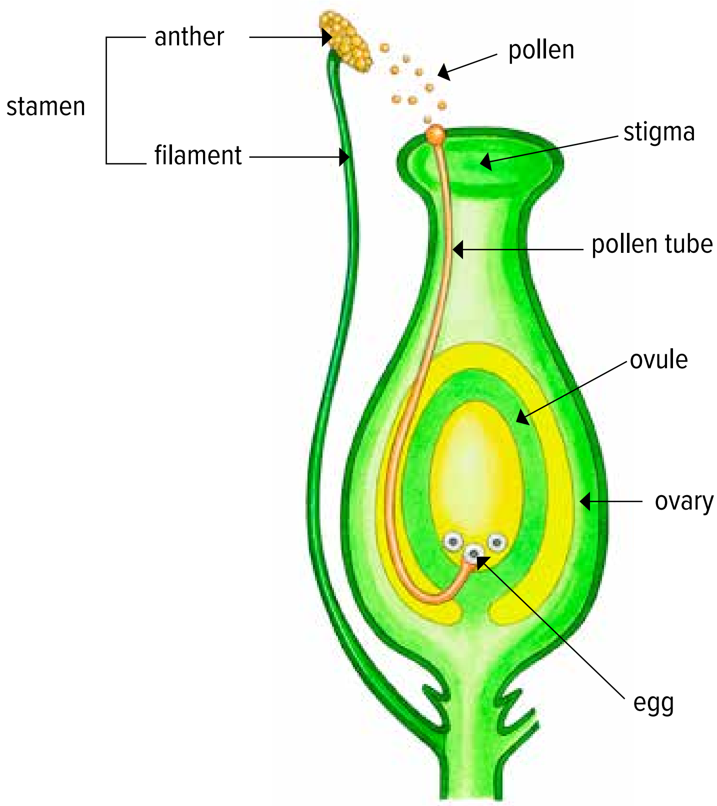
May–June in the Northern Hemisphere, November–December in the Southern Hemisphere

What the vine needs during this stage:

- Warm temperatures (minimum 17°C/63°F)
- Sunlight, warmth, water and nutrients for bud fruitfulness in the next growing season

Adverse conditions:

- Rainy
- Cloudy
- Windy
- Cold temperatures



Parts of a vine flower

New buds develop at the base of the leaf stalks (petioles) on the new growing shoots. Prompt buds will burst within the growing season producing new shoots called lateral shoots (see The Anatomy of the Vine). Compound buds will remain dormant until the following spring and provide the shoots for next year. Shading of compound buds, temperatures that are too low (under 25°C / 77°F), water stress and nutrient deficiency can all limit bud fruitfulness (the number of inflorescences that will develop from a bud) in the next growing season. Given that each inflorescence will become a bunch of grapes, the conditions during this part of the growing season can have a substantial influence on the next year's yield. That said, there is some variation between grape varieties. Riesling, for example, is able to form potentially fruitful buds at relatively low temperatures making it well-suited to cool climates.

The yield and quality of grapes in the current growing season are strongly influenced by the processes of flowering and fruit set. Flowering describes the opening of the individual flowers within an inflorescence. Within this process, the pollen-laden stamens (consisting of an anther and filament) are exposed. The pollen grains are shed and land on the moistened

An inflorescence before flowering

A close-up of an inflorescence in flower

Fruit set

stigma surface, a process called pollination. Here, they germinate, with each pollen grain producing a pollen tube. These pollen tubes penetrate the stigma and then the ovule (the female reproductive cells) in the ovary. The pollen tube delivers the sperm cells that fertilise the eggs in the ovule. This leads to the formation of a grape berry. The fertilised ovules form seeds, with up to four per grape. The wall of the ovary enlarges to form the skin and pulp of the grape. Fruit set is the term used to describe this transition from flower to grape. Research has shown that cultivated varieties of vines are normally self-pollinating (the pollen from the stamens of one flower is transferred to the stigma of the same flower, or a different flower in the same plant). Insects and wind make little contribution to pollination in grapevines.

CONDITIONS FOR SUCCESSFUL FLOWERING

Flowering typically takes place within eight weeks of budburst. However, this timing is extremely temperature dependent, with warm conditions leading to earlier flowering. Warm conditions (minimum temperature of 17°C / 63°F) are also favourable for successful flowering. With such temperatures, an individual inflorescence can start and finish flowering within a few days. Low temperatures can lengthen the duration of flowering, with weeks passing between the start and end. This has a consequential negative effect on the evenness of grape ripening.

CONDITIONS FOR SUCCESSFUL FRUIT SET

Not all flowers become grapes. Typically, 30 per cent of flowers will become grapes, but this can range from zero to 60 per cent. Pollen germination requires warm temperatures (optimal at 26–32°C / 79–90°F). Pollen tube growth is negatively affected by cold, rainy and/or windy conditions and this can result in irregular fruit set and is a key cause of poor yields in cool climates. Hot, dry, windy conditions leading to water stress in the vine can also have a negative effect, again leading to reduced yields.

Two common forms of irregular fruit set are:

A bunch showing the effects of irregular fruit set (Merlot, Bordeaux)

Coulure

A condition of the grape bunch in which fruit set has failed for a high proportion of flowers. This occurs when ovule fertilisation is unsuccessful and therefore no grape develops. Some coulure is normal; however, excessive coulure can reduce yield dramatically.

Coulure is caused by an imbalance in carbohydrate levels. This can result from low rates of photosynthesis, which may be caused by cold, cloudy conditions or hot, arid conditions with high water stress (the vine stops photosynthesis to retain water). It can also result from vigorous shoot growth diverting carbohydrates from the inflorescence. Very fertile soils, heavy application of fertilisers and vigorous rootstocks can all cause strong shoot growth and therefore lead to coulure. Some grape varieties are also naturally more susceptible to coulure than others; Grenache, Cabernet Sauvignon, Merlot and Malbec are all very susceptible.

Millerandage

A condition of the grape bunch in which there is a high proportion of seedless grapes. The seedless grapes can still ripen normally, but are smaller than grapes with seeds. Millerandage may therefore reduce the volume of wine that can be produced. Some seedless grapes stay small, green and unripe, which can be negative for wine quality. Millerandage can result from cold, wet, windy weather at fruit set, with some varieties, such as Chardonnay and Merlot, being more susceptible than others.

2.5. Grape Development

June–September in the Northern Hemisphere, December–March in the Southern Hemisphere

What the vine needs during this stage:
- Sunlight
- Warmth
- Mild water stress

Adverse conditions:
- Too much water and nutrients
- Excessive shading of grapes
- Very cold or very hot conditions throughout the day and night

Grape development is typically split into four stages.

STAGE 1: EARLY GRAPE GROWTH

This stage starts soon after fruit set. Hard green grapes start to grow in size, and tartaric and malic acids accumulate. Some aroma compounds and aroma precursors (compounds with no aroma that will become aroma compounds during the fermentation process; see Wine Components) also develop, such as methoxypyrazines. Methoxypyrazines contribute to herbaceous aromas/flavours in some wines, such as those made from Sauvignon Blanc, Cabernet Sauvignon and Cabernet Franc. Tannins accumulate and are very bitter at this time. Sunshine on the grapes promotes tannin accumulation. Sugar levels are low throughout this stage. Water flow into the grape is high at this stage and it is mainly transported to the grape by the xylem (a type of transport tissue that transfers water and some nutrients from the roots to other parts of the vine).

Immature grapes before véraison

Too much water and nitrogen can prolong this stage, as these factors encourage shoot growth in preference to grape ripening. This causes a delay in the onset of the ripening stage and could mean that there is not sufficient time for ripening before the weather becomes cooler and the grapes need to be harvested.

Mild water stress can speed up this stage and lead to the production of smaller grapes, reducing juice yield but leading to greater skin to pulp ratio, which in red wines can be associated with better quality (higher levels of colour, tannins and aroma compounds). Grape growers may monitor and manage water levels at this time through irrigation to influence grape formation.

Shoot growth continues through this stage, but usually more slowly than earlier in the growing season.

STAGE 2: VÉRAISON

Grape growth slows down for a few days (often called the lag phase). The grape cell walls become more stretchy and supple, green-coloured chlorophyll in skin cells is broken

Black grapes during véraison

down and grapes of black varieties start to become red in colour due to the synthesis (the construction of complex chemical compounds from simpler ones) of compounds called anthocyanins.

STAGE 3: RIPENING

This is arguably the most important vine process in determining final grape quality. Shoot growth should have slowed down substantially by this time. During this stage, the cells in the grape expand rapidly, sugar and water accumulate, and acid levels fall. Tannins, colour and a number of aroma precursors and aroma compounds develop. Harvest usually marks the end of this stage and tends to occur August–September in the Northern Hemisphere or February–April in the Southern Hemisphere.

Sugar accumulation is very rapid at the start of the ripening stage and then slows towards the end. Sugar is produced in the vines' leaves by photosynthesis. Photosynthesis can take place at a maximum rate at temperatures between 18–33°C (64–91°F) and at sunlight levels that are above one third of full sunshine. Therefore, in years with cold weather or constant cloud, rate of photosynthesis may hinder sugar levels in the grapes. By contrast, very hot, dry conditions that can lead to extreme water stress can cause photosynthesis to slow or stop (see The Effects of Water) and hence hinder sugar accumulation in this way.

During this stage of ripening, water flow via the xylem slows down and a sugar solution (a mixture of mainly sugar and water) is transported to the grape by the phloem (a type of transport tissue that transfers sugars from the leaves to other parts of the vine). The movement of the sugary solution from the phloem into the grape, and hence the sugar accumulation within the grape is correlated to the rate of grape transpiration. In broad terms, grape transpiration and therefore sugar accumulation is faster in warm, dry conditions than cool, humid conditions. In warm conditions, this accumulation of sugar can be too rapid and reach high levels before aromas/flavours and tannins have developed fully (see The Effects of Temperature).

The total amount of tartaric acid in the grape generally does not change; however, its concentration falls during ripening due to dilution, as sugar and water accumulate in the grape. The concentration of malic acid usually falls even further than that of tartaric acid. This is because malic acid can be metabolised in respiration during the ripening stage (before this point, sugar is metabolised in respiration). Respiration is slower at cool temperatures than warm ones and this is why wines from cooler climates tend to have higher natural acidity.

Mean temperatures above 21°C (70°F) in the final month of ripening can lead to a rapid loss of acidity (and a rise in pH), whereas mean temperatures below 15°C (59°F) can reduce acid loss to a point that acidity levels in the must are too high. Cool night time temperatures also mean that less malic acid is lost during respiration. This is why warm areas with a high diurnal range, such as Central Otago and the wine regions in Washington State, USA, can produce wines with higher acidity than those with warmer night time temperatures.

During ripening, methoxypyrazine levels fall, but cool temperatures and limited sunlight (e.g. due to excessive shading of bunches or cloud cover) can hinder this decrease and the resulting wines may show particularly herbaceous aromas/flavours. Other aroma compounds and aroma precursors increase during the ripening stage, for example, terpenes, which give floral and citrus aromas such as the grapey aromas found in Muscat. (The flavour characteristics we perceive when we taste a wine are due to the same compounds as those responsible for aromas but they reach our sensory tissue through different pathways. In this text, the compounds that are responsible for both aroma and flavour will simply be called aroma compounds or aroma precursors.)

The influence of grape variety and natural resources, such as heat and light (or indeed other factors in the growing environment and grape growing), on the synthesis of different aroma compounds and aroma precursors is extremely complex. The range of different aroma compounds and precursors that can be found in grapes is huge, and the synthesis, degradation or retention of each of these compounds may be influenced by heat and light in a different way.

Although it is difficult to make a direct link between ripening conditions and aroma compounds in the grapes (and even more difficult to make this link to the final aromas that are perceived in the wine), experience from tasting shows that some aromas are more associated with grape varieties grown in certain climates. For example, Chardonnay shows aromas of green and citrus fruit in cool climates and stone fruit and tropical fruit in warm climates. As this example illustrates, broadly speaking, warmer, sunnier climates tend to produce grapes and wines with aromas that could be described as ‘riper’ than cooler, less sunny climates.

In black grapes, levels of tannins are high at *véraison* and decrease slightly throughout ripening. The tannins polymerise (a process in which relatively small molecules combine chemically to produce a very large chainlike or network molecule). This causes them to become less bitter. Sunshine on the grapes promotes tannin accumulation pre-*véraison* and greater polymerisation post-*véraison*. In white grapes, tannin levels are much lower and, in any case, winemakers rarely look to extract these tannins through prolonged skin contact or other means.

Anthocyanins increase during the ripening stage, and increase most rapidly with plentiful sunlight and temperatures between approximately 15°C (59°F) and 25°C (77°F).

The length of the ripening stage will depend on several factors:

- **Grape variety** – Some grape varieties naturally ripen earlier than others. Chardonnay and Pinot Noir are examples of early ripening grape varieties. Cabernet Sauvignon and Grenache are late ripening varieties. Some grape varieties, such as Zinfandel, are particularly prone to uneven ripening, with some grapes becoming extra ripe as others are just becoming ripe.

- **Climatic conditions** – Sugar ripening is quickest in warm, dry conditions. However, very hot or dry conditions can cause the vine to shut down, which inhibits grape formation and ripening.
- **Management of the vine and vineyard** – High yields, excessive shading within the vine canopy and shoots that are still actively growing can all slow down ripening.
- **Time of harvest** – Harvest depends on human factors (desired wine style, logistics) or natural factors (weather such as rain, onset of disease).

STAGE 4: EXTRA-RIPENING

If the grapes are left on the vine, they start to shrivel. No more sugar or water are imported to the grape by the phloem at this stage, but water loss in the grape through grape transpiration means that sugars are concentrated. Extra-ripe aromas can also develop in this stage. This may be desirable in some styles of wine, but not in others. Grape shrivelling is most likely in hot, sunny, dry climates. In addition, some grape varieties are more susceptible than others (e.g. Syrah is particularly susceptible). It is not always possible to leave grapes on the vine; the weather conditions and disease pressure must be considered.

2.6. Other Changes in the Vine

In late summer the green shoots lignify (become woody and rigid). These are then described as canes. In autumn, leaves fall, carbohydrate reserves are laid down in the roots, trunk and branches, and the vine enters its dormant period.

Vines in winter before pruning. The shoots from the previous growing season have turned brown and woody.

DEFINING RIPENESS

The main aim of the grape grower or wine producer is to get the grapes ripe for the style of wine being made. What is determined as 'ripe' may depend on a number of parameters.

The level of sugar in the grapes is one of the key parameters that determines ripeness. In dry wines, the amount of sugar in the grapes will be directly linked to the alcohol in the wine. In sweet wines, the amount of sugar in the grapes will influence both the sweetness of the final wine and the alcohol.

The level of acidity in the grapes will have a significant impact on the taste of the wine and hence is also a key determinant of ripeness. The desired level of acidity will depend on the type of wine being created with high levels of acidity being particularly desired in sparkling and sweet wines.

The profile of the aromas/flavours in the grapes is an important parameter in deciding whether grapes are ready to be harvested. This parameter in particular may be very individual to the grape grower or wine producer and the style of wine that is to be made. In very broad terms, as grapes ripen the aromas tend to change from underripe and often herbaceous, to fresh fruit and then to riper fruit, and even jammy or cooked.

Tannin ripeness is another essential parameter in red wine production. During grape formation, skin tannins accumulate but are bitter to taste. During ripening, tannins polymerise and become less bitter. The relationship between the tannin compounds in the grapes and the sensation of tannins in the finished wine is very complex and not well understood. During winemaking and maturation, the tannin compounds that are extracted from the grapes react with other compounds and, as part of this, their expression may change. Furthermore, even without these reactions, other compounds in the wine can change our perceptions of tannins, for example, a small amount of residual sugar can make tannins appear softer, whereas in bone dry wines with high acidity, tannins can often be perceived as having more astringency. In any case, wine producers are generally looking to avoid bitter unripe tannins, and this will therefore play a part in harvesting decisions.

However, sugar, acidity, aroma compounds and tannins are influenced by the growing environment in different ways. Sugar tends to accumulate in the grapes most quickly in warm, dry climates. (Though hot temperatures and lack of water may lead to water stress, and this may slow down ripening.) In cooler conditions this process will be slower and in years where weather is cold and very cloudy grapes can struggle to reach suitable sugar ripeness before cold and wet autumn weather sets in. Acidity tends to follow the opposite pattern, falling most quickly in warm, dry climates and being better retained in cooler conditions (e.g. in cool regions or regions that have a high diurnal range). By comparison, the development of aromas/flavours and tannins is not so clear cut and is not necessarily increased by rising temperatures. In particular the potential range of aroma compounds in grapes is so large that it is very likely that different temperatures (and other factors in the growing environment) favour the synthesis, degradation or retention of the various aroma compounds in different ways. The relationship between the aromas compounds in the grapes and the aromas/flavours perceived in the wine is also very complex (see Wine Components).

Therefore, in warm climates the desired sugar and acidity levels may be reached before the desired ripeness of aromas and tannins. This is why wines from warm climates tend to have higher levels of alcohol from the grapes' own sugars. What is considered as optimal ripeness (the time at which the combination of the sugar, acid, tannin and aroma ripeness is at its most favourable) will depend on wine style, grape variety, and the preferences of the winemaker, but, ultimately, the aim will be to produce a balanced wine. If this is not possible naturally, adjustments in the winery can be made. It is easier to adjust sugar, alcohol or acid levels than to work with grapes that have unripe tannins and/or aromas; therefore, many grape growers will focus on attaining the desired level of tannin and aroma ripeness.

(There are other parameters that the grape grower may consider and/or measure, for example, pH levels and colour development, but they are generally considered as less critical than those above. Terms such as physiological ripeness or phenolic ripeness are sometimes used to define ripeness (usually to describe tannin ripeness, development of colour and sometimes aroma/flavour ripeness), but these terms often have different meanings to different people.)

3 The Growing Environment

The amount of warmth, sunlight, water and nutrients and the timing of these key resources within the growth cycle are important if the vine is to produce and ripen grapes suitable for making wine. The natural resources available to a particular vineyard or even a particular vine depend on the growing environment. In turn, the growing environment is often a function of the positioning of the vineyard site, which is a key reason why delimited geographical indications are so important throughout the world of wine. The grape grower can manage the vineyard to make best use of the natural resources available, and indeed the winemaker can manage the must or wine to shape the style of the finished product. However, in the vast majority of cases, the growing environment and its effect on natural resources will have a defining influence on the wine produced.

This chapter will explore the key resources needed by the vine and examine how the growing environment influences these resources, and in turn, the vine's ability to produce and ripen grapes.

3.1. Temperature and Sunlight

Warmth and light are critical for vine growth and grape formation and ripening. Temperature in particular is thought to have a very significant effect on vine functioning and can have a huge influence on potential wine style and quality (and indeed whether grapes can ripen at all).

Solar radiation is the main source of both heat and sunlight and therefore many of the factors that influence one also influence the other.

THE EFFECTS OF TEMPERATURE

Temperature has a huge influence on vine growth and/or grape ripening in all stages of the vine growth cycle. A summary is provided below:

- Cold temperatures (under 10°C / 50°F) in the winter ensure the dormancy of the vine, however, extreme temperatures (around –20°C / –4°F) can cause winter freeze and damage the vine.
- Temperatures above 10°C (50°F) stimulate budburst, and budburst is often more successful and uniform if there is a significant rise in temperature at this point. Warm soil temperatures can also promote budburst. Cold temperatures that bring frost can be very harmful for buds and new growth and can reduce yields substantially.
- As the new shoots grow and leaves develop, the vine begins to use photosynthesis to create sugar for energy. The optimum temperature range for this is approximately 18–33°C (64–91°F), and hence temperature is not usually a limiting factor at this time.
- Warm temperatures promote successful, uniform flowering (optimum above 17°C / 63°F) and fruit set (optimum range 26–32°C / 79–90°F), whereas cold, damp conditions can cause problems for flowering and fruit set and therefore reductions in yield and, potentially, quality of the grapes and wine.
- Warm temperatures at this time also promote increased bud fruitfulness (above 25°C / 77°F is best) in the next year, and therefore affects yields in the next growing season.

- Temperature also has an influence on many aspects of grape ripening. Sugar accumulation in the grapes is generally faster at warm temperatures due to both optimum rates of photosynthesis producing sugars and because increased grape transpiration promotes the movement of sugar into the grape. Malic acid degradation is also increased at warm temperatures. Mean temperatures above 21°C (70°F) in the final month of ripening can lead to a rapid loss of acidity, whereas mean temperatures below 15°C (59°F) can reduce acid loss to a point that acidity levels in the must are too high. The effect of temperature on the formation of aroma precursors and aroma compounds is very complex; generally riper aroma/flavours are associated with grapes grown in warmer climates. Cool conditions may hinder the breakdown of methoxypyrazines, which can give herbaceous aromas. In black grapes, anthocyanin synthesis (and therefore the development of colour) is optimum at 15–25°C (59–77°F). (It is thought that tannin synthesis may follow the same pattern, but more research is needed to confirm this.)
- Extreme heat, especially when paired with dry conditions, can cause photosynthesis to slow or stop, slowing vine growth and grape ripening. In addition, water stress, which is typical in many hot regions, can also cause photosynthesis to slow down or stop due to the shutting of stomata to prevent water loss (see The Effects of Water). The closed stomata limit intake of carbon dioxide, which is needed for photosynthesis.

Different grape varieties have different needs and sensitivities regarding temperature. Late-ripening varieties may need a greater amount of heat through the growing season to ripen sufficiently (both in terms of sugar accumulation and also aroma and tannin ripeness). Early-ripening varieties, such as Pinot Noir and Chardonnay, will need less heat in total and will ripen very early in warm climates.

THE EFFECTS OF SUNLIGHT

The vine needs sunlight for photosynthesis, which is needed for vine growth and early grape growth and ripening. However, full sunshine (intense sunlight, not blocked by cloud) is not essential, and generally amount of light only becomes the limiting factor to the rate of photosynthesis if light levels drop below one third of full sunshine. Hence, fog can slow photosynthesis, but an average cloudy day will not.

Grape exposure to sunshine has a number of effects, including enhancing the development of anthocyanins (colour pigments) in black grapes and reducing levels of methoxypyrazines. Sunshine on the grapes leads to a greater accumulation of tannins pre-*véraison* and promotes tannin polymerisation after *véraison*, which results in a reduction in bitterness. It is also associated with increased levels of some favourable aroma precursors and aroma

Solar radiation is the main source of both heat and sunlight for the vine.

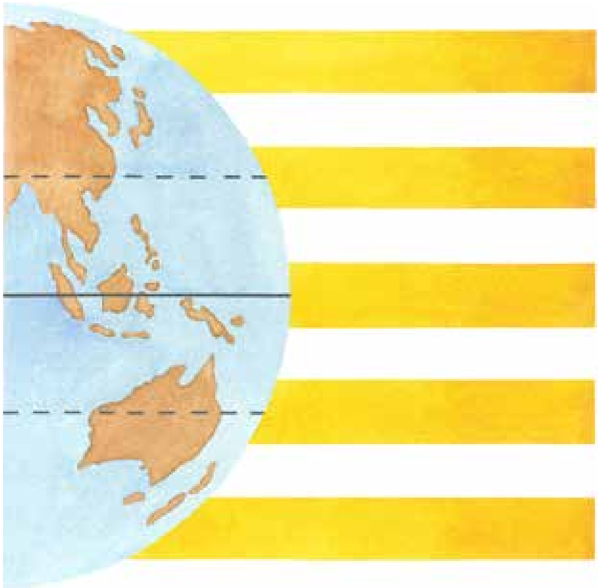
compounds (such as terpenes which are responsible for many of the fruity and floral aromas in wines, e.g. the grapey aromas found in Muscat). Sunshine also warms the grapes and, because of this, increases the rate at which malic acid is used up in grape respiration, leading to lower acidity levels.

Prolonged periods of sunshine and hot temperatures can lead to sunburn on sun-exposed grapes, which has a negative effect on grape quality and yields (for more details see Sunburn in Hazards). In climates that are warm or hot and/or very sunny, some shading of the fruit is usually beneficial. The grape grower may ensure the grapes are protected with one thin layer of leaves, so that the bunches receive dappled sunshine.

Sunshine in late spring / early summer is also associated with successful fruit set and the exposure of compound buds to sunshine promotes bud fruitfulness in next year's growing season.

NATURAL FACTORS THAT AFFECT TEMPERATURE AND SUNLIGHT

Latitude



The sun's energy is concentrated in a smaller area at the Equator than at the poles.

All other factors being equal, regions at lower latitudes (nearer the Equator, e.g. Mendoza, South Africa, New South Wales) will receive more solar radiation per annum than regions at higher latitudes (nearer the Poles, e.g. northern France and Germany).

Regions nearer the Equator also receive more intense solar radiation than those nearer the poles. Solar radiation is absorbed (held by water droplets, dust and ozone) and scattered as it travels through the Earth's atmosphere, decreasing its intensity. The curvature of the Earth means that nearer the poles solar radiation must travel through a larger section of atmosphere to reach the Earth's surface. It also means that the radiation hits the Earth at a low angle, so the radiation is spread over a larger area (it is more diffuse). By contrast, at the Equator the radiation travels through a smaller section of atmosphere and hits the Earth's surface at a larger angle (nearer perpendicular), so that solar radiation here is more powerful. Overall, this means that, if all other factors were equal, temperatures would be warmer and sunshine more intense in regions at lower latitudes than those at higher latitudes. Very broadly speaking, this means that grapes grown at lower latitudes can have higher levels of sugar, lower levels of acidity, riper aromas and, in black grapes, higher but riper tannins and more colour intensity than those at higher latitudes (again, if all other factors were equal).

The number of hours of solar radiation through different times in the year is also determined by latitude. Low latitude regions receive similar daylight hours (and hence heat and sunlight) throughout all seasons of the year. High latitude regions have longer daylight hours in the summer and shorter daylight hours in the winter. This permits a longer duration of time over which photosynthesis can take place in the growing season. Given the cooler temperatures in these locations, this can be useful in helping the vine to produce enough sugar for ripening grapes.

It is generally said that grapes for wine production can grow between 30° and 50° latitude on each side of the Equator. There are exceptions to this. However, regions nearer the Equator are usually too hot during the day. Vines transpire to regulate their temperature and if water is not readily available, this can cause water stress. Grapes can also suffer from sunburn. Regions near the poles are simply not warm enough during the growing season (despite long daylight hours) for enough sugar to accumulate in the grapes.

Altitude

Vineyards in Salta Province, Argentina, range from approximately 1,280 to 3,000 metres above sea level.

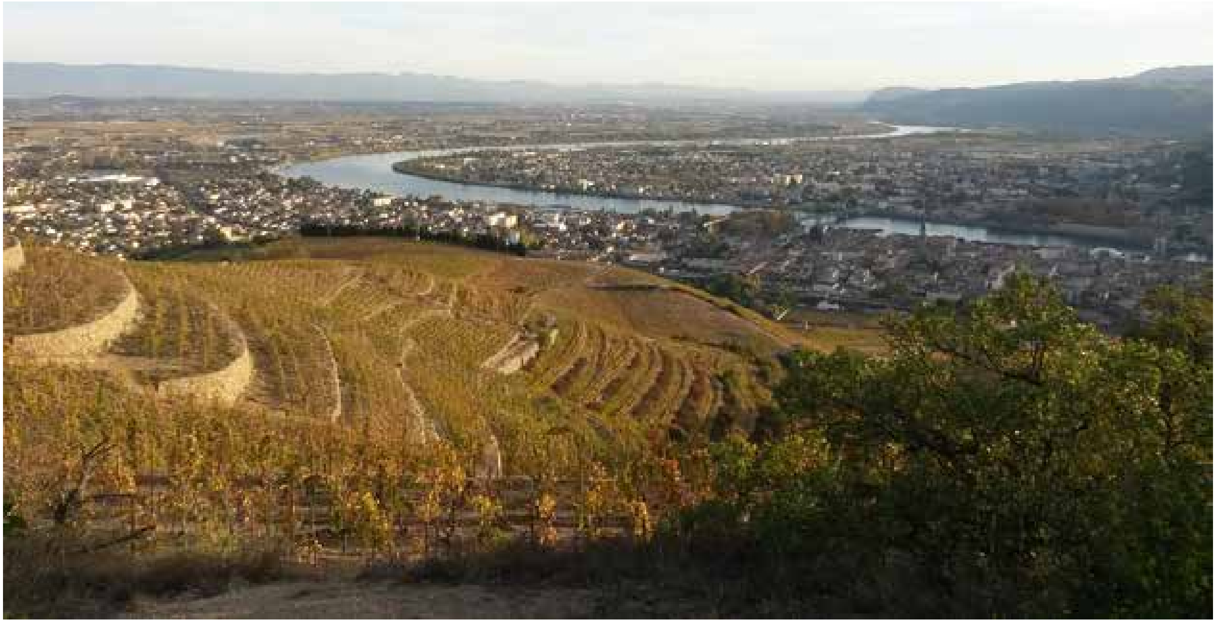
Temperature falls by approximately 0.6°C (1.1°F) over every 100 m increase in altitude. High-altitude sites can therefore be favourable in areas of low latitude that would otherwise be too hot. There are vineyards in Salta, Argentina (a low latitude region) planted at up to approximately 3,000 m above sea level, and here grapes may struggle to ripen sufficiently every year. By comparison, many of the best vineyard sites in high latitude areas, such as Burgundy and Loire Valley, are at relatively low altitudes, as otherwise temperatures would be too low for sufficient ripening.

Sunshine is more intense at high altitudes than low altitudes because the solar radiation travels through less atmosphere before it reaches these sites. Ultraviolet radiation (radiation with a lower wavelength than visible sunlight) is also greater at higher altitudes. Both of these factors are thought to promote anthocyanin and tannin synthesis.

High-altitude sites often have a high diurnal range (the difference between day and night temperatures). The ground absorbs energy from solar radiation during the day and releases energy into the atmosphere during the night. At lower altitudes the air in the atmosphere (particularly the water vapour) absorbs some of this energy, meaning some heat is retained at night. At high altitudes the air is thinner and holds less moisture and therefore heat rapidly escapes, leading to relatively cool night-time temperatures. In warm climates, high diurnal range can be beneficial for the retention of acidity during grape ripening. For more information see Diurnal Range.

Slopes and Aspect

Vineyards planted on slopes will face a particular direction. This is called aspect. Vineyards that face the sun throughout most of the day (south-facing in the northern hemisphere and north-facing in the southern hemisphere) will receive more solar radiation than those facing the opposite direction.



The southerly aspect of the vineyards on the hill of Hermitage means that the Syrah gains extra ripeness.

The importance of aspect and the steepness of the slope increases at high latitudes. This is because solar radiation hits the Earth at a low angle at high latitudes. In the context of the vine growth cycle, the angle is lowest in the spring and autumn (compared to the summer). The slope increases the angle (nearer to perpendicular) at which the solar radiation hits the Earth's surface, hence increasing the intensity of heat and light. The amount of warmth is also often a limiting factor in high latitude areas, so a slope can make a marked difference on the viability of a vineyard, the grape varieties that can be grown there and the ripeness of those grapes. Extra warmth and light during spring and autumn extend the viable growing season for vines grown on slopes that face towards the sun. As evidence of this, in the cool climate regions of Burgundy and Alsace, the Grand Cru sites that give wines with greater ripeness and concentration are usually positioned on south-east facing slopes, while the vineyards of the generic appellation are found on the flat.

In warm climates, it may be desirable to limit the amount of heat and light. Planting on slopes that face away from the sun throughout most of the day can help achieve this. This may allow the grape grower to grow earlier-ripening grape varieties or produce wines with less alcohol and more acidity than would otherwise be the case at that latitude. For example, in Stellenbosch, white grape varieties are sometimes planted on south-facing slopes so that the grapes retain refreshing acidity.

Slopes facing east benefit from morning sunshine that can heat up the atmosphere when air and soil temperatures are at their lowest. This can extend the hours of vine growth and grape ripening each day, especially in cool climates. The grape canopy, which can be covered with dew in the morning, also dries out earlier in east-facing vineyards, reducing the spread of fungal disease, which is beneficial for grape quality and yields. Slopes that face west receive the afternoon sun and may become too hot, especially in warm climates, and risk of sunburnt grapes is increased (see Sunburn in Hazards). However, in areas with coasts to the west, e.g. California and Western Australia, cool afternoon sea breezes may alleviate this.

Slopes can provide additional benefits, including shallower, poorer soils and better drainage. Slopes can also provide shelter from winds and rain, and protection from frosts (air movement down the slope prevents frosts from forming; see Frosts in Hazards). However, soil erosion and the inability to use machinery on steep slopes can be problematic.

Proximity to Water

Large bodies of water, such as lakes and seas, can have a significant impact on nearby vineyards. This is because water heats up and cools down more slowly than dry land. During the day, the water and the air above a body of water remains relatively cool and lowers the average temperature in the local area. Air directly above dry land heats up more quickly than that above the water, and this warm air rises. Cool air from above the water is drawn to the land to replace the warm air as it rises, resulting in cool, humid afternoon breezes.

The opposite happens at night. The water retains the warmth gained during the day, whereas, without solar radiation, the land loses heat relatively quickly. The warmth of the body of water keeps the local area warmer. The same effect can be experienced over the year, with large bodies of water giving cooler summers and milder winters.

This can be positive for both warm and cool climate regions. For example, in the Finger Lakes in New York State, close proximity to deep lakes reduces the severity of winter freeze, which would damage or even kill the vines. The movement of air also helps to protect against

The moderating influence of the Finger Lakes helps to make grape growing viable in upstate New York.

spring frosts that could reduce yields. By comparison, in Carneros, California, the proximity to the San Pablo Bay means that early-ripening grape varieties such as Chardonnay and Pinot Noir can be grown here (for still and sparkling wine) due to the moderating influence of cooling afternoon breezes. By contrast, later-ripening grape varieties such as Cabernet Sauvignon tend to be grown further inland where warm afternoons help ripen the grapes.

Vineyard areas in coastal regions can also be affected by ocean currents, which can have a marked influence on temperatures. For example, both the Willamette Valley in Oregon and Margaux in Bordeaux are located at approximately 45° latitude; however, the main grape in the Willamette is early-ripening Pinot Noir, whereas Margaux is capable of growing late-ripening Cabernet Sauvignon. The warmer climate in Bordeaux (average growing season temperature 17.7°C / 64°F) is at least partially due to the Gulf Stream, which flows from the Gulf of Mexico and warms many European wine regions. By contrast, the west coast of North America, including Oregon, is cooled by the cold California current, which flows from the northern Pacific (average growing season temperature in Willamette Valley is 15.9°C / 61°F). In the western USA, wine regions that are sheltered from the ocean influence, for example by mountain ranges, are much warmer and drier than those that are not.

Vineyards located in very close proximity to large bodies of water can benefit from radiation reflected from the water surface. The amount of radiation reflected depends on the angle at which the solar radiation hits the water and is greatest at high latitudes. Reflected sunshine is advantageous in cool climates that have limited sunshine (very cloudy conditions); for more details see The Effects of Sunlight.

El Niño-Southern Oscillation (ENSO) is a climatic cycle in the Pacific Ocean that has a significant effect on weather patterns. It has two opposite phases, El Niño and La Niña. El Niño starts when warm water in the western Pacific Ocean moves eastwards along the Equator towards the Caribbean. The eastern Pacific Ocean becomes warmer than average and this tends to cause high levels of rainfall and risk of hurricanes in South America and California. Any hurricanes clearly have a destructive influence. The rainfall can disrupt pollination and fruit set and lead to excessive water availability, which can increase vegetative growth and hinder ripening. However, El Niño brings warmer than average temperatures and drier conditions to the more northerly states of Washington and Oregon. On the western side of the Pacific Ocean in Australia, El Niño tends to cause warmer temperatures and drought conditions, which can cause extreme vine stress and vine damage. El Niño events typically occur once every 3–7 years, with extreme El Niño events being rarer. It is thought, however, that these extreme events are becoming more frequent as a part of climate change.

La Niña is caused when the eastern Pacific Ocean is cooler than average. It tends to result in cooler, wetter conditions in Washington and Oregon, but warmer, drier conditions in California and South America. La Niña also causes wetter and cooler conditions in Australia.

Winds

Winds and breezes can have a warming or cooling influence in many wine regions. Areas near to a body of water may experience cool breezes during the day, moderating the diurnal range of such regions (see Proximity to Water above). Valleys that face the coast or other areas of low land (e.g. the Petaluma Gap in California) can mean that winds are felt even relatively far inland. Valleys can also lead to stronger winds as the moving air is funnelled. Winds that have travelled over hot land masses can bring warm air that heats the vineyard area, e.g. the Zonda in Mendoza.

Rows of trees provide windbreaks in Neuquén, Argentina.

As well as influencing temperature, winds and breezes reduce the occurrence of humid, stagnant air in the vine canopy that encourages the development of fungal diseases. They also increase evapotranspiration from the vine, meaning that vines' water needs may be higher than in non-windy areas (see Evapotranspiration Rate in Water). If water isn't readily available, for example through irrigation, this can lead the vine to become water stressed (for more details on water stress see The Effects of Water).

Strong winds can cause damage to vines and vineyard trellising, which may result in lower yields and higher equipment and labour costs. Rows of trees can be planted at the edges of vineyards to act as windbreaks; however, care must be taken as they can compete with the nearest vines for water and nutrients. Fences can also be used but are less aesthetic and require maintenance.

Characteristics of the Soil

Soil can also have an important effect on temperature. The drainage of the soil, its texture and colour all influence the warmth of the soil and the air directly above it.

Soils that drain freely, for example sandy or stony soils (see Soil in Nutrients for details), warm up more quickly in the spring than damp soils. Rising soil temperature encourages the breakdown of starch in the roots, which stimulates budburst and shoot growth. Therefore, it is desirable for cool-climate vineyard areas to have free-draining soils to promote early budburst, and hence potentially a longer growing season within which to get the grapes ripe. However, early budburst does increase the risk of harmful spring frosts damaging young buds and shoots. Warm soils also encourage root growth, which means the vine can absorb more water and nutrients.

The colour of the soil is also important. Light-coloured soils, such as those rich in chalk (e.g. as found in Sancerre and Champagne), reflect some energy from solar radiation. Extra light energy into the lower parts of the canopy, which may receive less sunlight from above, can be beneficial to increase photosynthesis and grape ripening in cool and cloudy climates or where late-ripening grapes are used (see Effects of Sunlight). However, in warm climates this may increase temperatures in the warmest parts of the day. Dark-coloured soils, such as some of those from volcanic origin (e.g. as found in Etna), absorb more energy and re-radiate most of it when temperatures are cooler, for example at night. This can be useful, especially in cool climates or for late-ripening grapes, allowing the development of colour and degradation of acid to continue during the night. Stony soils, especially if the underlying soil is slightly damp, are also very effective at absorbing heat and releasing it at night. This is because stone and water are good conductors compared to air.

Mist, Fog and Clouds

A number of vineyard areas are prone to mist. Mists are formed by tiny drops of water collecting in the air just above an area of ground or water. They are usually formed when warm air is rapidly cooled, causing water vapour in the air to condense. This may occur, for example, at night when warm air over a body of water meets cooler conditions above the land.

Dense mist is called fog. Mist and fog can form in different vineyard regions at different times of the day, although morning is the most common time, as found in parts of Sonoma, Napa, Leyda Valley and Sauternes, among other regions.

Fog in Sonoma Coast cools the climate.

Whereas mist and fog occur at ground level, clouds usually form higher in the sky. Depending on the density of the mist, fog or amount of cloud cover, sunlight can be limited to such an extent that photosynthesis is reduced. With less solar radiation, temperatures can be lower, particularly if morning fog or cloud delays the time at which the morning sun begins to warm the land. Where mists, fogs and cloudy conditions are regular, this can slow down sugar accumulation and acid degradation in the grapes, which may be beneficial in warm regions or when growing early-ripening grape varieties. As mists and fogs are made up from water droplets and occur at ground level they can also increase humidity in the vineyard and therefore the occurrence of fungal disease or, in areas with dry, sunny afternoons, noble rot (see Specific Options for Producing Wines with Residual Sugar).

DIURNAL RANGE

The diurnal range of a region or vineyard site is the average difference between day-time and night-time temperatures. Regions with continental climates or at high altitude tend to have higher diurnal ranges (larger difference between day and night temperatures), whereas regions near a large body of water tend to have lower diurnal ranges (smaller difference between day and night temperatures).

The precise effects of different diurnal ranges are not yet fully understood. There are some schools of thought that suggest constant temperatures are more favourable for producing quality grapes. There are others that believe that a significant difference in night time temperatures is beneficial. The effects will depend on the average day and night time temperatures, as well as a number of factors such as the grape variety, time in the growing season and availability of water.

In warm or hot climates, such as those found in Mendoza or Ribera del Duero, a large diurnal range is often thought to be favourable. In these climates, a relatively cool period during the night can slow the respiration of malic acid and be beneficial for the formation of anthocyanins (day-time temperatures are too hot).

In cool and moderate climates, such as Mornington Peninsula or Mosel, a low diurnal range may be favourable so that night-time temperatures still allow ripening (e.g. acid degradation, anthocyanin synthesis) to continue, which may be needed for grapes to ripen sufficiently.

It is also thought that night-time temperatures can have some influence on aroma compounds. For example, warmer night temperatures are associated with a greater breakdown of methoxypyrazines, which may be important in cool climates, and cooler temperatures are associated with a greater retention of some other compounds, such as rotundone. Given the number of aroma compounds and precursors in grapes and their interactions such relationships are complex.

There are exceptions to the general theories, where cold night-time temperatures (e.g. under 15°C / 59°F) seem to be beneficial in cool climates. For example, many of the top sites in the Wachau, Austria, see relatively cool days and cold nights. The exact reasons behind this are unknown. It is perhaps related to the extension in the growing season that cool nights give; however, there could be other influences that are as yet unidentified.

More certain is that extremely cold or extremely hot temperatures in the growing season can cause damage, whether that be by spring frost or intense heat in summer.

3.2. Water

The vine needs water to survive; in addition, adequate water availability is vital for healthy vine growth and grape ripening. Generally, the vine needs a minimum of 500 mm of rainfall per year in cool climates and at least 750 mm in warm regions. The vine needs water for turgidity (so that it doesn't wilt), photosynthesis and regulating its temperature. Water also acts as a solvent for nutrients in the soil, which is important for their uptake by the vine. It is the medium in which all of the vine's biochemical and physiological mechanisms take place. Either too little or too much water can have a negative influence.

THE EFFECTS OF WATER

Water vapour diffuses out of the stomata (tiny pores) on the underside of vine leaves. The loss of water from the cells in the leaf causes water to be pulled upwards from the soil, through the roots and the above-ground parts of the vine. This is called transpiration.

Open stomata allow the free exchange of water vapour out of the vine and also let carbon dioxide and oxygen diffuse in and out of the leaves. If the vine has sufficient water, it can keep its stomata open all day. A lack of water causes the vine to close its stomata partially. This can help conserve water, but also reduces or even stops photosynthesis due to lack of carbon dioxide entering the leaves. As photosynthesis is the way that the plant makes sugars for energy, this causes the vine's growth to be stunted and ripening to slow down. Extreme cases of water stress can lead to leaf loss and vine death. Lack of rainfall in the growing season can be an issue in several wine regions, including many of those within Argentina, California, South Africa and Australia. In many of these regions, irrigation (see Water Management) is needed for viticulture to be possible.

A plentiful supply of water in the spring encourages the growth of lots of leaves and hence the establishment of a large leaf surface area to support the growth of the vine and ripening of grapes.

However, if water is too easily available into late spring and early summer, vegetative growth (the growth of shoots and leaves) is promoted and prolonged into the period of grape ripening. This acts as a competitive source for the vine's sugars, which can delay and compromise ripening. It is therefore thought that mild water stress before *véraison* is beneficial as it inhibits further vegetative growth. An excessive amount of shoots and leaves in the canopy can cause too much shading of the grape bunches. Unless adequately controlled (by canopy management techniques), this can lead to reduced formation of anthocyanins, tannins and aroma compounds, less tannin polymerisation and higher levels of methoxypyrazines. Dense canopies of shoots and leaves also have poor ventilation, which can encourage fungal disease in rainy or humid climates.

The optimum amount of water required by the vine between *véraison* and ripening is not clear. However, it is widely agreed that severe water stress or plentiful water (that could restart vegetative growth or be taken up into the grapes) is not favourable. Too much water available late in the ripening period can cause dilution of sugars in the grapes and even grape splitting, which in turn encourages botrytis (see Untimely Rainfall in Hazards). By comparison, a water deficit during ripening may lead to the early onset of grape shrivel and reduced ability of the grapes to reach the desired level of ripeness.

As well as the direct influence of water availability on the vine, water also has an impact on the growing environment. Damp soils are often cold, especially early in the growing season, and can delay budburst, which can shorten the growing season. By contrast, warm soils promote budburst and also encourage root growth and therefore the ability of the vine to take up water and nutrients. Hail can cause major damage to the green parts of the vine at any point in the growing season, leading to lower yields and potentially reduced quality of the remaining fruit (for more details see Hail in Hazards). Rainfall at pollination and fruit set can negatively affect these important stages of the vine growth cycle (although water stress can also), resulting in uneven ripening or lower yields (for more details see Flowering and Fruit Set). Rain often creates a humid environment in the vine canopy that can then lead to fungal diseases such as downy mildew and botrytis. By comparison, air that is low in humidity can increase evapotranspiration and therefore the potential for water stress. It is also associated with increased grape transpiration and hence higher sugar accumulation in the grapes.

The presence of a large body of water can moderate both diurnal and seasonal temperatures. Ocean currents can also either increase or decrease the average temperature in the growing season of nearby wine regions. A lake or river can encourage breezes that may reduce likelihood of frost. However, proximity to water can also increase the level of humidity in the vineyard, which can encourage fungal disease; note that many of the vineyard areas famous for botrytised sweet wines are near bodies of water, such as Sauternes, Tokaj and Mosel. For more details see Proximity to Water in Temperature and Sunlight.

More information on the effects of too much or too little water can be found in Hazards.

NATURAL FACTORS THAT AFFECT WATER AVAILABILITY

Rainfall

Rainfall is the natural source of water for the vine, and therefore the amount and timing of rainfall each year is an important factor in producing high quality grapes. This is moderated by the water-holding capacity and depth of the soil. In areas where there is not sufficient rainfall to meet the vine's needs, irrigation may be used (depending on legislation, availability of irrigation water and other factors).

Rainfall is caused by water vapour condensing and precipitating. Warm temperatures cause moisture from the land to evaporate. As the warm moist air rises in the atmosphere, it cools and condenses into clouds and eventually rain. Snow and hail are other forms of precipitation and can also be natural sources of water when they melt.

Topography can have an influence on patterns of rainfall. Mountain ranges can force winds of warm moist air upwards over high altitudes. This causes the water vapour to cool,

On the west of the Cascade Mountains, Puget Sound AVA is relatively cool and wet.

In the Horse Heaven Hills AVA within Columbia Valley irrigation is needed for grape growing to be viable.

condense and precipitate. This can mean that the regions on one side of the mountain experience greater rainfall, whereas regions on the other side are sheltered from the rain-bearing winds and often have very dry conditions (these regions are located in a ‘rain shadow’). The wine regions of Washington State are an example of this effect. On the west of the Cascade Mountains the AVA of Puget Sound is cooler and much wetter than the warmer, drier AVAs to the east of the mountains, for example Columbia Valley. Plentiful rainfall in the winter and early spring mean that grape growers in Puget Sound can dry farm (apply no irrigation) whereas irrigation is needed in Columbia Valley for vines to survive.

As well as providing water in the soil that the vine can take up, rain also wets the canopy of the vine and increases humidity. Wine regions with frequent rainfall are therefore often more prone to some fungal diseases.

Characteristics of the Soil and Land

The characteristics of the soil can have a significant influence on the availability of water for the vine’s roots. The amount of water available to the vine depends on how easily the water drains, the water-holding properties of the soil (a function of the soil’s texture and organic matter content) and the soil depth.

Soil drainage and water retention depends on the soil structure and texture. Hawke’s Bay in New Zealand receives around 1,000 mm rainfall annually, however, the extremely free draining nature of the gravel soils in the Gimblett Gravels area mean that irrigation is often required. By comparison, Jerez in Spain receives 650 mm with virtually no rainfall in the summer months. Here, the main soil type is *albariza*, a clay soil that has good water retention and which releases water slowly to the vines. This soil also forms a crust when dry, which reduces evaporation. Together, this means that irrigation is not necessary (and indeed is only

Stony, free-draining soil in Hawke’s Bay means irrigation is often necessary.

permitted in exceptional circumstances of extreme hydric stress).

Although soils that retain some water can be advantageous, especially in areas of low rainfall, water-logged soils (usually as a result of poor drainage) are harmful to the vine, reducing the amount of oxygen available to the roots (which slows their growth) and eventually killing the vine.

The *albariza* soil in Jerez forms a crust when dry, limiting evaporation.

Topography also has an influence. There will be greater surface run-off in vineyards on slopes. This can mean there is less penetration of water into the soil and therefore less water available to vine roots. This may be advantageous in regions with high rainfall. However, the surface run-off causes erosion of the soil and leaching of nutrients and these issues need to be factored into vineyard management. Due to erosion (even without surface run-off, the soil on slopes generally gradually falls down the slope), soils on slopes are generally thin, limiting the area over which vines can obtain water and nutrients.

There are ways in which the grape grower can manage the vineyard and the soil to either promote or reduce water availability to vine roots (for details see Water Management).

Evapotranspiration Rate

Evapotranspiration rate is the amount of transpiration from the vine, combined with the evaporation of water from the soil surface. It is therefore the rate at which water is no longer available, either because it has been taken up by the vine or because it has been lost to the atmosphere (e.g. evaporation from the soil surface). Evapotranspiration rate depends on the temperature, humidity and wind, with hot, dry, windy weather (such as that in Mendoza and Patagonia) leading to the fastest rates.

A high evapotranspiration rate means that more water is needed to satisfy the vine's requirements than at a low evapotranspiration rate. Therefore, vines in hot, dry, windy conditions need more water than vines in cool and humid conditions. However, regions with hot and dry conditions are often those with least rainfall, and therefore irrigation may be needed to meet the vine's needs.

For more details on the effects of winds and breezes see Winds in Temperature and Sunlight.

3.3. Nutrients

The vine acquires the nutrients it needs from the soil. Nutrients are important for healthy vine growth and can have an influence on yield and grape composition. Vines require low levels of nutrients and therefore most soils are able to sustain vine growth (unless the vine is over-cropped; see Canopy Management and Vine Balance in The Aims of Canopy Management). However, soil nutrients are depleted by viticulture and therefore it is important for the grape grower to monitor nutrient levels for deficiencies.

The most important nutrients are:

Nitrogen – Nitrogen is essential for vine growth and can have a major impact on vine vigour and on grape quality. It is a component of proteins and chlorophyll (required for photosynthesis). Too much nitrogen in the soil causes excessive vegetative growth, with sugars being diverted to the growing shoots and leaves rather than the grapes, hindering ripening. An excess of shoots and leaves in the canopy can cause shading of fruit and buds (with a number of consequences, see The Effects of Sunlight in Temperature and Sunlight) and poor ventilation (leading to fungal disease) unless adequately managed. Too little nitrogen results in reduced vigour and yellowing of vine leaves. Grapes that have low nitrogen levels can also be problematic for fermentation (see Yeast in Alcoholic Fermentation for more details). Overall, vines with a restricted supply of nitrogen tend to produce higher quality grapes.

Potassium – Potassium is also essential for vine growth and helps regulate the flow of water in the vine. Very high potassium levels in soils can cause problems in the uptake of magnesium, and this may lead to reduced yields and poor ripening. High potassium levels in the soil can lead to high potassium levels within the grapes. This has a significant effect on wine quality, as high levels of potassium in the grape must are linked to high pH (see Acids in Wine Components). Low levels of potassium can lead to low sugar accumulation in the grapes, reduced grape yields and poor vine growth in general.

Phosphorus – Phosphorus is important for photosynthesis. Vines need only a small amount, and usually there is enough phosphorus naturally present in the soil. A deficiency in phosphorus leads to poorly developed root systems (and hence a diminished ability to take up water and nutrients), reduced vine growth and lower yields.

Calcium – Calcium has an important role in the structure of plant cells and in photosynthesis. Calcium deficiency is rare but can have a negative influence on fruit set.

Magnesium – Magnesium is found in chlorophyll and has a key role in photosynthesis. Deficiency can result in reduced grape yields and poor ripening.

Several other nutrients play a role in vine growth and reproduction. These include sulfur, manganese, boron, copper, iron and zinc.

NATURAL FACTORS THAT EFFECT NUTRIENT AVAILABILITY

Vine nutrients dissolve in soil water, which is then taken up by the roots of the vine. This means that the soil factors that influence water availability also impact nutrient availability.

Soil pH also has a key influence on nutrient availability. Different nutrients become more or less available at different pH levels. For example, iron is poorly available in soils with high pH (e.g. soils with a high proportion of calcium carbonate such as limestone) and this can cause chlorosis. This is a condition in which leaves turn yellow and photosynthesis stops, so grape ripening and yields are negatively affected as a result. By contrast, vines can struggle to take up phosphorus in highly acidic soils.

A vine suffering from chlorosis

Organic nutrient compounds found in and added to soils (e.g. in the form of manure or compost) are not available in a form that the vine can take up and need to be converted into inorganic compounds. (In this context, 'organic' describes compounds that contains carbon; 'inorganic' generally describes compounds that do not contain carbon.) Organisms that live in the soil (such as bacteria, fungi, earthworms, etc.) are important in this process, feeding on the organic matter and converting it into available forms, a process called mineralisation. (These organisms can also convert organic matter to humus (see Soil below).) It is therefore thought to be highly beneficial to encourage soil life and ecosystems within the vineyard (see Managing Soil Health).

Different soil textures also have varying abilities to hold nutrients. Soils with a high proportion of clay are good at holding nutrients, whereas sandy soils are poor at holding nutrients. Humus can increase the soil's ability to hold nutrients.

The topography of the vineyard may also have an impact on the soils and their levels of nutrients. Soils on slopes are often thinner and less fertile than those on plains or valley floors.

There are ways in which the grape grower can manage the vineyard and the soil to either promote or reduce availability of nutrients to vine roots (see Nutrient Management).

SOIL

Soil is the upper layer of the earth and is typically made up of geological sediment (solid matter (sand, pebbles, rocks etc.) that has been moved and deposited in a new location e.g. by wind or water), organic remains in the form of humus, and the pores in between the sediment that contain water and air. Geological sediment comes from the weathering of bedrock (the solid rock below the soil).

The soil in a vineyard can often be made up of different layers formed at different periods of time, each of which may have a different texture, structure and characteristics. The sediment in the soil may not be the same as the bedrock underneath; for example, over time the sediment may have been transported by water, winds, glaciers or gravity (down-slope).

In the context of the vineyard, the soil supports the vines' roots and is the medium from which vines take up water and nutrients. It is also a key habitat for the vineyard ecosystem supporting a number of animals and microbes. The influence of soil in terms of wine style and quality is complex. Scientific backing to support any links between the chemical composition of soil or bedrock and particular aromas/flavours in a wine is lacking. However, the importance of the soil's physical parameters on water availability and therefore vine growth and grape ripening is well recognised. (The physical parameters of the soil also influence nutrient availability, but as vines need low levels of nutrients, and fertilisers are easy to apply where necessary, this is thought to be less impactful on vine growth.)

Dark-coloured soils in Sicily absorb energy and re-radiate it at night.

The most important physical elements of a soil are its texture and structure:

- The texture of the soil describes the proportions of the mineral particles of sand, silt and clay. Soils with a high proportion of clay are said to be finely textured; clay particles are very small, and because of this have a large surface area compared to their volume, so they are very effective at holding water and nutrients. Sand particles are relatively large and have a small surface area compared to their volume. They therefore have limited capacity to hold water and it can drain through them easily. They are also poor at retaining nutrients. Sandy soils have a loose texture, making them workable and easy for vine roots grow through. Silt has particles of intermediate size and its properties sit between those of clay and sand. 'Loam' describes a soil that has moderate proportions of clay, silt and sand. As well as sand, silt and/or clay, the soil may also contain a proportion of larger rock fragments, such as gravel or pebbles (larger than gravel). These larger particles improve water drainage but lower water- and nutrient-holding capacity.
- The structure of the soil describes how the mineral particles in the soil form aggregates (crumbs). The size, shape and stability of these aggregates are also important for determining water drainage, root growth and workability of the soil. Soils that have a very high clay content are sticky and may form aggregates that are hard for vine roots to penetrate and challenging for soil cultivation. The vines' roots may be limited to cracks or gaps between the aggregates. By comparison, soils that are high in sand or larger particles such as gravels or pebbles are very loosely structured and, in fact, need some clay to help bind them together. Humus is organic

matter in the soil that is formed by the partial decomposition of plant and animal material by soil microbes and earthworms. It has a spongey texture, large surface area and is able to adsorb water and nutrients. It helps to bind soils together and can help soils to retain water and nutrients.

The suitability of the soil for viticulture will depend on the texture and structure of the soil combined with how far the roots are able to penetrate. Very sandy or stony soils have poor water and nutrient-holding capacity but may prove suitable if the vine roots are able to grow freely and deeply, giving a large area over which the vine can obtain water. The suitability of the soil also depends on the climate in which the vine is growing. Free draining soils can be beneficial for avoiding excess water in rainy climates (e.g. the gravelly soils in the Haut-Médoc). Excess water can displace oxygen in the soil, and oxygen is essential for the respiration of vine roots and soil organisms. Waterlogged soils can lead to reduced vine growth and, eventually, vine death. There are several options that the grape grower can take if the soil is not completely suitable; for example, compost can be added to provide nutrients and improve soil structure and irrigation can be installed if soils are too free draining.

Soil can also have an impact on the availability of heat and light within the vineyard (for more details see Characteristics of the Soil in Temperature and Sunlight). Light-coloured soils will reflect sunlight back into the vine canopy during daylight hours, maximising sunlight exposure, especially within parts of the vine canopy that are not in direct sunlight. Dark-coloured soils absorb heat from solar radiation during the day and release it slowly during the night; this can moderate diurnal range.

3.4. Climate Classifications

A region's climate is defined as the annual pattern of temperature, sunlight, rainfall, humidity and wind averaged out over several years (30 years is the timescale generally agreed). The climate does not change from one year to the next, although it can alter over a period of decades.

Temperature, sunlight and water from rainfall have a vital influence on the vine's ability to grow and ripen grapes, and the style and quality of wines that can be made in a region. For this reason, a number of models of climate classification have been created, grouping vineyard areas into different climatic bands. These models can often help in the comparison of different global vineyard areas and the resulting wine styles that they can make successfully.

To date, most climate classifications have focused on patterns of temperature (often considered the most important influence on the vine cycle) and sometimes rainfall. However, it should be noted that even quite complex models can only give a broad picture of a climate because they cannot account for all the natural and human factors that may affect a region or a specific vineyard.

GROWING DEGREE DAYS (GDD)

This model of heat summation during the growing season was created by Amerine and Winkler (1944). It was originally intended for the vineyard regions in California. To calculate the GDD:

- For Celsius, subtract 10 (the temperature in Celsius below which vines cannot grow) from the average mean temperature of a month in the growing season. For Fahrenheit, subtract 50 (the temperature in Fahrenheit below which vines cannot grow) from the average mean temperature (in Fahrenheit) of a month in the growing season.
- Multiply this by the number of days in that month.
- Make the same calculation for each month in the growing season (April to October in the Northern Hemisphere, October to April in the Southern Hemisphere) and add together the totals to get the GDD. (Any months with a negative value would not be counted.)

As part of the model, the GDDs are grouped in five bands. This makes the data easier to use and communicate. The climate of a region in 'Winkler Zone I' (lowest GDDs) is cool, whereas a region in 'Winkler Zone V' (highest GDDs) is very hot. This model has been updated relatively recently to add new bands at the upper and lower ends.

THE HUGLIN INDEX
The Huglin Index, created by Huglin (1978), uses a similar formula to GDD, but differs in that the calculation takes into account both mean and maximum temperatures and the increased day length experienced at higher latitudes. The index is split into bands, with the most suitable grape varieties mapped to each range. This model is widely used in Europe.

MEAN TEMPERATURE OF THE WARMEST MONTH (MJT)
This model, created by Smart and Dry (1980), uses the mean temperature of either July in the Northern Hemisphere or January in the Southern Hemisphere, termed MJT (mean January/July temperature), as well as measures of continentality, humidity and hours of sunshine. Again, the temperatures have been divided into six bands to aid description and communication, ranging from cold to very hot.

GROWING SEASON TEMPERATURE (GST)
This model uses the mean temperature of the whole growing season and, again, these temperatures are grouped into climatic bands ranging from cool to hot. It is very closely correlated to GDD and is easier to calculate.

OTHER WAYS OF DESCRIBING AND CATEGORISING CLIMATES
Although more specific climate classifications (such as the others detailed) are required in viticulture, in very broad terms the majority of the world's wine regions can be categorised under three headings: maritime, Mediterranean and continental. These categories are based very loosely on part of Köppen's climate classification (which was first created in 1900), and consider both temperature and rainfall patterns. The categories apply to wine regions in temperate zones, not vineyards located in the tropics.

Maritime – Maritime climates experience low annual differences between summer and winter temperatures. Rainfall is also relatively evenly spread throughout the year. An example of a maritime region is Bordeaux.

Mediterranean – Mediterranean climates also experience low annual differences between summer and winter temperatures. The annual rainfall tends to fall in the winter months, giving dry summers. Examples include Napa Valley and Coonawarra.

Continental – Continental climates have more extreme differences between summer and winter temperatures. They often have short summers and cold winters with temperatures rapidly changing in the spring and autumn. Examples include Burgundy and Alsace.

These broad categories are often qualified with a temperature categorisation. WSET uses the following ranges:

Cool climates – regions with an average GST of 16.5°C (62°F) or below.

Moderate climates – regions with an average GST of 16.5–18.5°C (62–65°F).

Warm climates – regions with an average GST of 18.5–21°C (65–70°F).

Hot climates – regions with an average GST in excess of 21°C (70°F).

Variations in temperature and timing of rainfall can have a significant influence on vine growth, grape ripening and subsequent wine style and quality. The extreme winters found in continental climates can lead to winter freeze, but often the rapid increase in temperature in the spring can lead to even budburst. There is also a rapid drop in temperature in the autumn and therefore a shorter growing season.

In regions with warm summers, the risk of not accumulating sufficient sugar in the grapes is reduced. However, the grapes can have high sugar levels and low acidity levels by the time aroma compounds, colour and/or tannins have reached optimum ripeness, and this can lead to wines with high levels of alcohol and low levels of acid. In climates with cool growing seasons, the grapes may be too low in sugar and too high in acid in the coolest years. However, the low annual differences in temperature in maritime or Mediterranean climates mean that such climates often have long autumns at suitable temperatures for ripening, extending the growing season.

Climates with even levels of rainfall throughout the year, such as maritime climates, are less likely to experience extreme water stress. However, too much water can cause excessive vine vigour. Rain also increases humidity, and can increase incidence of fungal disease, which can be particularly problematic near harvest time. Vines that are grown in climates that are cool, cloudy and rainy in late spring or early summer are also susceptible to poor flowering and fruit set.

CONTINENTALITY

Continentality is a measure of the difference between the annual mean temperatures of the hottest and coldest months. Large bodies of water, such as oceans, seas or large lakes, heat up and cool down more slowly than landmasses. Therefore, in winter they have a warming effect on the surrounding air and in summer they have a cooling effect. Regions near the coast or that are nearby a large body of water therefore have low continentality and tend to be categorised as either 'maritime' or 'Mediterranean'. By contrast, regions that are far inland or are protected from ocean influences have high continentality and tend to be categorised as 'continental'.

3.5. Weather

A region's weather is the annual variation that happens relative to the climatic average. Some regions experience greater variation in this pattern than others. For example, the amount and timing of rainfall in Bordeaux can vary quite considerably. In 2013 the region had a cold, wet spring resulting in uneven flowering, reducing yields and a rainy, humid harvest period forcing producers to pick early, resulting in low quantity and quality. By contrast, 2016 saw good weather during flowering, followed by a long, warm and dry summer and harvest period, resulting in high quality and volume. The weather in other regions, such as Central Valley in California, is far more predictable, with hot dry weather from one growing season to the next.

Weather can have a significant influence on the style and quality of wines produced in that year and this is often termed vintage variation. The weather in a particular year can influence sugar and acid levels, and tannin and aroma/flavour ripeness. This may have a subsequent effect on how the wines are made in the winery (e.g., adjustments to the must or wine may be beneficial, greater extraction may be desirable for red wines in warmer years to balance higher alcohol levels, etc.). In some wine styles, vintage variation is expected and often welcomed. In others, such as non-vintage sparkling wines and many high-volume, inexpensive wines where consumers are expecting the wine to taste consistent regardless of the year, vintage variation is not desirable and winemaking choices may be made that reduce any vintage variation in the final wine.

Weather can also affect yields. Rainy years can bring more fungal disease, reducing yields; spring frosts can also lead to significant reductions in yield, especially if no frost protection is available. Having substantially less wine to sell in a particular year can often be extremely problematic for cash flow and customer relations (wine businesses and consumers may find a replacement if a particular product is not available, and then continue to buy the replacement product in the future). Yields that are substantially larger than normal can also be problematic. The winery may not have the capacity for the increased volume of fruit, and finding routes to market/customers for all the wine (at a profit) may be difficult. The dynamics of supply and demand will be covered in more detail in D2: Wine Business.

In some regions, winemakers may adapt by producing different styles of wine in cooler years (e.g. more sparkling wine or rosé) compared to warmer or drier years.

3.6. Climate Change

Climate change is admitted by the overwhelming majority of the scientific community. As an industry that is highly dependent on climate, wine production is likely to be strongly affected. The main measurable effect of climate change is a rise in temperatures. It also has the consequent effect of greater evapotranspiration and therefore likelihood of water stress. Other effects include changes in the geographical distribution of rainfall, greater weather variability and a greater frequency of extreme weather events.

The effect of rising temperatures on viticulture has already started to be witnessed. In warmer temperatures, the vine cycle is faster. Budburst occurs earlier in the spring and each stage of the vine cycle becomes quicker. The increased temperatures speed up the rate of sugar accumulation and reduction of acidity, but do not quicken the ripening of most aroma and tannin compounds. In order not to compromise the ripeness of aromas and tannins, and the accumulation of colour, grapes may be picked with higher levels of sugar, causing higher alcohol levels in wines and lower levels of acidity. The more rapid fall in acidity can give wines with higher pH levels, and this can be problematic in winemaking.

Drought stressed vines

The effects on aroma compounds is complex, but it is likely that, as temperatures continue to rise, the grapes from certain vineyard regions may no longer exhibit the same aroma profiles as they do now. For example, black pepper is often a characteristic of Syrah grown in moderate climates, such as the Northern Rhône. With increasing temperatures in this region, it is likely that this hallmark aroma may no longer develop. Some regions may become too warm for certain grape varieties, and it may be preferable to grow different, later-ripening grape varieties to continue to provide balanced wines. Although rises in temperature are likely to be problematic for many existing wine regions, there is the potential for production to increase or improve in quality in regions and countries that have previously been too cold to ripen grapes (however, extreme and erratic weather and altered rainfall patterns still pose a risk in these areas).

Drier conditions resulting from greater evapotranspiration and altered rainfall patterns are likely to have a negative impact around the world. In regions that already experience dry growing seasons, the vines may be regularly subjected to extreme water stress, causing photosynthesis to stop and the vines' leaves to fall off. A number of wine regions are starting to experience very significant problems with excessive temperatures and/or drought (e.g. parts of California and South Africa), and it is thought that at least some vineyard sites in many of these regions will be abandoned in the next 50–100 years. Even in regions that currently gain adequate levels of rainfall, increased rainfall and humidity at undesirable times of the year, such as just before the harvest period, will bring problems in the form of increased disease pressure.

The increased frequency of extreme and erratic weather events is problematic for all regions. These can take several forms including storms, hurricanes, floods, unseasonal frosts and heatwaves, all of which can substantially reduce yields or grape quality.

See here for further discussion on how the wine industry should be reacting to climate change.

Many grape growers and wine businesses have already started to act, both to mitigate climate change and to better adapt to the effects of climate change. Many wine businesses now practise sustainable techniques such as using renewable energy resources and protecting natural ecosystems (see Sustainable Viticulture). To better prepare for the effects of climate change, site selection, choice of planting material and/or efficacy of different vineyard management techniques are being reviewed by forward-thinking companies.

Approaches to Grape Growing 4

Contemporary viticulture is marked by several different approaches, which take a range of factors into account: overall approach including world view and ethical issues, desired level of production, intended wine quality, return on investment, cost, availability of labour and environmental impact.

This chapter will describe different approaches to grape growing and examine their advantages and disadvantages.

4.1. Conventional Viticulture

In the second half of the twentieth century, viticulture, in common with production-oriented farming for other crops, underwent a significant change. In effect it became intensive fruit farming. Aside from small-scale artisan grape growing, the new approach was widely implemented around the world. The aims included raising production levels and reducing labour requirements. This was achieved by mechanisation, chemical inputs, irrigation and clonal selection. Viticulture became a monoculture. Vineyards were kept weed free by ploughing between the rows and spraying with herbicides. The use of agrochemicals in the vineyard to control pests and diseases significantly increased. There was also an increased use of mineral fertilisers.

Spraying in Marlborough

Monocultures have advantages and disadvantages. The advantages include:

- The ability to mechanise the work in the vineyard.
- The reduction of competition from other plants.
- The ability to tend to the specific needs of the grape variety planted (irrigation, nutrition level, treatments against hazards, pests and diseases) and hence to increase yields while minimising costs.

The disadvantages are that:

- Plants in a monoculture are much more prone to diseases (e.g. the common fungal diseases) and pests and therefore need more treatments or protection. This is because, for example, fungal diseases spread more quickly in a monoculture and because all the plants are affected simultaneously.
- Nutrients can be depleted as there is no natural ecosystem to replenish nutrients, requiring more applications of fertilisers.
- Residual chemicals from treatments can find their way into groundwater (the water found underground in spaces within the soil or cracks in the bedrock) or the air, creating environmental damage.

By the late twentieth century there was an increasing realisation that spraying pesticides on a regular basis and routine use of mineral fertilisers were harmful to soil quality, expensive, detrimental to the environment and potentially hazardous for vineyard workers and even the consumer. Intensive fruit farming methods had become an increasing worry to many grape growers, consumers and legislators. In many major vineyard regions there are increasing efforts to reduce the quantity of chemicals used. There are three main options available to grape growers wishing to do this.

4.2. Sustainable Viticulture

Sustainable grape growing has three themes: economic, social and environmental sustainability.

The focus in this unit is primarily with environmental impact. In this sense, sustainable viticulture aims to promote the natural ecosystems in the vineyard, maintain biodiversity, manage waste, minimise applications of chemicals and energy use, and reduce the impact of viticulture on the wider environment. Grape growers are encouraged to develop an in-depth understanding of the lifecycles of the vine and of vineyard pests and to monitor weather forecasts so that they can predict and prevent a pest or disease outbreak (e.g. downy mildew) before it occurs. Rather than simply following a regimented calendar of spraying, this enables them to time the applications so that they have the greatest impact. As a result, fewer applications are needed.

Integrated pest management (IPM, also known as *lutte raisonée*) is a key part of sustainable agriculture. It builds on some of the insights of organic viticulture, but it is prepared to use chemical interventions when necessary. It includes setting thresholds at which action needs to be taken (e.g. if pest populations reach a certain level), identifying and monitoring pests, setting up preventative measures, and evaluating and implementing control options (if threshold levels are exceeded and preventative measures have not been effective).

Institutions that support grape growers (e.g. the University of California's IPM department), issue detailed for grape growers to:

- know when to look for a named pest (e.g. caterpillars, moths)
- know what signs to look for
- see photos of the pest and the damage it does, to help with identification know how to calculate thresholds when treatment is warranted.

The grape grower regularly monitors the scale of potential problems and only intervenes before they reach an economic threshold (i.e. when the level of damage will exceed the cost of intervention). They seek to anticipate problems, to boost the vine's own defence mechanisms and to act at the most effective time. Acting in this way helps to limit serious damage to the grape crop, reduce the amount of chemicals used, save on costs and prevent weeds from building up resistance to those chemicals.

Many countries and regions have guidelines and standards for sustainable viticulture. Because of the differing circumstances (e.g. dry versus wet climates), these vary from place to place. They are more about setting in place a way of working (identifying key challenges and hazards, record keeping, ways of calculating thresholds) than absolute standards. Examples include LODI RULES (for Lodi, California), Sustainable Winegrowing NZ and Sustainable Winegrowing South Africa.

The advantages of sustainable viticulture are:

- A more thoughtful approach to grape growing, with attention to the economic, social and environmental impact of viticulture.
- The deployment of a scientific understanding of the threats to successful grape growing (pests and diseases) to minimise the number of interventions needed.
- A reduction in the spraying of synthetic and traditional treatments.
- The consequent cost saving that has incentivised grape growers to work in a more sustainable way.

The disadvantages are:

- The term is not protected and therefore can be used to promote wine without a clear set of standards.
- The danger that nationwide standards for sustainability can be set too low. New Zealand's high rate of uptake for its scheme – virtually all commercial grape growers – has both been praised for reducing the amount of pesticides used but criticised for setting too low a bar for sustainable certification.

4.3. Organic Viticulture

Organic viticulture seeks to improve the soil of the vineyard and the range of microbes and animals, such as earthworms, within it and thereby increase the health and disease-resistance of the vine. It rejects the use of manufactured (also known as synthetic) fertilisers, fungicides, herbicides and pesticides. The key features are:

- The application of **compost** that breaks down in the soil. This provides a slow release of nutrients for vines, improves the structure of the soil and increases the biomass in the soil (the total quantity or weight of organisms in a given area or volume).
- The use of **natural fertilisers** (animal dung, natural calcium carbonate, etc.). The idea is to restore the natural balance of the vineyard.
- The cultivation of **cover crops** to prevent erosion of the soil and to contribute to the improvement of the life of the soil. This can be through ploughing them in ('green manure') or by improving biodiversity.
- The **reduction of monoculture** of vineyards by growing cover crops, planting hedges and establishing 'islands' of biodiversity.

(The above techniques are also often used in sustainable viticulture to promote biodiversity and soil health, and hence reduce chemical applications.)

Organic grape growers use traditional remedies such as sulfur and copper sulfate to combat mildews, and monitor the weather closely to determine when spraying against mildew is really necessary.

Pheromone tags used to control mealy bug populations

However, the build-up of the heavy metal, copper, in the soil where frequent sprays are necessary has led some to conclude that careful use of longer-lasting synthetic chemical sprays are a better option for the environment. The reduced need to use tractors in the vineyard is also a bonus for those using synthetic chemicals.

In addition, organic grape growers can make use of natural predators and ecosystem mechanisms. For example, to protect against grey rot, the bacterium *Bacillus subtilis* can be introduced, which competes with *Botrytis cinerea* for space on the grape. 'Sexual confusion' techniques are also commonly used. They involve the use of pheromone tags or capsules to disrupt the mating patterns of insects such as moths and mealy bugs, and in this way, limit their populations.

There are many certification bodies for organic viticulture throughout the world. Although many of these organisations operate on similar principles, the exact standards each one sets may be slightly different. Therefore, and perhaps confusingly, some wines made from organically-farmed grapes may have been subject to stricter rules than others. All certification bodies should meet the standards set by IFOAM (International Federation of Organic Agriculture Movements). A universal requirement is that the vineyard must undergo a period of conversion working to organic standards before it can be certified. Certification adds an extra cost to the production of wine. However, it may be that the grape grower can gain an advantage in promoting and selling such wine depending on the target consumer and market.

Evaluating the cost/benefits of organic viticulture is at a very early stage. In some studies, it has been found that organic viticulture leads to slightly lower yields than conventional viticulture. Others have found that the additional cost comes from the need for additional labour. However, any additional costs of organic viticulture are likely to vary around the world (in cool, wet climates it is more difficult to manage without chemical sprays, in some countries labour costs will be higher than others).

The percentage of vineyards farmed organically (certified or in conversion) in Europe has grown dramatically over the last two decades. In 2017, 5.4% of the world's vineyards were certified organic. Europe leads the way with 84 per cent of the organic viticulture in the world. Italy has the highest percentage of organic vineyards at 15.8 per cent, as well as being the largest producer and exporter of organic wines. Agence BIO show that companies in countries outside the EU have lower or much lower percentages of organic viticulture: 4.3 per cent in New Zealand, 2.7 per cent in USA, and less than 2.5 per cent in each of Argentina, Chile and South Africa.[1]

The largest markets in the world for organic still wine are Germany, France, the UK, the USA, Sweden and Japan.

The advantages of organic grape growing are:

- the improvement of the health and disease-resistance of the vine
- the improvement of the health of the soil
- the elimination of spraying synthetic chemicals
- a saving on the cost of synthetic chemicals.

Disadvantages of organic viticulture are:

- a possible small reduction in yield generally
- possibility of significant reductions in yield in difficult years (e.g. long periods of rainfall or high humidity)
- increased reliance on copper sprays, which may in turn lead to the build-up of heavy metal in the soils
- the cost and time expended on certification where this is sought.

4.4. Biodynamic Viticulture

Biodynamic viticulture is based on the work of Rudolf Steiner and Maria Thun. It includes organic practices but also incorporates philosophy and cosmology, regarding the farm as an organism and seeking to achieve a balance between the physical and higher, non-physical realms. The vineyard soil is seen as part of a connected system with the planet Earth, other planets and the air. Practitioners adapt their grape growing practices to coincide with the cycles of the planets, moon and stars.

Read more about the philosophy and practice of biodynamic farming: Alternative Farming Systems Guide: Biodynamic farming and compost preparation, Demeter-USA

For example, when the moon is ascending, a summer mood is evoked, sap is rising and therefore this is an appropriate time to take cuttings for grafting, but pruning should be avoided. When the moon is descending, a winter mood is evoked, and roots are favoured: this is the best time to plant vines or to prune. From this basis, Maria Thun, followed by others, further developed calendars to advise grape growers on root, leaf, flower or fruit days, which indicate the best days for certain activities.

Burying cow horns in Marlborough as part of a biodynamic preparation

Homeopathic remedies called 'preparations' are used to fertilise the soil, treat diseases and ward off pests, and, more generally, to enhance and strengthen the life forces on the farm. These procedures include:

Preparation 500 (horn manure) – This is made by stuffing cow manure into a cow's horn and burying the horn in the soil throughout the winter. It is then dug up and the contents are dynamised. This is the action of stirring the contents of the horn into water (creating a vortex and then reversing it) so that the water is said to memorise the power of the preparation, which can then be passed on to the vineyard. This preparation is then sprayed onto the soil as a homeopathic compost; it is believed to catalyse humus formation.

Preparation 501 (horn silica) – This is made by filling a cow's horn with ground quartz (silica) and burying it for six months. It is also then dug up, dynamised and sprayed onto the soil. It is thought to encourage plant growth.

Compost – Biodynamic grape growers believe that biodynamic compost has to be first 'activated' by a series of starters added in tiny quantities (yarrow, chamomile, nettle, oak bark, dandelion or valerian prepared in various ways; for example, the yarrow is buried in a deer's bladder). These are known as preparations 502–507 and they assist with the decomposition of the compost.

Like organic grape growers, biodynamic grape growers use traditional chemicals to spray against disease, including sulfur and copper sprays. Some practise ashing: spreading the ashes of burnt weed seeds or harmful animals (e.g. rats or sparrows) on the vineyards to ward off these hazards.

The most common certification body for biodynamic grape growers is Demeter, which sets international standards for farming and animal husbandry. It has member organisations in many countries. The standards for biodynamic viticulture include organic certification of vineyards as a baseline, but then goes on to specify the principles that should be followed. Each national association interprets these in the light of local circumstances.

The additional costs of biodynamic grape growing are estimated to be little more than organic growing, generally due to the need for additional labour to tend the vineyard.

Biodynamic grape growing has mainly been taken up by smaller scale grape growers and estates, including some of the most prestigious domaines in Burgundy (e.g. Domaine de la Romanée-Conti). It has been particularly popular in the Loire Valley, and has advocates around the world.

The advantages and disadvantages of biodynamic grape growing include those of organic grape growing. There has been limited research comparing organic and biodynamic grape growing (testing, for example, the quality of the soil or the composition of wine made from the grapes), which have so far proved inconclusive.

4.5. Precision Viticulture

Traditionally, grape growers have adopted a uniform approach to work in the vineyard, whether this is in preparing the soil, pruning the vines or applying treatments. However, both experience and recent research shows big variations in the response of vines, even in the same vineyard or plot.

In response to this, precision viticulture (PV), a branch of precision agriculture, makes use of data collected from the vineyard (soil, vine vigour, topography, plant growth) to respond to changes from plot to plot and from row to row. The data is collected by sensors either on aircraft ('remote') or mounted on a tractor or harvester in the field ('proximal'). Geospatial technology such as global positioning systems (GPS) and geographical information systems (GIS) allows the data to be presented visually in the form of maps. The data collected can be about the composition of soils, the rate of growth of the canopy and many other examples.

Interventions in the vineyard are then targeted in the light of the data collected. This is known as variable-rate application technology. Thus, the grape grower can respond to the significant differences from plot to plot (or smaller) in the vineyard. The idea is for all key interventions, for example, pruning, leaf removal, treatments, irrigation, crop thinning and harvesting, to be carried out precisely with the aim of producing the best quality and yield, reducing environmental impact and, where possible, reducing costs on treatments. Examples of changes made in the light of the data include changing the rootstock halfway along rows of vines as the soil gets more fertile or increasing levels of leaf-stripping in areas showing particularly high vigour.

A map generated as part of precision viticulture. This image shows differences in vegetative vigour throughout the vineyards.

As precision viticulture requires considerable upfront investment (sensors, software), it is only an option in large scale viticulture or on high-value, smaller estates. It has been most widely used in California and in Australia. It is most effective where the data collected is used systematically to control treatment application rates or irrigation rates. Precision viticulture not only seeks to respond to variations (e.g. in vine vigour) in the vineyard, but, if possible, to reduce them. Also, it can be used to identify different quality zones within the same vineyard.

Precision viticulture is often used as part of sustainable or organic viticulture.

Advantages include:

- detailed understanding of variations in the vineyard that affect yield and quality between and within vineyards
- ability to tailor a wide range of interventions (choice of variety and rootstock, canopy management, treatments, harvest dates) to individual blocks or even rows of vines, with the aim of improving yields and/or quality.

Disadvantages are:

- initial cost of remote data collection
- cost of sensors and software and of either consultancy or trained staff to interpret the data and make interventions in the light of it.

Reference

1. *L'Agriculture Bio dans le Monde 2019*, Agence Bio, p. 68 (retrieved 11 March 2020)

Vineyard Establishment 5

The various stages within the establishment of a vineyard are hugely important. Many of the decisions made and processes carried out during this time are difficult to rectify once the vineyard has been planted; hence, compromises or lack of planning at this stage, due either to cost or time, may result in problems later in the life of the vineyard. Therefore, although site selection, soil preparation and planting materials are covered in this chapter, many of the options described within Nutrient Management, Water Management and Canopy Management will also be considered and planned at this time.

A detailed site assessment should be carried out to determine the suitability of the land and decide on the steps that need to be taken before planting.

5.1. Site Selection

The growing environment of a vineyard depends on its location. For this reason, site selection is very important when determining where a vineyard could be planted. The style, quality and price of the wines to be made will be a key influence on site selection (and vice versa).

To produce high volume, inexpensive or mid-priced wines, high yields of healthy grapes need to be produced consistently and relatively cheaply. A flat, fertile site in a warm, dry climate may be ideal, for example those found in the Central Valley of Chile. The fertile soils and plentiful warmth (plus the option of irrigation) may mean high yields of grapes can be ripened adequately. The dry climate may reduce the incidence of fungal diseases, which in turn could save money on fungicide spraying and grape sorting in the winery. Flat land also allows for mechanisation, which can be quicker and cheaper, especially for large vineyards.

By comparison, to produce premium or super-premium wines, the criteria for site selection may be very different. Obtaining healthy grapes of the optimum composition (considering levels of sugar, acidity, colour, tannins and aroma compounds) for the style being made will be a priority, rather than keeping costs as low as possible. In cool climates, the producer may look for sites that will maximise potential to ripen the grapes, such as those with aspects that will receive most sunshine throughout the day, as found in the Rheingau, Germany. Conversely, in warm climates the producer may favour relatively cool sites, such as those at high altitude, as seen in Lújan de Cuyo in Mendoza, Argentina, or those exposed to cooling sea breezes, as in Casablanca, Chile, to bring better balance to the wine.

However, it is not only the natural resources that will be considered when selecting a vineyard site, and several logistical, legal and cost factors often need to be considered:

- The price of the land itself within desirable geographical indications (GIs) (e.g. Burgundy Grand Crus such as Clos des Lambrays) is much more expensive than land that simply qualifies for wine of that country or region (e.g. Vin de France).
- The location, layout and topography of the site may have cost implications. Sometimes, this is linked to natural factors. For example, a vineyard that sits in a frost pocket may produce less reliable yields and thus slower return on investment or may require more

expensive frost protection strategies than a better protected site. Sites that are known to be susceptible to certain diseases or pests pose a similar problem.
- Steep slopes can be unsuitable for mechanisation and labour can be expensive, slow-paced and hard to attain in some regions.
- If the vineyard will require irrigation, the source of irrigation water and its cost will need to be considered.
- Ease of access to the vineyard site and distance from the winery should also be considered to ensure that healthy grapes can be delivered to the winery with limited risk of oxidation and microbial spoilage.
- Proximity of the vineyard and winery to towns and cities for labour, supplies, cellar door customers, retail or distribution businesses may also be a key factor.

Many wine regions, especially those in the EU, are subject to local or national laws. For example, wines with a Protected Designation of Origin (PDO) will be subject to rules that stipulate what grape varieties can be used, maximum yields and viticultural and winemaking practices. A producer investing in expensive PDO land with the intention of creating a wine that does not meet the rules (and therefore will be declassified) is taking a business risk and not likely to get an appropriate return on investment. To survive as a business, the producer must get a return on investment from selling the grapes, must or wine. Therefore, if the vineyard site is going to be expensive to buy, establish and manage, the producer must be confident that the quality and/or type of grapes, must or wine produced on the site will sell for a price that will bring a return on investment.

THE IDEA OF *TERROIR*

The French word *terroir* comes from the word *terre* meaning 'land'. It is much used in discussion about wine and in the marketing of wine. It is an overarching concept which claims that the distinctiveness of quality wines is due to their sense of place.

However, a precise and agreed definition of *terroir* does not exist and a common issue is that people often use the term *terroir* without first defining what they mean. A number of uses and issues can be identified:

- A sense of place: a wine shows characteristics that relate to the particular place in which the grapes are grown – climate, soil, aspect, elevation. Thus, famously, wines made from grapes grown with a few hundred metres of each other on the Côte d'Or taste different from each other because of the location of the vines on the slope, small differences in soil type, aspect, drainage and so on. This is the physical definition of *terroir*.
- Some commentators include human interventions in the concept of *terroir*; for example, where French PDOs stipulate planting density, type of trellising and so on in their regulations. This a cultural definition that includes the physical elements but goes beyond them.
- Especially for marketing purposes, wines may claim to be directly influenced by the geological make-up of the soil; for example, the claim that the perceived chalkiness of the taste of Chardonnay is attributable to the vines being grown in chalky soils.

The implication is that the vine is taking up elements from the soil that directly affect the taste of the wine. This direct connection is strongly contested by the scientific community. It notes that photosynthesis is the primary driver of vine growth, that all aroma compounds are synthesised in the vine and that grape must is further transformed through the process of fermentation.

- Many commentators believe that overly zealous winemaking practices can obscure *terroir*. For example, picking over-ripe fruit and ageing wines in new oak can mask their inherent character, the *terroir* expression of a wine.
- While *terroir* has been strongly associated with French and then other classic European wines (e.g. Mosel), winemakers around the world are now showing an interest in the different expressions of wines made from grapes in single vineyards or specific locations. This is being strengthened through the use of soil mapping technology (see Precision Viticulture).

5.2. Soil Preparation

The grape grower needs to ensure the soil within the vineyard is suitable for planting vines and growing grapes. The main factors that the grape grower will need to assess, and potentially rectify, are the drainage and structure of the soil, its mineral composition and the presence of pests or unwanted plants. In some cases, the topography of the vineyard may be modified. In nearly all cases, rectifying any problems at this stage is easier than when the new vines are planted.

The structure of the soil has a significant influence on root penetration, water drainage, nutrient holding capacity and workability (see Soil) and therefore soil structures that negatively affect these factors may need to be resolved. Very large rocks at or near the surface may be removed. If the land has previously been used for agriculture, a plough pan (an impervious layer of soil) may have formed from years of ploughing at the same depth. This may need breaking down (a process called subsoiling) before further cultivation can take place. This process promotes better drainage and makes the soil easier to cultivate once the vineyard has been established.

If vines or other crops have been uprooted to plant new vines, it is important to ensure old roots are removed. The roots must be burnt as they can otherwise

A young vineyard in Tuscany. The soil has recently been cultivated.

harbour disease. If weeds are a particular problem on the site, it may be advisable to use systemic herbicides at this point (see Nutrient Management).

Farmyard manure, compost and fertilisers may also be applied to increase the levels of nutrients and organic matter of the soil. Ploughing (turning over the surface layer of the soil and burying it) incorporates these additions into the soil. If soil pH needs adjusting this is also an opportune time to rectify it. For acidic soils, such as those found in Beaujolais, lime (a calcium-based substance) can be spread on the soil and then ploughed in. (Lime just applied to the soil surface can take a long time to have any effect.)

In extreme cases, substantial and costly landscaping work may be required to dramatically change the natural topography of the site in order to make viticulture viable. In regions with steep slopes, such as the Douro Valley, terraces may be constructed to provide flat land on which to plant vines.

5.3. Planting Materials

In establishing a vineyard, a grape grower has to make some key decisions regarding what to plant. These will include the grape variety and its clone, and, if grafting onto a rootstock, which rootstock to use.

GRAPE VARIETIES

There are over one thousand grape varieties in commercial use, each with their own specific set of characteristics. Although the consumer may be mainly concerned with the aroma/flavour properties of the grape variety, the grape grower also needs to consider the factors listed below.

There are a number of ways in which certain grape varieties can be more or less adapted to their climate:

- **Time of budding** – Early budding grape varieties, such as Chardonnay, are more at risk from spring frost damage compared to late budding varieties, such as Riesling.
- **Duration of annual life-cycle** – Early ripening grape varieties, such as Chardonnay and Pinot Noir, are best suited to cool climates, ensuring that they reach a suitable level of ripeness before wet, cold weather starts towards late autumn. Late ripening grape varieties, such as Mourvèdre, are better suited to warm and hot climates. Early ripening varieties in these climates would gain sugar and lose acidity too rapidly, resulting in unbalanced wines.
- **Tolerance of drought** – Grape varieties that are able to withstand a high level of water stress, such as Grenache, can be the best option in dry climates such as the southern Rhône, inland Spain and McLaren Vale.
- **Resistance to disease** – Some grape varieties are less susceptible to fungal diseases, meaning that they require less monitoring and/or treating in damp climates. For example, Cabernet Sauvignon is less susceptible to grey rot than Merlot, one of the reasons why these two grape varieties make useful blending partners, particularly in maritime Bordeaux.
- **Winter hardiness** – Some grape varieties, such as Vidal and Riesling, are relatively tolerant of very cold winter temperatures, making them suitable for the harsh winters experienced in Ontario and the Finger Lakes.

- **Vigour** – If high vigour grape varieties, such as Sauvignon Blanc, are grown on fertile soils with plentiful water, it is likely that their vigour will need managing to avoid excessive shoot growth.

As well as climatic factors, choice of grape variety may also depend upon the following:

- **Style of wine** – The characteristics of the grapes should be consistent with the style of wine that the producer wants to make. For example, a producer wanting to make a low tannin, fruity red for early drinking is more likely to choose Gamay or Grenache than Nebbiolo or Aglianico.
- **Yield** – High yielding grape varieties (e.g. Grenache) or clones allow the production of higher yields. This can be a prime concern when making inexpensive wines, allowing more wine to be made at a set cost.
- **Cost** – Some grape varieties are more difficult, and therefore more expensive, to grow. For example, Pinot Noir is prone to disease and therefore is likely to need more monitoring and spraying.
- **Law** – In many EU countries, wine legislation restricts what grape varieties can be planted. For example, a wine labelled Prosecco in the EU must be made predominantly from Glera.
- **Availability** – The risk of spreading pests and diseases means that strict quarantine procedures are in place when introducing new planting material to a country or region. Although in some wine regions there is a large range of choices, in others certain grape varieties or clones may not be available or be sold out due to high demand.
- **Market demand** – To be commercially successful, a producer must identify the demand and the route to market for the wine that they are ultimately going to produce and select the variety to plant accordingly. Fashions for particular grape varieties or styles of wine can clearly be seen in today's market place; for example, the success of Sauvignon Blanc.

A recently head-grafted vine. The two canes are held secure with tape, which, in this instance, has been covered with pruning paint to protect the wound.

An established head graft

To capitalise on such trends, a grape grower can cut the original vine at the trunk and graft a bud from a new grape variety on top. This is called head grafting or top grafting. The benefit is that, with an established root system, the new grape variety can produce fruit suitable for wine much more quickly than a brand-new planting. A disadvantage is that the rootstock will have been selected based on the characteristics of the original grape variety, and may not be equally suited to the new grape variety.

CLONES

If the grape grower buys young vines from a nursery, there may be a choice of clones for some or all grape varieties (see Vine Propagation). Many of the factors detailed in Grape Varieties also apply to the choice of clone, though this is less impactful than choice of grape variety and much less affected by legislation and consumer popularity.

ROOTSTOCKS

The vast majority of grapevines are grafted onto rootstocks. The main reason for grafting is to protect the vine from phylloxera (see Pests). However, a range of different rootstocks exist with varying characteristics. The characteristics of a rootstock are usually linked to its parentage, and many rootstocks are hybrids of two different vine species in order to take advantage of some of the characteristics of both species.

The grape grower may choose a rootstock based on any of the following criteria:

- **Pests** – As well as being tolerant of phylloxera, some rootstocks are also tolerant of root-knot nematodes (for more details see Pests). Ramsey and Dog Ridge (both *Vitis champini*) are two examples of rootstocks that are tolerant of root-knot nematodes.
- **Water** – Rootstocks that are hybrids of *V. rupestris* and *V. berlandieri*, such as 110R or 140R, are highly tolerant of drought because of their ability to root deeply and quickly. Rootstocks based on *V. riparia*, such as Riparia Gloire, are tolerant of water- logged soil and so can be useful in regions with high rainfall and water-retaining soils. In areas where salinity (high levels of salt in the water) is a problem, rootstocks based on *V. berlandieri* that are tolerant of soils with higher levels of dissolved salt, such as 1103P, may be used.
- **Soil pH** – Rootstocks can also help alleviate problems caused by soils that have very low or high pH (see Natural Factors that affect Nutrient Availability). 99R and 110R, both hybrids of *V. rupestris* and *V. berlandieri*, are examples of rootstocks that have high tolerance to acidic soils. Rootstocks that are based on *V. berlandieri*, such as 41B, tend to be tolerant of soils with high lime content (high pH).
- **Vigour** – Rootstocks can be used to moderate or enhance the vigour of the vine. Low vigour rootstocks can advance ripening, which may be useful in cool climates. These tend to be based on *V. riparia*, such as 420A and 3309C. High vigour rootstocks based on *V. rupestris*, such as 140R, can be useful if the grape grower wants to boost vine growth and yields in vineyard areas with unfertile soils and dry conditions. This decision may also be based on the style of the wine to be produced. For example, a grape grower may use a high vigour rootstock to produce grapes for sparkling wine where high yields of grapes with delicate aromas and high acidity is more desirable than lower yields of grapes with more concentrated aromas, colour and/or tannins.

VINE AGE

In the first two or three years of a vine's life, it is common for the grape grower to remove inflorescences as they form so that the young vine can concentrate its resources on growth. In some GIs, legislation restricts the use of fruit from very young vines.

Young vines (up to approximately five years old) typically produce relatively low yields because their root system is yet to fully establish. Depending on the grape variety and environmental conditions, between around 10 to 40 years, the vine is able to produce its maximum yields of fruit, then beyond that age the vine's yield starts to decrease as its vigour decreases. The grape grower must decide at what point the decreasing yield is no longer profitable.

Thus, very old vines (50 years or more) may well remain profitable in famous old vineyards in Burgundy or in the Eden Valley where the wine will obtain super-premium prices. However, in some areas making inexpensive or mid-priced wines, medium to high yields are required, and the old vines will be replaced.

It is often cited that older vines produce a higher quality of fruit, capable of producing well-balanced wines with greater concentration, than young or 'middle-aged' vines. There are a number of theories behind this view. It could be that with age these vines have become better balanced (see Canopy Management and Vine Balance) and adapted to their environment. It could be that the lower yields sometimes lead to more concentration in each grape (the vines' resources are shared among fewer grapes). Old vines also tend

An old bush vine in Spain

to have more old wood and therefore have a bigger store of carbohydrates to rely upon early in the growing season or when they are stressed. It could also be that these vines have survived better than other vines over time because they were planted in the most favourable locations, and therefore they always produced high quality fruit. The grape grower is also likely to keep the best vines for longer before grubbing them up (digging them out of the ground) and replanting with a young vine. There are often too many variables (such as clone, rootstock, irrigation management, training and trellising) to make a direct comparison between the young and old vines of a particular grape variety and/or within a particular area.

The notion that old vines produce better fruit is not a definitive rule; a young vine planted in a suitable location and trained and trellised well is likely to produce better fruit than an old vine in an unsuitable location or that is badly maintained.

Because of its connotations of quality, the term ‘old vines’ (or equivalents in other languages such as ‘*vieilles vignes*’ or ‘*viñas viejas*’) is commonly seen on wine labels. This term is not regulated, however, and therefore ‘old vines’ for one producer may be 30 years, whereas it may be 100 years for another. Some regions have put in place associations that help to protect and classify their old vines, such as The Historic Vineyard Society in California and The Barossa Old Vine Charter. Such classifications will often specify a minimum vine age.

Managing Nutrients and Water 6

Vines gain the water and nutrients that they need to survive, grow and produce fruit from the soil. Ensuring the soil is healthy is therefore seen as a vital part of good vineyard management. Many methods of managing the vine's access to water and nutrients involve monitoring and managing the structure and texture of the soil and the organisms (earthworms, microbes and other plants) that live within it. Despite this, in some regions, interventions such as irrigation or drainage channels may be necessary or beneficial to ensure the vine has access to appropriate amounts of water throughout the growth cycle (for more details see Water).

This chapter will introduce the concept of soil health and then examine options for managing water and nutrients in the vineyard.

6.1. Managing Soil Health

Soil health describes the continued capacity of the soil to act as a living ecosystem that sustains plants, animals and humans.[1] It is related to:

- the structure of the soil: beneficial properties include good drainage, sufficient water-holding capacity, sufficient oxygen, the ability to resist erosion and to allow the roots of the vine to penetrate to sufficient depth (see Soil Preparation)
- the amount of organic matter and humus in the soil: decomposing organic matter supplies nutrients, and humus improves the structure of soil and its water-holding capacity
- the number of living organisms in the soil: earthworms and microbes break down organic matter into humus and inorganic nutrients that are accessible to the vine
- the total amount of available nutrients that the vine needs to grow successfully (see Nutrients).

Poor soil health can lead to problems with the availability and uptake of nutrients and water in the soil, and hence poor vine growth and ripening. Grape growers may have the soil tests conducted when establishing the vineyard and then annually so that corrective measures, such as improving the structure of the soil or adjusting nutrient levels, can be taken.

6.2. Nutrient Management

As covered in Nutrients, the right balance of nitrogen, phosphorus and potassium as well as many other nutrients is essential for healthy vine growth and the ripening of grapes. There are several methods that can be used during the growing season to control the level of nutrients in the soil and their accessibility to the vine (nutrients must be in an inorganic form – see Natural Factors that affect Nutrient Availability). Some of these techniques involve direct application of nutrients (in either organic or inorganic form), some involve the promotion of biological activity and soil structure, and some involve the management of weeds (unwanted plants) that can compete with the vine for nutrients (and water). Many of these techniques have multiple functions and can influence accessibility of water as well as nutrients.

The removal of weeds is usually desirable for additional reasons. Bare, moist soils are best at absorbing heat during the day and the heat they release at night reduces frost risk. By comparison, weeds, as well as cover crops and mulches, can increase frost risk. Some weeds also hamper the passage of machinery and personnel (e.g. stinging nettles, brambles).

APPLICATION OF FERTILISERS

Fertilisers may be added before planting to help the growth of young vines. They may also be applied to established vineyards to correct any detected nutrient deficiencies. However, excessive addition of fertilisers may lead to excess vigour and an unbalanced vine (see Canopy Management and Vine Balance). Fertilisers can be organic or mineral.

Organic Fertilisers

Organic fertilisers are derived from fresh or composted plant or animal material, such as manure or slurry (manure in semi-liquid form). Cover crops can be grown, mown and turned into the soil to decompose and provide nutrients (termed green manure).

Organic fertilisers are often cheap or even free. Some are high in humus and therefore good for soil structure and water retention. As their nutrients tend to be in organic form, they provide nutrition for soil organisms, promoting the living matter in the soil.

However, because the organic nutrients need to be broken down into inorganic nutrients by these organisms, these fertilisers require incorporation into the soil, which requires labour. This also means that the nutrients become available to the vine gradually, which can be an advantage. However, a disadvantage is that they can be bulky and therefore expensive to transport and spread.

A tractor is used to transport and spread bulky compost.

Inorganic Fertilisers

Inorganic fertilisers, also called synthetic fertilisers, are manufactured from minerals extracted from the ground or synthetic chemicals. They can provide a single nutrient or several nutrients; therefore, they can be more tailored than organic fertilisers. The nutrients are already in an inorganic form and therefore can be more readily available to the vines. They hold no benefit for soil organisms and do not improve soil structure. They are often more expensive than organic fertilisers to purchase, but, as they are more concentrated, much cheaper to transport and distribute.

CULTIVATION

Cultivation is a method of weed control that involves ploughing the soil to cut or disturb the weeds' root systems.

Advantages include:

- This method does not use any chemicals and so can be used in organic and biodynamic viticulture.
- It enables fertiliser and, where relevant, mown cover crops to be incorporated into the soil at the same time as removing weeds.

Recently cultivated soil in Lodi

Disadvantages include:

- Repeated cultivation can damage the soil's structure and ecology due to the breakdown of organic matter and disruption of earthworms in their habitat.
- It is costly as it requires both skilled labour and machinery.
- Disturbing the soil buries seeds, thus encouraging the weeds to grow back.
- It can increase vine vigour too much as there is no competition for water or nutrients (not necessarily a disadvantage in low vigour sites (poor soils and/or lack of water)).

HERBICIDES

Herbicides are chemical sprays that kill weeds. There are three types of herbicides:

- Pre-emergence herbicides are sprayed before weeds establish. They persist in the surface layers of the soil but are absorbed by the weeds' roots and inhibit germination of young seedlings.
- Contact herbicides are sprayed on established weeds and kill the green parts of the weed that they contact, resulting in the death of the plant.
- Systemic herbicides are sprayed on established weeds and are taken in by the leaves. The herbicide travels up and down the weed in the sap and kills the whole plant.

Advantages include:

- They are cheap in terms of labour and machinery requirements.
- They are highly effective, particularly in the under-row area.
- They are less damaging to the soil structure than cultivation.

Disadvantages include:

- They present the risks of poisoning to the operator, consumer and environment, and do not encourage vineyard ecosystems.
- Weeds can become resistant and therefore larger doses or different chemicals need to be used. The routine use of glyphosate, one of the most common herbicides, in South Africa and elsewhere has given grape growers a particular problem with glyphosate-resistant ryegrass.
- They can increase vine vigour too much as there is no competition for water or nutrients (not necessarily a disadvantage in low vigour sites).
- They are not allowed in organic and biodynamic viticulture.

ANIMAL GRAZING

Another method of weed control is to allow animals, such as sheep, to graze in the vineyard.

Advantages include:

- This method does not use any chemicals and so can be used in organic and biodynamic viticulture.
- The animals can provide the vineyard with manure.
- The animals can be a source of meat for humans.

Disadvantages include:

- The vines must be trained suitably high or the grazing must be conducted out of growing season, otherwise the animals may eat leaves and grapes off the vines.
- The animals need caring for if they belong to the vineyard owners, which requires labour.
- The animals are often susceptible to vineyard pesticides.

COVER CROPS

Cover crops are plants that are specifically planted, or allowed to grow, that have a beneficial effect on the vineyard. Cover crops may be grown to suppress weeds. They may also be planted to improve soil structure, compete with the vine for nutrient and water availability in fertile sites, manage soil erosion, enhance biodiversity and provide a surface to drive on.

Cover crops that are quick to establish and are adapted to the soil and climatic conditions are best. Examples of cover crops include legumes (such as beans and clover) and various cereals (such as ryegrass and oats). Cover crops are widely used around the world but have to be matched to the needs of the vineyard. For example, Wine Australia provides an online cover crop finder for particular conditions for its grape growers.

A cover crop has been planted in between the rows of vines.

It is also possible to leave natural vegetation to grow in the vineyard to achieve any of the above aims. Although this is cheap, and can permit greater diversity, specific cover crops with known characteristics allow more control.

The cover crop must be managed so that it does not compete too much with the vine for water and nutrients at key times in the vine cycle. If ploughed into the soil, the cover crop or natural vegetation can provide organic matter and, in this way, fertilise the soil (this is called green manure).

Advantages include:

- This method does not use any chemicals and increases soil biological activity and biodiversity in the vineyard, so is commonly used in organic and biodynamic viticulture.
- The ability to influence the vigour of the vine by introducing competition for water and nutrients.
- The provision of a good surface for machinery, particularly in climates with high annual rainfall.

Disadvantages include:

- A reduction in vine vigour (through competition for water and nutrients) that can be excessive in poor soils and dry environments.
- The difficulty of mowing the under-row area, particularly near the vine trunks, which has implications on time and labour.
- The unsuitability for steeply sloping vineyards, as they are slippery when wet.

MULCHING

Mulching is the spreading of matter onto the vineyard soil to suppress the growth of weeds. Mulches are usually made of biodegradable materials, such as straw or bark chips, that ultimately provide nutrients for the vines. Materials with a high nutrient content can be chosen in nutrient-poor vineyards.

Advantages include:

- This method does not use any chemicals, so can be used in organic and biodynamic viticulture.
- It can reduce water evaporation from the soil, which can be advantageous in dry climates.
- It can ultimately be a source of nutrients and humus, which promotes soil biological activity and good soil structure.

Disadvantages include:

- Mulch tends to be very bulky, and therefore is expensive to transport and spread.
- It is only effective if applied in a thick layer, so a lot can be needed.
- It can increase vigour too much as there is no competition for water or nutrients (not necessarily a disadvantage in low vigour sites).

Straw is piled up along the vine rows to provide a biodegradable mulch.

6.3. Water Management

Water is a key natural resource for the vine and the amount and timing of water available through the vine cycle has a significant influence on the vine's growth and ability to ripen grapes (see Water).

IRRIGATION

If the vineyard is located in an area that is likely to receive very little water through the growing season, or has very free-draining soils, irrigation may be necessary and should be a part of vineyard design and establishment. Irrigation systems can be fitted in an established vineyard if the need is persistent, but this can be much more difficult because of potential disruption to the vineyard in order to lay pipes. It must be noted that some EU GIs do not permit irrigation or only allow it for emergency situations (establishing young vines, drought that threatens the livelihood of grape growers). In other cases, difficulty in sourcing water for irrigation may mean that it cannot be used.

Sources of Water and Efficiency of Use

Water for irrigation can come from many sources, such as a nearby river, lake, reservoir or bore-hole. However, water is a precious resource and therefore in many countries water use is tightly regulated.

Australia, California and South Africa have experienced extreme shortages in water supply in recent times resulting from prolonged periods of dry weather. Therefore, for sustainability, it is important to increase the efficiency of water use. Steps taken in the vineyard include:

- use of certain water-efficient irrigation systems and techniques combined with better monitoring of water take-up by the vines (e.g. dripper systems and regulated deficit irrigation)

The Rio Negro is the essential source of water for the wine regions of Neuquén and Rio Negro, Argentina.

- use of drought-tolerant grape varieties (e.g. Grenache), and rootstocks (e.g. 140R)
- reducing evaporation (e.g. by applying a mulch – see Nutrient Management)
- reducing competition (e.g. removing weeds)
- increasing humus levels in the soil to improve water retention (e.g. by adding organic matter such as compost)
- promoting the growth of vine roots deep into the soil (e.g. through cultivation – see Nutrient Management).

Water is also a valuable resource in the winery, where it is mainly used for cleaning. Consideration of ways in which this water can be re-used (e.g. some may be suitable for irrigation) can also maximise efficiency of water consumption.

Water Quality

Assessing the water quality is also important. Water that is high in dissolved solids such as mud can block sprinkler and drip irrigation systems and therefore needs settling and filtering before use. Water that contains high levels of salt (high salinity) can also be problematic, as is the case in many areas in Australia. This water increases salt levels in the soil and makes it more difficult for vine roots to take up water. The vine becomes dehydrated and the green parts of the vine start to wilt and eventually die. This is particularly a problem when drip irrigation is used, as the salt accumulates at the root zone, rather than being washed deeper into the soil, for example by flood irrigation.

Types of Irrigation

Drip irrigation is by far the most common type of irrigation used in vineyards. Narrow water pipes are laid along each row, typically tied to the lowest trellis wire. Drippers are fitted at appropriate intervals. The drippers are positioned far enough away from the vines to encourage the roots to grow and seek out water. (If the drippers are positioned near to the vine trunk, the roots will simply collect near the trunk where the water falls.) The key benefits of these systems are that:

- they permit an economic use of water
- it is possible to control water supply to individual rows or blocks of vines, allowing more tailored management of the vineyard and thus potentially higher yields and quality
- they can also be used to supply fertiliser (liquid fertiliser is added to the water supply); this is called fertigation
- they can be used on slopes.

The disadvantages are that:

- installation costs are relatively high, but maintenance costs are moderate
- clean water is required, otherwise the drippers quickly become blocked
- even with clean water, the drippers can gradually become blocked by algae, bacteria or high levels of minerals and salts; therefore, some maintenance work is usually required
- they cannot be used in frost protection (aspersion) as the drippers are below the green parts of the vine.

A channel carrying water for flood or channel irrigation

Channels in the soil formed for channel irrigation

A young vineyard in South Africa. The irrigation pipes are clear to see.

There are number of other systems for irrigation that are less widely used. They vary in terms of amount of water applied, how targeted the water application is and the cost of establishment and maintenance. In flood irrigation, water is stored behind a sluice and at the scheduled time released to flood the vineyard. It is cheap to install and maintain, but is inefficient as a lot of the water is not taken up by the vine. It can also only be used on flat or gently sloping land. Channel irrigation is similar; however, the water flows down furrows dug between the vine rows, which can help increase efficiency of water use. These systems are common in Argentina because of abundant water from the Andes. They are not suitable where water supply is limited. Another option is overhead sprinklers, which pump water and shower it over the vineyard. They are expensive to install and maintain due to the high water pressures needed and still use a relatively large amount of water compared to drip irrigation. However, they can be used as a method of frost protection (see Frosts in Hazards).

Amount and Timing of Irrigation

The vine's requirement for water varies throughout the vine cycle (see Water). Grape growers in dry climates can use irrigation to control the water supplied to the vine and therefore put the vine under mild stress at the appropriate times in the vine cycle. A plentiful supply of water in the spring encourages the establishment of a large leaf surface area to support the production of high yields of grapes. By comparison, mild water stress can often be desirable between fruit set to *véraison* to stop the growth of shoots and encourage grape development and ripening.

Regulated deficit irrigation (RDI) is a system of timing and regulating the amount of irrigation so that the vine is put under mild to moderate water stress for a specified time within the growing season. This water deficit is usually scheduled between fruit set and *véraison* to limit further shoot growth and encourage grape development. A dripper system is used to permit best control over application of water. RDI is easiest in regions with a dry growing season and sandy or loam soils that dry out and can be re-wetted quickly. It can be much more difficult to create the ideal conditions in regions with heavy rainfall in spring and/or frequent rain in the growing season, and with heavy clay soils that take a long time to dry out.

The benefits of RDI are that vine growth and grape development can be better controlled and that less water can be used. This type of irrigation regime is often favoured for black grapes as it can reduce grape size, which increases the proportion of skins to juice, and hence increases the concentration of anthocyanins and tannins, often seen as a sign of quality.

However, timing of water application and monitoring of soil water levels is critical. As stated, although mild stress between fruit set and véraison can be beneficial, prolonged or extreme stress can lead to reduction in yield and quality.

Even if RDI is carried out successfully, it often results in lower yields, and therefore the grape grower must be confident that any improvements in grape quality will make up for smaller volumes. The additional costs (assuming the vineyard already has drip irrigation) is the equipment to monitor and respond to levels of moisture in the soil.

Some grape growers do not use irrigation; this may or may not be through choice. This practice is often called 'dry farming' and tends to refer to not using irrigation in areas with limited rainfall in the growing season (rather than not using irrigation because there is plentiful rainfall). Similar to limiting the amount of water in irrigation, this can lead to lower yields but potentially an improvement in grape quality.

DRAINAGE

One of the factors that leads to high quality wines in the Médoc is the presence of fast-draining gravel soils in this maritime climate.

Some vineyard areas receive plentiful rainfall, and if the soils are not suitably free draining, this can cause a number of problems (for more details see Water and Excess of Water). In these cases, artificial drainage systems may need to be installed. This can only be done practically before the vineyard is planted. The cost of the drainage and its maintenance will typically be more than off-set in the medium term by having healthier, better-balanced vines that are better able to ripen grapes consistently. Good drainage also aids mechanisation in the vineyard by providing a better surface to drive on (better grip for vehicles) and by reducing the soil compaction that results from driving on wet soils.

Drainage pipe installation

In areas with high rainfall in the growing season, the water available to the vine can also be regulated by:

- leaving natural vegetation to grow or planting specific crops to provide competition for water, leaving less available for the vine (see Cover Crops in Nutrient Management)
- improving soil structure and removing any plough pans to better regulate water drainage (see Soil Preparation).

Reference

1. *Soil Health*, Natural Resources Conservation Service, USDA (retrieved 17 January 2020)

7 Canopy Management

Canopy management involves the organisation of the shoots, leaves and fruit of the vine in order to maximise grape yield and quality.

This chapter will focus on the aims and functions of canopy management and then the various techniques involved.

7.1. The Aims of Canopy Management

The key aims of canopy management are to:

- maximise the effectiveness of light interception by the vine canopy
- reduce the shade within the canopy
- ensure that the microclimate for the grapes is as uniform as possible so that grapes ripen evenly
- promote balance between the vegetative and reproductive functions of the vine
- arrange the vine canopy to ease mechanisation and/or manual labour
- promote air circulation through the canopy to reduce incidence of disease.

As seen below, canopy management can have important implications on both the production and ripening of grapes, including grape yield, health and ripening.

Vine organs (buds, leaves and fruit) develop in different ways when they are in shade or exposed to sunlight. Exposure to sunlight is associated with greater bud fruitfulness, which describes the number of inflorescences developing inside a latent bud. Shady conditions are associated with reduced bud fruitfulness, with the bud producing more vegetative structures such as tendrils, rather than reproductive structures such as inflorescences. The reasons for this link back to the way that vines grow in the wild. Outside of the vineyard setting, a vine needs its fruit to be visible to birds for propagation of its seeds. In forest conditions, the vine will grow until it finds sunlight (generally indicating an opening in the forest canopy), at which point, priority will be given to developing inflorescences and bearing fruit. This means that, in viticulture, a vine canopy that is well exposed to sunlight will increase bud fruitfulness and hence has positive implications for grape yields in the next growing season.

Canopy management can also help maximise the leaf surface area that is exposed to sunlight. This increases the vine's photosynthetic capacity (compared to a vine with a dense, shaded canopy) and means it can ripen larger yields.

The influence of canopy management in determining the exposure of the leaves and grapes to sunlight also has implications for the level and balance of components in the grape, and hence potential style and quality. The effects of promoting sunlight exposure within the canopy include:

- increased sugar levels in grapes through greater overall photosynthesis in the vine
- increased tannin levels and greater polymerisation of those tannins, leading to less bitterness
- enhanced anthocyanin (colour) development in black grapes

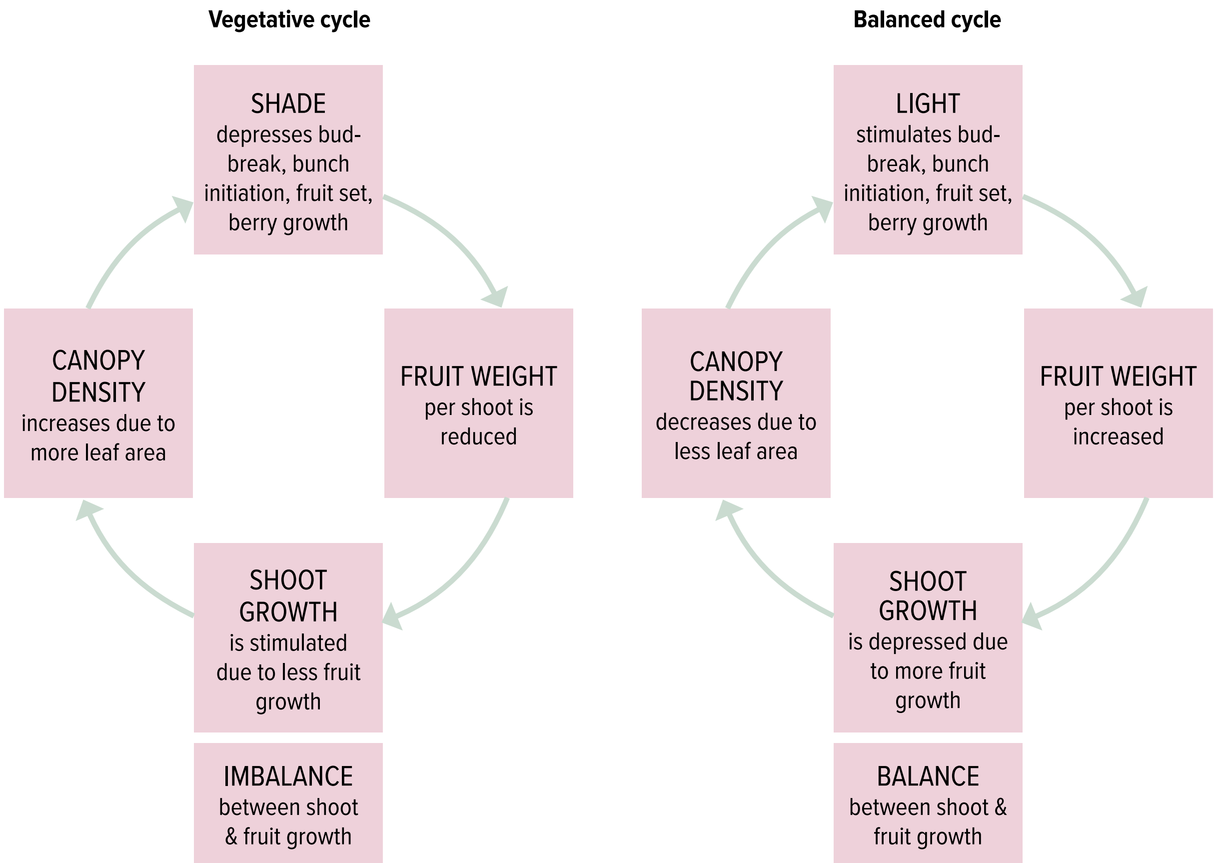
- decreased malic acid – warmer grape temperatures lead to more malic acid being broken down in cellular respiration, otherwise, especially in cool climates, acidity levels in the wine could be unpleasantly high (tartaric acid remains)
- increased levels of some favourable aroma precursors and aroma compounds (such as terpenes, which are responsible for many of the fruity and floral aromas in wines such as the grapey aromas found in Muscat)
- decreased methoxypyrazines, which give herbaceous characters in grape varieties such as Cabernet Sauvignon.

However, maximising sun exposure is not always desirable, particularly as hot temperatures and intense sunshine on the grapes can lead to grape sunburn, which has a negative impact on grape quality and yields (see Sunburn in Hazards). In such climates, therefore, canopy management may be focused on providing a certain amount of shade for the grapes.

Good canopy management can also influence both yields and grape health by reducing fungal disease pressure. Due to poor air circulation, dense, shaded canopies dry out more slowly after rainfall or morning dew and provide suitable conditions for fungal diseases to develop. Dense canopies are also problematic when spraying fungicides, as it is more difficult to ensure the spray reaches all areas of the canopy.

CANOPY MANAGEMENT AND VINE BALANCE

As well as maximising the effectiveness of light exposure within the vine canopy, one of the key aims of canopy management is to promote vine balance. Achieving a suitable balance between the vine's vigour (see Shoot and Leaf Growth) and its yield of grapes is essential for



Source: Smart & Robinson (1991)[1]

successful grape ripening and sustained production over future growing seasons. The optimal yield is one that will allow the grape grower to grow the maximum weight of grapes that have the required composition for the desired wine style and quality.

As seen in the Vine Growth Cycle, until *véraison* the vine's sugars and nutrients are mainly allocated to shoot and root growth and storage. After *véraison*, sugars and other compounds needed for growth are mainly allocated to the fruit, and shoot growth is depressed. Because shoot growth is reduced, the canopy is less likely to become dense and shady, and light exposure in the canopy is improved, leading to high quality fruit. It also results in enhanced bud fruitfulness the next year, and the balanced cycle continues.

By comparison, if the yield of fruit is too low (termed under-cropping) for the vigour of the vine, shoot growth continues through the vine cycle because there is not much fruit to ripen. The growing shoots and leaves compete with the grapes for sugar and other compounds needed for growth and can negatively affect grape formation and ripening. This also leads to a dense, shady canopy, and hence lower quality fruit due to lack of sunlight interception. This may also result in low yields the next year due to reduced bud fruitfulness. Low yields in the next season may lead to under-cropping in that year and hence the vine enters what is known as 'a vegetative cycle'.

If the yield of fruit is too high compared to the vigour of the vine (termed over-cropping), the vine may gain sugars from the carbohydrates stored in the trunks, cordons (where applicable) and roots. The vine generally needs these carbohydrate sources in the winter and next spring, and too high a yield therefore weakens the vine in future years.

The ideal amount of fruit on the vine to create the correct balance will depend on its growing environment. In environments with warm temperatures, enough water and fertile soils, vines can grow vigorously, producing lots of shoots and leaves. With many leaves, the vines have a high capacity to photosynthesise and produce sugars and other compounds needed for growth. These vines can successfully ripen large yields. By comparison, vines that are grown in regions with limited resources, such as little water and/or very poor soils, will not grow so many shoots and leaves, will be low in vigour and therefore not be able to ripen the same crop levels.

The correct balance for the vine will also depend on the vine itself. Some grape varieties and clones are naturally more vigorous than others. For example, Cabernet Sauvignon is a vigorous variety and will grow larger and ripen a larger yield than Merlot, a lower vigour variety, given similar environmental conditions. Choice of rootstock can also have a significant influence on vigour.

The presence of diseases can also influence vigour, for example, viruses can lower vine vigour. Similarly, very old vines will be less vigorous than vines that are 10-40 years old.

It will also depend on the wine style being produced. For example, vines producing grapes for rosé wines can generally sustain larger yields than those producing grapes for red wines as tannin ripeness is less critical for rosé wines that undergo very short macerations.

Winter pruning is the key time when decisions are made that will influence number of shoots and potential yield in the coming growing season. Summer pruning techniques may be applied during the growing season to amend the vine balance and enhance ripeness as needed.

YIELDS

Yield is a measure of the amount of fruit produced. It can either be measured per vine (e.g. kg per vine) or over a set area (e.g. kg per hectare or tons per acre). There is a link between the yield of a vine and the quality of fruit in that a vine that is either over-cropped or under-cropped, and hence out of balance, is likely to produce fruit of lesser quality than a balanced vine.

However, the yield at which the vine is balanced will depend on the natural resources of the vineyard, the planting material (plus age of vine and presence of any disease) and the wine style. Therefore, some vines will be balanced at higher yields than others.

The yield over a set area will depend on the yield per vine and the planting density. The higher the yield within a set area, the more wine can be made and sold. Therefore, even if yield per vine is low, the vines may be planted very densely to gain as much yield from the vineyard area as possible. In EU countries, legislation typically specifies maximum yields per set area. In these cases, if too much fruit is produced it may have to be removed when ripening or left in the vineyard at picking.

7.2. Canopy Management Techniques

Canopy management encompasses a range of techniques that include:

- vine training
- winter pruning
- vine trellising
- overall plant vigour management (nitrogen fertilisation, irrigation, cover cropping etc.)
- summer pruning
  - disbudding
  - shoot removal
  - shoot positioning
  - pinching
  - shoot trimming
  - leaf removal
  - crop thinning/green harvesting.

Canopy management should be a key consideration when establishing a vineyard and assessment of the vineyard site will determine certain decisions such as grape variety, rootstock vigour, planting density and row orientation. Choices regarding vine density will affect the vine training and trellising, and therefore these all need to be decided before vine planting. However, even with suitable training and trellising, the weather in any one year may vary and have a negative effect on flowering, fruit set or ripening. Therefore, summer pruning techniques may be necessary to adjust the balance of the vine and enhance grape ripening.

VINE DENSITY

Vine density is the number of vines that are planted per hectare of vineyard. Vine densities range from as low as a few hundred vines per hectare to over 10,000 per hectare.

Vine density will influence within-row spacing and the between-row spacing of the vines, and therefore needs to be considered during vineyard establishment. The optimum vine density is influenced by the vigour of the vine (which in turn is influenced by natural resources and planting materials), the type of trellising system used and what access is needed between the vines. Vines that are low in vigour and VSP trellised (see Trellising below) can be planted very closely together within the row as the individual vines are relatively small. Planting the vines with greater within-row spacing would not maximise the vineyard land (leaving gaps in the canopy within the vine rows), particularly important on expensive land such as Grand Cru Burgundy vineyards. By comparison, vines that are high in vigour will need greater within-row spacing to grow and be in balance. Planting these vines too close together could lead to overlapping canopies and increased shading, reducing ripeness and quality. Vines grown in dry regions without irrigation may also be planted at low density, despite not being large in size, so that the roots can spread out (without competition from other vines) in search for as much water as possible.

Between-row spacing also needs to be considered. Vine rows should be planted far enough apart so that one row does not shade the next. Therefore, vigorous vines that are high-trained and trellised need greater spacing between the rows. The width of any machinery that might be used also needs to be considered when planning between-row spacing.

Overall, low density, widely spaced, trellised vineyards are usually cheaper to establish and maintain than high density, tightly spaced vineyards, requiring less planting material and permitting easier mechanisation.

ROW ORIENTATION

Row orientation will depend on both climatic and logistical factors. It is generally considered that a north-south orientation provides the most even sunlight exposure through the canopy. However, because conditions in the afternoon are usually warmer than those in the morning, grape bunches on the west side of the canopy (which are exposed to the afternoon sun) may require more shading from leaves to protect them from sunburn. Prevailing winds may also be a factor in decisions on row orientation, with grape growers choosing to orient the rows at a 90° angle to the direction of the wind to provide most protection.

From a logistical standpoint, orienting rows parallel to the longest side of the vineyard is often the most efficient option. Vineyards on slopes at an angle of greater than 10% need to be planted up and down the slope rather than across or machinery may slip (unless the vineyard is terraced).

VINE TRAINING, PRUNING AND TRELLISING

The optimum method of vine training must be decided at vineyard establishment. The most appropriate training and trellising method will depend on:

- **The vigour of the vine** – Vigour depends on the natural resources available to the vine (particularly temperature, water and nutrients), the planting material (grape variety, clone, rootstock) and the presence of any disease (e.g. viruses can lower vigour). Note that humans can have an influence on the natural resources available (e.g. vine vigour can be reduced by purposely limiting water availability in regulated deficit irrigation or by using low-vigour rootstocks).

- **The topography of the site** – Many trellising systems cannot be used on steep slopes or windy sites. For this reason, vines on some steep sites in the Northern Rhône, France and Mosel, Germany must be trained on individual stakes, rather than a wired trellis.
- **The need for mechanisation** – Certain training and trellising systems are more suited to mechanisation than others. VSP-trellised vines (see Trellising below) are generally suited to mechanisation as all the fruit tends to be in the same area for each vine. Bush vines or individually staked vines are less uniform and therefore much more difficult.

Vine Training

Vine training typically refers to the shape of the permanent wood of the vine and can be split broadly into two categories: head training or cordon training. Either system can be low-trained (the vine trunk is short), to benefit from heat retained by the soil or provide greater protection from wind, or high-trained (the vine trunk is long), to better avoid frosts or make manual interventions, such as harvesting, easier. Some trellising systems are only possible with relatively high training.

Head training – These vines have relatively little permanent wood. The permanent wood usually consists of the trunk, sometimes with a few short stubs growing from the top of the trunk. These vines can either be spur-pruned or replacement cane-pruned.

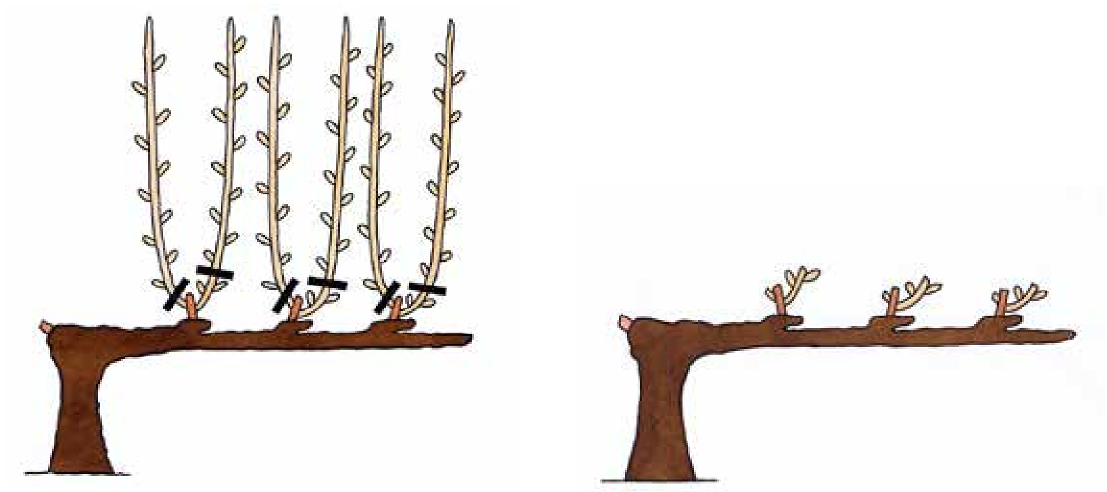
Cordon training – These vines typically have a trunk and one or more permanent horizontal arms of permanent wood, typically called ‘cordons’. They are usually spur-pruned. Cordon training takes longer to establish than head training due to the amount of permanent wood.

Vine Pruning

Pruning is the removal of unwanted parts of the vine. It takes place in the winter and summer. Winter pruning is particularly important as it determines the number and location of buds that will form shoots in the coming growing season, and hence impacts on the potential yield.

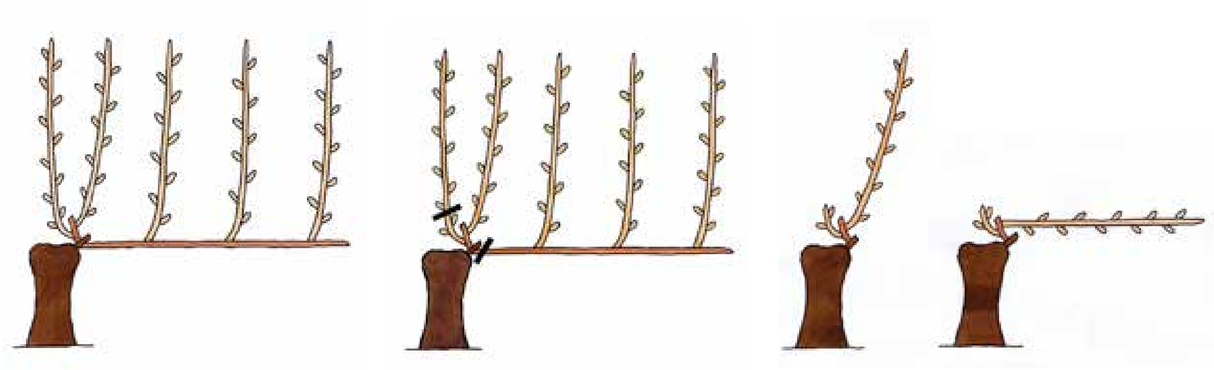
There are two types of winter pruning:

Spur pruning – Spurs are short sections of one-year-old wood (the shoots from the last growing season that have lignified) that have been cut back to only two or three buds. Spurs can either be distributed along a cordon (cordon training) or around the top of the trunk (head training). Spur pruning is easier to carry out than replacement cane pruning and can often be mechanised.



Spurs are cut down to 2-3 buds

Replacement cane pruning – Canes are longer sections of one-year-old wood and can have anything between 8 and 20 buds. They are typically laid down horizontally and need tying to a trellis for support and positioning. Replacement cane pruning is more complex than spur pruning and requires a skilled labour force to select suitable canes and train them.



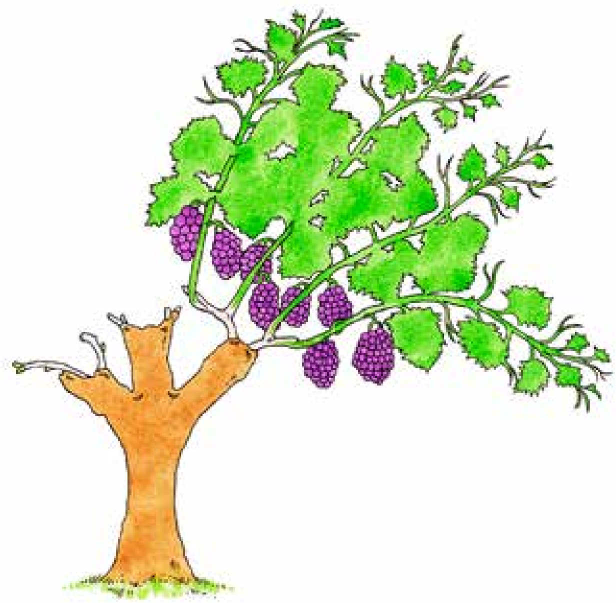
In this example one cane has been left. The cane will be bent down and the shoots will grow from this cane in the coming growing season. A spur is also left and the shoots growing from the spur will form the next year's cane.

The number of buds left on the vine will depend on the vigour of the vine, with more buds left on for more vigorous vines. This in turn influences the number and size of shoots in the growing season and the amount of fruit, thus greatly influencing the balance of the vine. There are various techniques grape growers can use as indications as to whether the vine is balanced and whether more or less buds need to be retained to keep the vine in its balanced cycle. These generally involve calculations that take into account the yield and the weight of the pruning cuttings in the dormant season.

Trellising

Trellises are permanent structures of posts and wires that help to support and position the vine's shoots. The vine's tendrils will naturally curl around the trellis wires and help keep the canopy in place. The grape grower will also tie in branches and shoots to the trellis as necessary.

Untrellised vineyards – In some regions, the vines may not have a trellis. In most cases these vines are head-trained and spur- pruned, and are called bush vines. The benefit of this system is that it is simple and therefore easy and inexpensive to develop. The shoots may also droop down, providing shade for the grapes. These vines are usually planted in hot and sunny regions, such as La Mancha in Spain, so some shade can be beneficial to avoid the grapes becoming sunburnt. However, a potential disadvantage of this system is that it is not suitable for mechanisation. It is best suited to vineyards that have dry conditions, which restrict the vine's vigour. If the vine is too vigorous, the canopy can become too dense and shade the fruit too much. Wet conditions would also promote the development of disease in this dense canopy.

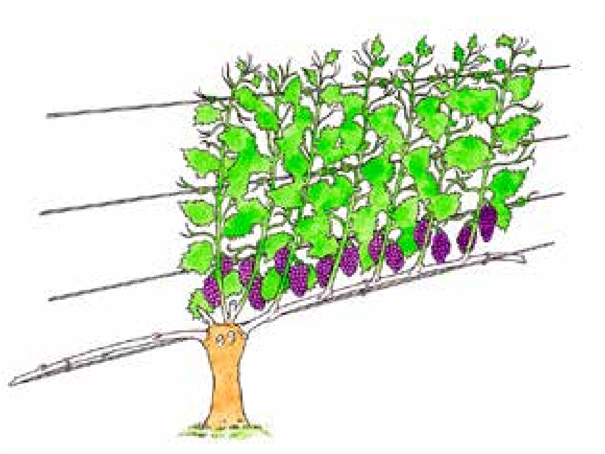


A bush vine: head-trained, spur-pruned. The left of the picture shows the vine after winter pruning, the right of the picture shows the vine before harvest.

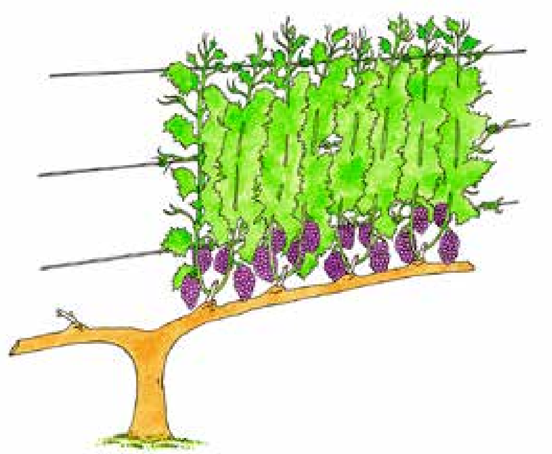
Trellised vineyards –Trellised vineyards are very common. The advantages of trellising are that the shoots can be spread out to maximise light interception, increase air flow through the canopy (reducing risk of fungal disease) and, by positioning the fruit in one area, aid mechanisation. The disadvantage compared to untrellised vineyards is that they are expensive to establish, particularly for more complex systems, and need maintaining. The type of trellis system that is most appropriate will depend on the vigour of the vines:

- **Vertical shoot positioning (VSP)** – VSP is the most common type of trellising system and one of the most simple. The vine's shoots are trained vertically and are held in place onto the trellis forming a single narrow canopy. It can be used on both head-trained, replacement cane-pruned vines and cordon-trained, spur-pruned vines. When used on replacement cane-pruned vines, it is typically called Guyot training: one cane is retained in Single Guyot; two in Double Guyot. VSP is best suited to vines with low or moderate vigour.

- **Complex training systems** – Vines that are vigorous can produce a lot of shoots and ripen high yields of fruit. If these vines are trellised using VSP, the canopy can be too dense, resulting in too much shading of leaves and fruit. Complex training systems have therefore been invented to split the canopy to reduce shade and maximise light

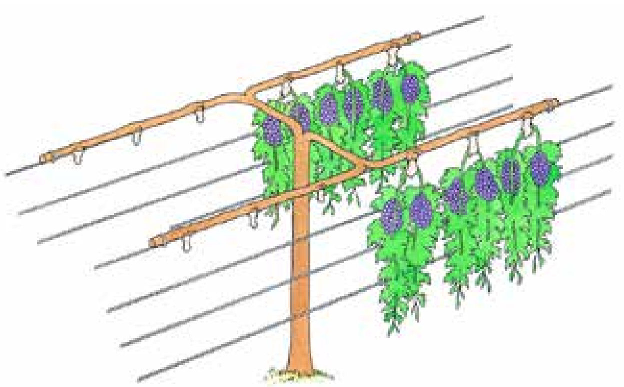


Vertical shoot positioning on a replacement cane-pruned vine

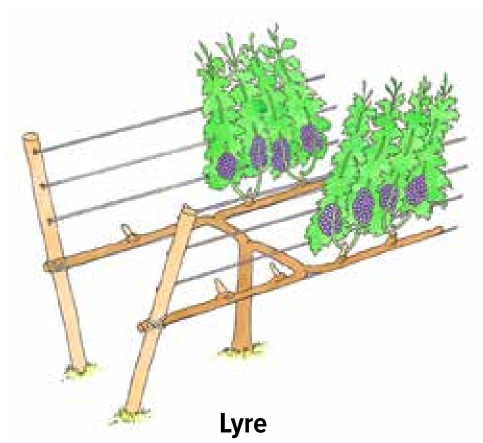


Vertical shoot positioning on a cordon trained vine

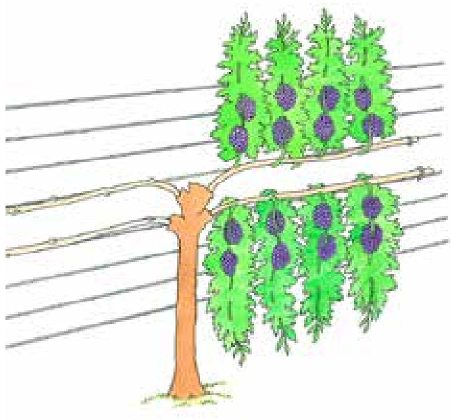
interception. The canopy can either be split horizontally, in the case of Geneva Double Curtain (GDC) or Lyre, or vertically, as in the case of Smart-Dyson or Scott-Henry. Using these systems, it is possible to make best use of vineyard space and resources to produce large yields of high-quality fruit, but they are more difficult to manage and mechanise.



Geneva Double Curtain



Lyre



Scott-Henry

(Other forms of trellising systems do exist and will be covered within D3: Wines of the World with the countries/regions with which they are associated.)

Summer Pruning
Summer pruning includes a variety of techniques to keep the canopy of the vine maintained. Many of these activities take place in summer, but some are carried out in spring. They are usually aimed at enhancing grape ripening, reducing chance of fungal disease or making the vineyard easier to manage. Except for pinching and disbudding, these techniques can all be mechanised if the vineyard is appropriately set up (straight, well- maintained trellised rows), and this becoming increasingly common in areas where skilled labour is difficult to find. They include:

The leaves have been removed from this vine to increase bunch exposure.

Disbudding – This activity (also called debudding) is the removal of buds and is conducted both to manage vine balance and yields, and to remove buds that are poorly positioned. Growers will often leave a high number of buds on the vine at winter pruning in case buds are damaged early in the growing season, for example, by spring frost. Disbudding in the late spring can be used to adjust the number of buds to bring the vine into balance and, where necessary, to comply with grape growing regulations. Further adjustments may be made later in the season by crop thinning (see below). It is also a chance to remove buds that are poorly positioned, for example, those facing downwards or those too close together. Disbudding is also used to remove buds of non-fruit-bearing shoots, which may compete with the grapes for sugar and other resources.

Shoot removal – The removal of shoots, often laterals, that are infertile or poorly positioned (e.g. too close together or low down on the trunk) will help to maintain a well-organised, open canopy.

Shoot positioning – The shoots are tucked into the trellis wires to better organise the canopy and facilitate mechanisation.

Pinching – This removes the shoot tips at flowering to improve fruit set.

Shoot trimming – Cutting shoots to limit growth and reduce canopy thickness enhances fruit ripening by reducing competition for carbohydrates between the shoot tips and fruit. It also lowers disease pressure through better air circulation and improved spray penetration.

Leaf removal – Removing leaves to reduce shading of fruit and hence enhance ripening, will also lower disease pressure through better air circulation and improved spray penetration.

However, in warm and hot climates, excessive removal of leaves can expose the grapes to too much sunshine and heat and lead to sunburn.

Crop thinning or green harvesting – This is the removal of bunches of grapes to increase ripeness of those grapes left on the vine. If this process is timed near *véraison*, it can enhance ripening. In cases where fruit ripening is uneven (e.g. because of uneven budburst or fruit set, frost or the presence of bunches on lateral shoots), the least ripe bunches of grapes may be removed to improve uniformity of ripening, and hence enhance quality.

Reference

1. Smart, R. and Robinson, M. (1991) *Sunlight into Wine*. Adelaide: Wintetitles

Hazards, Pests and Diseases 8

Hazards, pests and diseases are challenges that, between them, affect virtually all of the world's vineyards. Many of them substantially reduce yields and negatively affect the quality of the fruit, whilst prevention and management techniques can add considerably to annual costs.

This chapter will explore many of the most prevalent and/or serious hazards, pests and diseases and options for their management.

8.1. Hazards

DROUGHT

Vines need water to grow and to produce high quality fruit at yields that make grape growing financially viable. The amount needed is a minimum of 500 mm per year in cool climates and at least 750 mm in warm regions. A lack of water causes the vine to close the stomata on their leaves in order to limit water loss. This reduces photosynthesis. If this situation continues, the growth of the plant is impaired, grape size is reduced and ripening slows down. This results in potentially unripe grapes and lower yields. If prolonged, vines will lose their leaves and die.

In regions that depend on irrigation, if drought continues over several years, water may become so scarce that the use of water for irrigation is not allowed. As a result, entire vineyards can be lost (for example, in the high-volume Olifants River region of South Africa).

Management Options

- Where it is allowed, irrigation systems should be considered as part of the initial design of the vineyard. They can be fitted later if the need is urgent, but this can be much more difficult because of potential disruption to the vineyard for laying pipes. Some European appellations do not allow irrigation or only allow it for emergency situations (establishing young vines; drought that threatens the livelihood of growers).
- If a new vineyard is being planted, drought-resistance should be high on the list of priorities in choosing a rootstock. Examples include rootstocks from V. rupestris and V. berlandieri parentage (e.g. 110R and 140R).
- Choose a drought-tolerant variety such as Garnacha.

EXCESS OF WATER

An excess of water in summer can lead to too much vegetative growth, which can compete with grape ripening and also mean fruit is too shaded; both of which will result in less ripeness. Rainfall can also make the canopy prone to fungal diseases because of high humidity. If soils are not free draining, waterlogging may occur, reducing the amount of oxygen available to the roots, slowing down growth and eventually killing the vine. Equally, waterlogging can lead to compaction of the soils, making them difficult to work, and uncontrolled water run-off.

Management Options

If there is excess rainfall on a regular basis, then the planning of the vineyard must ensure that this issue is addressed by, where possible, planting on a slope or on free-draining soil to improve drainage, or by the construction of a drainage system (see Drainage in Water Management).

UNTIMELY RAINFALL

Excess rainfall during pollination and fruit set can lead to millerandage or coulure, reducing the size of the crop and potentially also lowering quality. Rain during the summer can also reduce the rate of ripening of fruit. Mild water deficiency before véraison reduces the growth of shoot tips, allowing the grapes to ripen more satisfactorily.

Heavy rainfall close to vintage can lead to the grapes being swollen with water (reducing the concentration of the must and with it the quality of wine) and to grapes splitting, leading to grey rot. It also makes working the harvest very difficult. Examples include difficulty using mechanical harvesters or pickers accessing the vineyard if on clay soils.

Management Options

- Nothing can be done about the incidence or amount of rainfall. However, the choice of site (climate in general, slope), condition of the soil, choice of whether or not to grass the land between rows of vines and the adequacy of drainage can mitigate some effects of untimely rainfall.
- Monitoring weather forecasts: in the case of forecast of heavy/prolonged rain, winemakers may have to weigh up the options of early harvest with potentially less-ripe fruit, taking the chance on the weather improving in time for a successful later harvest or losing part or all of the crop.

FREEZE

Fully dormant vines are relatively hardy and can tolerate quite severe frosts. However, if temperatures fall below −20°C / −4°F, the vine can be seriously damaged or even killed by winter freeze. If vines are grafted onto rootstock, the graft is the part of the vine that is most at risk (if it is above the surface of the ground). The canes or cordons are the next at risk. Frost can kill canes or cordons (reducing yield) or kill all parts of the vine above the ground, leading to the need to replace the vine.

Areas most affected are those with a strongly continental climate such as parts of Canada, Washington State and China.

Management Options

In areas with regularly very cold winters, growers have several options:

Site selection

- Hillside sites can be up to 5°C / 9°F warmer than the valley floor.
- Vineyards near large or deep bodies of water (for example, large lakes in North America) benefit from a moderating effect.
- Vines should be planted where snow settles most thickly, as a deep layer of snow can provide insulation for the vine.

Choice of varieties

- Some varieties are more resilient against winter freeze than others, e.g. Cabernet Franc or Riesling.
- Some American and Mongolian vine species (*V. amurensis*) are extremely winter hardy, as are hybrids that have these species as a parent. For example, the Concord variety, an American hybrid, can withstand temperatures down to nearly −30°C / −22°F.

Soil hilled up around a vine graft to protect from winter freeze

Protecting vines

- Building up soil around the vine graft (often called 'hilling up') is common practice in regions with cold winters, as the soil helps to insulate the vine.
- Burying vines is another approach in the most extreme climates. However, this is a very costly approach as it requires a lot of labour every year, with some Chinese regions seeing this as one of the costliest operations in the vineyard.
- Vines can also be pruned to have several trunks so that those killed in winter can be replaced.

FROSTS

Frosts occur when cold air below 0°C / 32°F collects at ground level, freezing water in the vine's growing buds and shoots. Cold winds blowing across the vineyard after budburst are also very dangerous. If the freeze event happens to newly burst buds or young shoots that have a high-water content, it kills them. The damage done and the impact on yields can be enormous, and in frost-prone regions growers go to great lengths to minimise this risk.

Vines in a range of climates are vulnerable. Cool climate areas are vulnerable though the vine responds to regular low temperatures by not growing until a mean air temperature of 10°C / 50°F is reached. Warmer areas are vulnerable because the vine begins to grow and will be damaged if there is a drop in temperature. If buds and young shoots are killed, the vine puts out more shoots from secondary buds (see The Anatomy of the Vine); however, these shoots are less fruitful and will take longer to ripen, which can itself be a problem (more likely to be affected by rain or autumn frost).

There are two types of frost:

- Advective frosts are caused by large volumes of cold air moving in from very cold areas.
- Radiative frosts are the result of heat being lost on still, cool nights. The earth is heated by the sun during the day and releases it during the night. The amount of heat lost depends on the level of cloud cover. Windless nights will allow a layer of freezing cold air to

develop just above the surface of the soil. As cold air is denser than warm air, this freezing cold air will collect in valley bottoms.

Management Options

There are several options for the grower where frost is an issue. These can be divided into actions that seek to reduce the risk of frost and those that seek to combat the hazard if frost does strike.

Reducing the risk

- In site selection, care must be taken to avoid frost pockets (places where cold air collects) and to choose hillside sites where cold air can drain away.
- Delaying pruning postpones budburst into warmer months. If buds at the end of canes get frosted, they can be removed.
- Choosing a variety that buds late, such as Riesling, can help.
- Vines trained high off the ground offer more protection, as the coldest air is near the ground.
- Having bare soil between the vines (rather than a cover crop) absorbs more heat during the day and radiates this heat during the night.

When frost threatens

There are several options, each of which has a cost:

- Water sprinklers (also known as aspersion): if the vineyard already has an irrigation system, then sprinklers can be used. Alternatively, sprinklers can be installed specifically for frost protection. As water freezes around the parts of the plant, it releases latent heat, protecting the plant. The system must be kept on until the temperature rises. The costs are for the equipment and for the water. The running costs can be much lower than wind machines or heaters, although not if the cost of water is high. This is the only method that can be used to combat advective frosts.
- Wind machines: these large fans, which are 4–7 m high, pull warmer air from above down to ground level, thereby raising the temperature. These are effective where there is an inversion layer, a warm zone of air 10 m above the ground (+3–5°C / 5–9°F). One study has found that the investment in wind machines is warranted if there is a chance of a damaging radiation frost once every five years.[1] The initial investment is considerable. Helicopters can be used to create the same effect. They are expensive, but may be worth it if the risk is severe but short term.
- Oil or propane gas burning heaters (also known as smudge pots) and wax candles ('bougies') can be placed in vineyards and lit when there is a risk of frost. The disadvantages are the high cost of fuel and labour, low heating efficiency and contribution to air pollution.

Wind machines can protect vineyards from frost by pulling warmer air to ground level.

A burner used for frost protection

HAIL

Hail, pellets of frozen rain, can cause severe damage to vines at various stages of development. Hailstones can damage and rip young shoots and leaves. Ripening grapes can both be damaged and become a point of entry for botrytis and other diseases.

Yields can be seriously reduced in the first and following seasons. If the damage is caused early in the season, the vine may be able to reshoot from existing buds. The occurrence of hail is unpredictable in general, although some regions (parts of Argentina and Burgundy) have suffered repeatedly.

Netting to protect against hail in Mendoza

Management Options

There are strategies for hail protection in use:

- Rockets may be fired into thunderclouds, seeding them with silver iodide to cause rainfall rather than hail.
- In areas with regular hailstorms (e.g. Mendoza), some grape growers net the fruit zone of the vines to protect ripening grapes. As netting creates some shading, this solution can only be used where there are high sunlight levels. It is therefore more appropriate in Argentina than in Burgundy.
- As hail damage can be very selective, in high-risk areas growers may seek to have a number of plots in different areas to ensure continuity of production.
- Growers may have to consider the additional cost of crop insurance against hail.

SUNBURN

Vines need sunlight for photosynthesis, which then enables vines to ripen grapes. However, in prolonged hot weather, sun- exposed grapes can be sunburnt. Grape transpiration is much more limited, and therefore less effective, than leaf transpiration. As a result, grapes can reach higher temperatures than the leaves and become burnt. There is a higher risk on vines already in a situation of water stress. Sunburn leads to scars on the skin of the grape and, in extreme cases, to the eventual death of the grapes. Sunburn has a negative impact on grape quality. Browning of the grape, a bitter taste, and increased susceptibility to rot (due to skin damage) have all been cited as potential issues. Therefore, sunburnt grapes typically need to be removed by sorting, which reduces yields.

Browning caused by sunburn on Chardonnay grapes

Management Options

- In designing new vineyards, row orientation and aspect can reduce the impact of the hottest afternoon sun. For example, in hot regions in the Northern Hemisphere, east-west row orientation should be avoided so that grapes on the south side of the row are not subject to day-long sun and, particularly, intense afternoon sunshine.
- The amount of direct sun exposure can be adjusted through canopy management techniques. Growers may choose to partially shade the fruit zone in hot regions.
- If a heatwave is forecast, additional irrigation, where allowed, may be applied to reduce water stress and, hence, the chance of sunburn.
- Special agricultural sunscreen spray can be applied or the vines can be shaded with a cloth or net.

FIRE

Fire is a serious hazard in hot and dry countries. Warmer, dryer weather associated with climate change has seen an increase in the incidence of fires. Parts of Australia, California and Chile have suffered in recent years. Fires may occur outside of human control and therefore are often difficult to prevent. However, vineyards that are near woodland, pastures or other crops may be more at risk as they provide fuel for the fire. Cover crops and organic mulches can also provide fuel, whereas fire spreads less easily through bare, cultivated soils. Damage may be to property, equipment and irrigation systems or, if severe, to the vines and their trellising. A major issue for wine quality is the smoke that these fires create. For smoke taint, see below.

Fire damage to a grass bank, whilst the vineyard remains relatively unharmed

Management Options

Wineries and vineyards in areas that are prone to fires can prepare their property by:

- installing fire detectors and sprinklers
- installing and maintaining a water tank
- providing employee training for action in the event of an emergency.

SMOKE TAINT

Smoke in the vineyard during the growing season can result in ‘smoky’ or ‘plastic’ aromas in the final wine. The effect on fruit increases in the period from *véraison* onwards. Aroma compounds in smoke can be absorbed by the grapes. Once in the grape these compounds often bind with sugars and form aroma-less precursors. Similar to other aroma precursors in the grapes (see Wine Components), these compounds then only become aromatic through the fermentation process. The strength of the aroma can increase during the ageing of wine and during bottle ageing as further aroma precursors break down and become aromatic.

Management Options

- Affected musts can be tested analytically and/or by micro-vinifications (to release the smoke aromas) in the days leading up to harvest to establish the extent of the problem (and hence what action may be needed).
- As it is thought that the smoke aroma precursors are present on the inside of the skin of grapes, how the grapes are handled can reduce the effect of smoke taint. Hand harvesting, gentle or whole bunch pressing, lower fermentation temperatures and reduced maceration times can reduce the uptake of the compounds.
- Flash détente (see Macerations using Heat in Crushed Fruit Fermentations) and reverse osmosis (see Post-Fermentation Adjustments) can also help, but will not remove the taint completely.

Winemakers may be able to rescue affected wines by a combination of these measures and by blending with unaffected wines.

8.2. Pests

Pests are organisms that harm the vine and impact the production of grapes in a negative way. Some compete for water or nutrients, while others directly attack the vine and/or grapes, affecting yield and quality. Grape growers have to evaluate the seriousness of the attack and decide whether measures need to be taken. This includes an evaluation of the economic cost of actions taken in relation to the potential damage.

Some major pests and diseases are the result of insects or fungi being imported from one territory where the vine species have natural resistance to those pests into another territory with different vine species. Thus, phylloxera and the two common forms of mildew were native to North America, but became serious threats when they were introduced into Europe. The European grapevine, *V. vinifera*, has no natural defence against these pests and so succumbed to them. In turn, the solution to some of these pests has been to use the natural resistance of American species to combat the disease; for example, in the grafting of European vines onto American rootstocks.

PHYLLOXERA

This aphid-like insect feeds and lays eggs on the roots of grapevines. The insects can spread through crawling but are most commonly transported by humans, for example, on the roots of young vines, in soil, on equipment such as leaf trimmers and harvesters and by irrigation water. Phylloxera harm vines by damaging the roots, reducing the uptake of nutrients and water. The damaged roots are also vulnerable to additional attack by bacteria and fungi. These attacks lead first to a weakening of plants (reducing growth and yield) and then to the death of the vines.

Vineyards with phylloxera infestation show the following symptoms:

- Vines die of drought in patches that increase in size year by year
- Vine roots are covered with the insects surrounded by yellow eggs
- Swellings on older roots
- Pale green leaf galls on the under-surface of the leaves
- Slow, stunted shoot growth and leaf yellowing appears in around three years, the plant dies after around five years.

Phylloxera was identified in Europe in 1863 having been accidentally introduced from the USA, probably on the roots of imported vines. Initially, it spread rapidly and destroyed two-thirds of the European vineyard in the late nineteenth century.

Management Options

In the nineteenth century it was noted that vineyards on sandy soil were immune to phylloxera, but this offers no help on other sorts of soil.

- The use of American vine species proved to be the way ahead, especially *V. berlandieri*, *V. riparia* and *V. rupestris*, which offer most protection. These species form hard, corky layers that surround the eggs, sealing the wounds and preventing invasion by bacteria or fungi. However, planting these American vines led to different and undesirable aromas in the resulting wine. The solution was to graft European varieties onto rootstocks from American vines.
- However, it was soon discovered that grafting onto the rootstocks of single American varieties caused problems in the typically calcareous soils of Europe as these varieties have little lime tolerance. The vines suffered from chlorosis turning the leaves yellow, halting photosynthesis and reducing yields and quality. The solution was to create rootstock hybrids between the various American species in order to balance the level of protection to phylloxera and resistance to lime in the soil.
- The use of rootstocks derived from American species enabled the development of many rootstocks, often with complex parentage, that can deal with a number of problems – phylloxera, nematodes, extremes of soil pH, water stress, salinity – and control the vigour of the vine.
- Today, the grape grower gets professional advice on the choice of rootstock and grape variety in order to match the appropriate rootstock to the vineyard soil, the pests to be combatted and the level of vigour desired (see Rootstocks in Planting Materials).

Planting on rootstocks is significantly more expensive than on the vines own roots, but has become a standard part of the cost of establishing a vineyard.

NEMATODES

Nematodes, microscopic worms, are very common in soils, but are usually too small to be seen by the naked eye. Some cause damage by feeding off vine roots, significantly reducing yields and vigour. They can cause slow, gradual decline. Others transmit viral diseases. For example, fanleaf virus is spread by the dagger nematode.

Two of the most commonly occurring are root-knot nematode and dagger nematode. Nematodes are either present in the soil already or can be spread by unclean nursery stock, irrigation water or vehicles. Once present, they can only be managed, not eliminated.

Management Options

Soil samples are taken and analysed in a laboratory to determine the number and type of nematodes present. There are very few options available to combat nematodes:

- Fumigate the soil. Chemicals used to be used, but these are now banned in most regions. Another method is to plough in a cover crop of mustard plant, which contains compounds that work as biofumigants, killing nematodes.
- For most, the best solution is the use of nematode-resistant rootstocks having ensured that plants bought from nurseries have been heat-treated to kill nematodes. Examples of nematode-resistant rootstocks include Ramsey and Dog Ridge (both *Vitis champini*).

GRAPE MOTHS

A number of different moths do damage to vines by feeding on flowers and grapes. Many species have several generations per season, attacking flowers in spring and grapes later in the year. The wounds created are then vulnerable to further attack from bacteria and fungi, including botrytis, and significant crop losses have been reported. The most common types are the light brown apple moth in Australia, the European grapevine moth in southern Europe and the grape berry moth in central and eastern North America. A number of species have inadvertently been imported into wine-growing areas even in recent times (e.g. European grapevine moth in the Napa Valley in 2009, declared eradicated in 2016).

Management Options

Grape moths can be controlled by a number of measures:

- Biological controls include the use of:
  - the bacterium *Bacillus thuringiensis* (which produces substances that are toxic to the moths)
  - use of pheromone capsules to disrupt mating (‘sexual confusion’)
  - natural predators (parasitic wasps, green lacewings, some spider species).
- Insecticides can be used.

SPIDER MITES

Several types of mites can damage vines, but spider mites are the most detrimental. The species of spider mite differs from region to region. Pacific spider mite is most destructive in California, while in Europe the red spider mite and two forms of yellow spider mite can cause damage. They feed on the surface cells of leaves. This leads to discoloration of the leaves, a reduction in photosynthesis, delayed ripening and a reduction in yields. Spider mites thrive in dusty conditions and are most damaging when vines are already water stressed.

Management Options

A number of options can be considered:

- Make the environment inhospitable by the use of water sprinklers and/or cover crops or mulches to reduce dust.
- Encourage predatory mites (by planting host species) that feed on spider mites.
- General pesticides may kill beneficial predatory mites. Specific sprays can be applied to kill only the mites that are problematic in the vineyard, but this can add to costs.

Other insect pests include leafhoppers (they cause direct damage to vine leaves) and ladybirds (which can cause taints to the wine if they are in amongst harvested grapes).

BIRDS

In nature, vines rely on birds to spread their seeds. However, birds can be a serious threat to vine growers as they can destroy an entire crop of grapes as they ripen. Isolated vineyards that provide the only source of food in an area are particularly in danger. In addition to physical damage to grapes, bird damage allows bacteria and fungi to enter bunches, which leads to rot. Starlings are one species that often attack vineyards.

Management Options

- The cost of total netting can be justified in high value areas (for example, Mornington Peninsula in Australia) or where birds are a major threat.
- Other measures such as bird scarers or noises can be used, but must be rotated regularly to avoid the birds getting used to them. Falcons are sometimes used to deter unwanted bird visitors.

Netting to protect vines against birds

MAMMALS

Mammals can do damage in vineyards by eating shoots, grapes and leaves, by breaking the skins of grapes, and thereby making them vulnerable to rot, and by damaging structures such as trellising. They thus reduce yield, lower the quality and introduce extra cost in repairing the damage. A range of animals are pests in different parts of the world. These include deer, rabbits, kangaroos, raccoons, wild boar and baboons.

Management Options

Mammals can be kept out by fencing but these have to both be sufficiently high and sunk into the soil to stop burrowing animals.

Baboons are a vineyard pest in South Africa

8.3. Fungal Diseases

POWDERY MILDEW

Grapevine powdery mildew is caused by the fungus *Erysiphe necator* which is also commonly called *Oidium tuckeri*. The fungus is specific to grapevines, with American species less vulnerable than *V. vinifera*. It was introduced to Europe in the middle of the 1800s and is now one of the most widespread vine diseases around the world. Some varieties are more susceptible than others, for example, Chardonnay and Cabernet Sauvignon, while Pinot Noir and Riesling are less prone to attack.

Powdery mildew overwinters in buds and on canes. It then attacks young, green parts of the vine. Affected parts of the vine show as dull grey patches and become black patches as they advance. Patches can damage young shoots, inflorescences and grapes, reducing yield.

Grapes can also split at *véraison* and become targets for other infections. The growth rate is determined by temperature, with an optimum temperature around 25°C (77°F), and it thrives in shady conditions. Unlike other mildews it does not require high humidity and so can spread in relatively dry conditions, especially in dense, shady canopies.

Management Options

- The preferred approach is to keep an open canopy to reduce shade and the density of leaves.
- Applications of sulfur help to prevent and treat the disease. Growers will spray the vines from a couple of weeks after budburst and up to *véraison*. It is important to spray early in the season as the disease is easier to prevent than to contain if it gets established.
- Systemic fungicides can be effective and, as they penetrate the green tissue of the vine, are not washed off by rain. However, the fungus can become resistant to some fungicides, so only a limited number of applications can be made in one year.

DOWNY MILDEW

Downy mildew is caused by *Peronospora*, a water mould that lives within vine tissue, not on the surface. It was introduced from North America in the last quarter of 1800s and is now common in most wine regions. It attacks green parts of the plant, especially young leaves and flowers, reducing yields by defoliating the vine. Grapes can also be affected, but this is less important than the threat of defoliation.

It needs rainfall and warm temperatures (20°C / 68°F) to spread. High-risk periods are warm springs and stormy but warm summers. The symptoms are yellow, circular 'oil spots' and then white, downy fungal growth on the underside of leaves.

Downy mildew forms a downy fungal growth on the underside of leaves

Management Options

- Traditionally, sprays made from copper salts have been used to prevent the spread of downy mildew. So-called Bordeaux mixture, a combination of copper sulfate and lime, became the standard treatment from the 1880s. Protection from these copper sprays only lasts until 20 mm of rain has fallen. This is the only option currently available to organic growers. However, there are concerns about the build-up of copper in the soil and in water and the EU is looking to reduce and, ultimately, eliminate its use.[2]
- Other fungicides can also be used.
- Good drainage and an open canopy that dries quickly are helpful to avoid the fungus developing and spreading.

GREY ROT

Botrytis cinerea is a fungus that can cause significant damage to fruit. It results in loss of yield and drop of quality in the wine (colour, body and aroma/flavour). Affected fruit should be selected out at harvest. Grapes are vulnerable if there are any points of entry (e.g. grapes having rubbed against each other in tight bunches or been punctured by birds/insects), leading to whole bunches being attacked. If the flowers are affected, the fungus can stay dormant in the grape and re-emerge after *véraison*. Varieties with tight bunches or thin skins are most at risk: Semillon, Sauvignon Blanc, Pinot Noir and many others. It is common in all grape growing areas.

The spores are typically present in the vineyard and become active in periods of rainfall and high humidity.

Management Options

- Selecting grape varieties that have small grapes with thick skins and therefore high levels of resistance (e.g. Petit Verdot) and protecting the grapes against other pests (which could split the skin of the grape) are the most important options.
- Keeping an open canopy and removing the leaves around bunches can also reduce the spread of grey rot.
- Traditional sulfur and copper sprays are ineffective, but other fungicides can be used. They should be applied at key points in the season – when flowering is nearly complete, at the end of grape formation, at bunch closure (when the grapes in a bunch get large enough so that they touch each other) and *véraison*. However, fungicides quickly become ineffective if the fungus develops resistance.
- Attention has therefore turned to using antagonistic bacteria; for example, *Bacillus subtilis* and other forms of biological control.

Grey rot can also be called botrytis bunch rot. The benign form of botrytis known as noble rot is covered in Specific Options for Producing Wines with Residual Sugar.

EUTYPA DIEBACK

Eutypa dieback (also called Dead arm) is a fungal trunk disease that leads to rotten wood in vines and can affect whole vineyards. It reduces yields significantly and kills vines over a ten-year period if not tackled. Spores are spread by wind over long distances. Infection occurs through pruning wounds in moderate temperatures and especially during rain. The effects of the fungus are evident in spring with affected vines displaying stunted shoot growth and yellow leaves. Grenache, Cabernet Sauvignon and Sauvignon Blanc, among other varieties, are particularly susceptible. While the disease is widespread, it has been particularly prevalent in South Australia, south-west France and parts of California.

Management Options

- Eutypa dieback is difficult to control, although pruning late and applying fungicide to pruning wounds can be effective.
- Affected trunks can be cut back 5–10 cm beyond the visible symptoms and treated with fungicide. Dead wood must be burnt to avoid spores spreading.
- Some biological controls (e.g. *Bacillus subtilis*) may be effective.

One cordon has been removed from this vine due to a fungal trunk disease. New wood is starting to be trained in its place

- If a plant is badly affected, the options are either to retrain from a sucker (a shoot that grows from the base of the vine) left on the trunk (which causes a loss of yield for two years) or removing the vine and replanting it.

PHOMOPSIS CANE AND LEAF SPOT

Phomopsis is a fungal disease that causes a reduction in yield. It is particularly prevalent in years with cool and wet springs followed by humidity and moderate temperatures. Infected canes whiten and break off easily. Shoots growing from these canes develop brown cracks at their bases. Leaves are also affected. Grenache is very susceptible, while Cabernet Sauvignon is less prone to it.

Management Options

- Fungicides should be applied three weeks after budburst and then every two weeks if wet conditions continue.
- Diseased and dead wood should be removed during pruning and the removed wood (prunings) then burnt or buried.
- Canopy management techniques that improve air flow within the canopy may also reduce risk of the disease.

ESCA

Esca is a complex fungal disease caused by a group of organisms particularly prevalent in warmer and drier climates; for example, in southern Europe and California. It typically enters the vine through pruning wounds. Symptoms include tiger-striping of the leaves and spotting inside the wood.

Esca reduces the yield of the plant and leads to its death within a few years.

Management Options

As there are no chemical controls, most attention has been paid to prevention of the disease: sourcing disease-free stock, trying new, less detrimental, pruning techniques, not pruning in the rain, removing prunings promptly from the vineyard and disinfecting pruning wounds. Research is continuing into using biological agents such as *Bacillus subtilis*.

Other fungal diseases include black rot, black-foot disease, Bot canker, anthracnose.

Stripey leaves is one of the symptoms of Esca.

8.4. Bacterial Diseases

PIERCE'S DISEASE

This is a bacterial disease that quickly kills vines. It originated on the American continent. It initially affected the southern USA and Central America, and is present in California. The bacterium lives in the sap channels of vines, which it clogs, leading to grape shrivelling, dropping leaves and the death of the vine between one and five years. The exact symptoms are unclear and so vines must be tested in a laboratory to ascertain whether they are infected. The bacterium is spread by the sharpshooter insect, which acts as a vector (an organism that transmits a disease). The glassy-winged sharpshooter has led to the disease being spread more rapidly from the 1980s on. Some grape varieties are more vulnerable than others; for example, Chardonnay and Pinot Noir.

Management Options

- There is no chemical control for the bacterium.
- Control is by reducing the number of the vector. For example, removing vines close to rivers has been effective as riverbanks can be a habitat for one of the vectors, the blue-green sharpshooter. Some chemical insecticides can also be used. Introducing a species of wasp that feeds on the eggs of sharpshooters has also been effective.
- Strict quarantine rules for the movement of plants have sought to prevent the further spread of the disease.
- For the future, work is being done on developing Pierce's Disease-resistant vines.

GRAPEVINE YELLOWS

Grapevine yellows is a group of diseases caused by a type of bacteria. It is a serious threat to viticulture as there is no treatment available. The disease is spread by vectors, which include leafhoppers, and by nurseries selling untreated, diseased stock. The most common type in Europe is *flavescence dorée*, which spread rapidly through much of France in the second half of the twentieth century. It is also present in Germany, southern Europe, New York State and, in a different form, in Australia. Symptoms include delayed budburst, a drooping posture because the new shoots fail to become woody, and the canopy turning yellow (in white varieties) and red (in black varieties). In some strains, the vine dies as the disease progresses, in others it can recover after an attack. The bacteria can live in a range of plants, including cover crops used in vineyards. Chardonnay and Riesling are among the most vulnerable varieties. The economic impact is through drastically reduced yields and lower quality (high acidity and low sugar contents of grapes).

Management Options

- There is no control against the bacteria that cause for grapevine yellows.
- The focus is on controlling the vector. Leafhopper populations can be reduced by insecticides, and the plants that host the hoppers, including cover crops, should be removed.
- Best practice in the nursery is to bathe the pruning wood in hot water to kill the disease.

Other bacterial diseases include bacterial blight and crown gall.

8.5. Viruses

FANLEAF VIRUS

This is a long-standing group of diseases (also called Fanleaf degeneration) that is now found around the world. Early shoot growth is stunted, canes can grow in distorted ways and leaves are very pale, malformed and can look like a fan. The effects vary widely from little effect to losing most of the crop in susceptible varieties such as Cabernet Sauvignon. The disease was spread enormously by the move to grafted vines following phylloxera and the inadvertent use of infected plant material. Otherwise, the disease is spread slowly by the dagger nematode.

Management Options

- There is no cure for the disease and, eventually, affected vines will have to be removed and replaced, adding to cost.
- Before vineyards are replanted, soil tests should be done to check for the presence of dagger nematodes and only virus-tested, clean planting material should be used.

LEAFROLL VIRUS

This is a group of viral diseases widely present around the world. The virus was spread by grafting and by mealy bugs, a key pest in South Africa, the Mediterranean, Argentina and some parts of California. While the condition does not kill vines, it can reduce yield by up to half and affect quality negatively. Leafroll virus slows down the growth of roots and shoots. Surviving fruit may take several additional weeks to ripen and have more acidity, less colour and lower sugar levels. The overall health of the vine is also affected as it stores less carbohydrate. The typical downward rolling of the vine's leaves usually occurs in autumn. The leaves change colour in the autumn to red for black grape varieties and to yellow for white grape varieties.

As the symptoms are not always clear, vines have to be tested in a laboratory. Some vines and rootstocks carry the virus without showing symptoms.

Leaves of black grape varieties with leafroll virus turn red in autumn.

A trap for mealy bugs as part of management for leafroll virus

Management Options

- There is no cure for leafroll virus and therefore the only solution is to remove unproductive vines and replant with virus-free stock.
- Nurseries can screen vines for virus infections.
- Mealy bugs favour humid environments and therefore open canopies help to reduce the pest. Control by spraying is difficult because of the mealy bug's waxy coating. Steps can be taken to encourage the mealy bug's natural predators: ladybugs, lacewings and others.

References

1. *How to prevent vineyard frost damage?* eVineyard, July 2019 (retrieved, 13 December 2019)
2. Henry, C, 2018, *Reduced copper spells trouble for Champagne*, Wine-searcher.com (retrieved 13 December 2019)

Harvest

9

Harvest (also known as picking) generally marks the end of grape ripening. As will be seen in this chapter, the timing of harvest can have a significant influence on the levels and nature of the various compounds within the grapes, and therefore can have an influence on grape quality and also the style and quality of the finished wine. An important choice is whether to harvest by machine or by hand. Which option is desirable, or even required, will depend on many factors including the style and quality of the wine to be made, logistics, legislation and costs.

9.1. Choosing the Date of Harvest

Traditionally, the rule-of-thumb was that grapes ripened 100 days after the beginning of flowering. Especially in European regions, readiness for harvest has been measured by potential alcohol levels. (Potential alcohol is the amount of alcohol that would be created by fermenting all the sugar in grape must into alcohol.) In cool regions, once potential alcohol has reached 9.5–11% abv, the grapes could be harvested. For example, Appellation d'Origine Controlee (AOC) regulations in Petit Chablis require a minimum of 9.5% potential alcohol, while Chablis requires 10% and Bourgogne Blanc 10.5%. Alcohol levels can be adjusted upwards by chaptalisation, within limits (see Enrichment).

However, more recently the context for making decisions about harvesting dates has changed due to:

- a generally warmer climate, making it easier to ripen grapes in cooler climates
- better viticulture, enabling the vine to ripen grapes fully
- a focus on aroma and tannin ripeness, which is sometimes considered as more important than optimum sugar ripeness.

One overriding factor is the threat of rain in the harvest period (see Untimely Rainfall in Hazards). If rain is forecast, grape growers may have to choose between harvesting underripe fruit or risk leaving grapes on the vine in the hope that the weather will improve. Rain in the last days before harvest can lead to diluting of the grape juice or, in the worst-case scenario, splitting of the skins due to rapid expansion of the grape, with consequent threat of grey rot and loss of some or all of the harvest.

MEASURING RIPENESS

'Ripeness' is a term that can have a number of different meanings, as covered in Defining Ripeness in Grape Development. Therefore, grape growers will often be measuring various components in the grapes in order to decide the optimum time of harvesting for the style of wine they are aiming for.

- **Sugar levels** – The amount of sugar in ripening grapes is easily measured by a handheld refractometer. Most dry still wines are harvested between 19° and 25° Brix (one of the scales used to measure the amount of sugar in the juice), which will convert into 11–15% abv.

- **Acidity levels** – Titration can be used to calculate acid levels. (Titration is a method of finding out the amount of a substance in a solution by gradually adding measured amounts of another substance that reacts in a known way.[1]) Similarly, the pH of the juice can be read by a pH meter.
- **Aroma and tannin ripeness** – Usually determined by taste (with experience).

There are various ways of measuring other compounds in the wine (which may support decisions regarding when to harvest).

Also, high tech means (visible or near infrared spectroscopy) are appearing on the market. The benefit of the latter is that they give multiple readings for sugar, acidity and various other wine compounds or measures. However, even with such detailed data regarding the components of grapes, tasting the grapes remains one of the most important ways of deciding when to harvest.

HARVESTING DATES FOR SPECIFIC WINE STYLES

Grape growers make choices about harvesting date, both in terms of the general issues covered in the preceding paragraphs and in relation to particular wine styles to be made. For example:

- Grape growers in the Loire harvest Chenin Blanc over a period of 4–6 weeks, according to the style of wine to be made: early for sparkling wine, mid-harvest for dry and off-dry styles and late for botrytis or late-harvest styles (see Concentrating the Grape Must).
- Grape growers in California can choose whether to harvest Zinfandel in early to mid-August for White Zinfandel or whether to harvest in September for red wine. As Zinfandel tends to have unripe and ripe fruit on the same vine, care has to be taken with selection if a consistently high quality is required. Equally, in hot areas grape growers must decide whether or not to include shrivelled grapes.

Zinfandel can be prone to uneven ripeness even within each bunch; note the presence of some shrivelled grapes.

- Harvest dates are extremely influential for a number of wines that have residual sugar. Some of these wines are made by harvesting late to concentrate the sugars in the grapes. The grapes for botrytised wines often need hand-harvesting over several passes through the vineyard to select the most botrytised grapes at that time. In the case of Eiswein or Icewine, grapes can only be picked when temperatures reach below certain levels (e.g. below -8°C / 18°F for Canadian Icewine). For more details, see Specific Options for producing Wines with Residual Sugar.

- There is a continuing debate over whether extended 'hang time' is detrimental to wine style. Some critics believe it leads to overly alcoholic and unbalanced wines lacking in natural acidity and having extra-ripe fruit character. Some grape growers say that critics reward these wines with high scores and that consumers like them.

9.2. Harvesting Options

In the past, harvesting was done by hand, as this was the only option. However, since the advent of machine or mechanical harvesting, many grape growers have a choice between harvesting by machine or by hand. While 'hand-picked' is still much used in wine promotion as an indicator of quality, in reality the issues are more complex. The choice depends on many factors, including the type of wine to be made.

MACHINE-HARVESTING PREFERRED

Machine harvesting has become the default option for inexpensive to mid-priced wine and for larger-scale production. (There are exceptions, e.g. in South Africa where most grapes are still hand-harvested because of the availability of labour at a low cost.) This is particularly the

Machine harvesting can be desirable as it keeps labour costs low.

case where vineyards have been designed from the start to facilitate it. Vineyards are now prepared and planted to maximise their suitability for mechanisation with even row spacing, a turning space at the end of rows and are on flat land or land with a small, regular gradient.

In the past, machine-harvesting used to be equated with only acceptable to good level quality wines. However, several steps can be taken to improve quality today – at a range of different costs. These include:

- selecting out undesirable fruit by hand before harvesting by machine
- using a bow-rod shaking machine (rather than the older machines, which beat vines to remove the fruit); this is gentler and can be set to be more selective
- investing in the very latest machines that have options for optical sorting devices on them and which can crush white grapes and add SO_2 in the machine itself to limit oxidation
- rigorous sorting on arrival in the winery, including removal of MOG (matter other than grapes) and unripe and rotten grapes.

Advantages of Machine-Harvesting

- Harvesting by machine is significantly faster and substantially cheaper in large vineyards, if the vineyards have been designed with this in mind. The proportions vary depending on the cost of labour and of machines, but studies conducted in California indicate that machine-harvesting can be one-third of the price of hand-harvesting.
- Machine-harvesting avoids issues of the lack of availability of, and possible unreliability among, casual workers.

Machine harvesters shake grapes off from the stem so are not suitable when making styles of wine where whole bunches are required or desired.

- Grapes can be harvested at night and be kept up to 15°C / 59°F cooler (than if they were picked during the day) and therefore in better condition. This can reduce microbial spoilage and oxidation. For white, fruity wines, starting the winemaking with cool fruit preserves the freshness of fruit aromas. It also helps to save the cost of refrigeration.
- The timing of the harvest can wait until the desired level of ripeness has been achieved and then carried out quickly. By comparison, assembling and deploying a group of pickers may be less flexible and slower.

Disadvantages of Machine-Harvesting

- Machine-harvesting, despite all the advances, is still less gentle than hand- harvesting. It involves grapes being shaken off the stems (potentially leading to rupture of the grape skin and some release of juice), rather than keeping the bunches intact. This is a consideration when making some styles of wine where whole bunches are required (see Hand Harvesting Required) and when wishing to avoid any oxidation or the extraction of phenolic compounds (see Wine Components), for example with delicate white wines.
- Rental or ownership of a machine is not cost effective for small vineyards.
- Machine-harvesting may be unsuitable for grape growers that have several different varieties ripening at different times in the same plot (depending on the size of the plot and organisation of the different varieties within the plot).
- It is not suitable for vineyards on steep slopes or with limited access.
- The quality of the work is only as good as the skills of the operator.
- Where an estate does not own its own harvester, there may be competition for the rental of the machine at the best moment for harvest.
- Purchasing a harvester is a major investment.

HAND-HARVESTING PREFERRED

Some grape growers, especially those aiming to make premium wines, prefer to harvest by hand. This involves teams of harvesters removing the whole grape bunches from the vines by cutting the stem of each bunch with secateurs.

Advantages of Hand-Harvesting

- Pickers can be highly selective at a bunch-by-bunch level and to remove any diseased, under- or extra-ripe fruit at the point of harvest.
- Pickers can deal with steeper slopes, irregular rows and mixed plantings in the same vineyard.
- If handled with care and put in small, stackable crates (with a maximum weight of 10–15 kilos), the crushing of grapes and the release of juice, which would then be prone to oxidization and to microbial spoilage, can be avoided.

Disadvantages of Hand-Harvesting

- It is more expensive than machine-harvesting in medium to large vineyards
- It requires the availability of a reliable work force and their training and supervision to ensure that they work to the required standard
- Harvest is most easily carried out in daylight hours and may not be able to avoid high temperatures; this raises the chance of grapes being spoiled by microbes or oxidation. (However, some producers hand harvest at night by providing their pickers with torches.)

Hand harvested fruit is collected in small bins.

Rising labour costs, the scarcity of labour and the advantages of machine-harvesting are making some producers of premium wines reconsider their options. By comparison, some inexpensive, high volume wines may be harvested by hand or part harvested by hand. For example, cooperatives in France or Italy receive fruit from small-scale grape growers and then use the fruit for large batches of wine.

HAND-HARVESTING REQUIRED

Some wine styles require hand-harvesting. These include premium sparkling wines made where whole bunches are required for whole bunch pressing (Champagne and most bottle-fermented sparkling wine around the world). Similarly, grapes for Beaujolais and other wines that will be made by carbonic or semi-carbonic maceration require whole bunches for the process. In addition, if making a style of wine that requires selective harvesting of certain grapes, harvesting must be done by hand. For example, pickers may be instructed to harvest only botrytis-affected bunches (e.g. for Trockenbeerenauslese Riesling in the Mosel).

Grapes are also hand-harvested where they are grown on steep slopes (e.g. in the Douro Valley) or uneven land. Bush vines are harvested by hand because, to be machine harvested, vines need to be held on a trellis. Without the trellis, there would be too much damage to plants and the grapes.

Reference

1. Cambridge English Dictionary

Viticulture Scenarios 10

The following scenarios have been provided to illustrate how many of the factors explained in grape growing sections of this book fit together in the context of a region. The regions have been chosen to include a range of different growing environments and the choices that are generally made in these areas to produce grapes for wine.

10.1. Priorat, Catalunya

Priorat is located in Catalunya in north-east Spain. Although there are variations in different subzones, in general Priorat experiences very hot, dry summers and cold winters. The area is so hot and sunny that the best vineyards are planted on slopes facing north-east to protect the vines from the most extreme afternoon heat. The soils in Priorat are stony slate and quartz. There is little organic matter and so the soils are low in nutrients but free draining. The hot, dry conditions result in a high evapotranspiration rate. Overall, this means that the vine struggles to obtain enough water. Irrigation is permitted but only with advanced authorisation and only to justify the survival of the vine or to improve the quality of the grapes. However, due to the dry and warm conditions, disease pressure is low.

The vigour of vines and their yield are naturally limited by the lack of water and soils that are poor in nutrients. The individual vines are therefore relatively small and the training and pruning options reflect this. Most of the vines in this region are bush vines. These are well adapted as the shoots and leaves provide some shading for the grapes in this hot and sunny location, but the vines are not so vigorous that excessive shading becomes an issue. The vines are planted at low density (often around 2500–3000 vines per hectare) so the roots of each vine can grow over a large area in search of water and nutrients. Yields are also extremely low due to the number of old vines in the region. Yields are approximately 15–25 hl/ha, but may be lower in some vineyards.

Garnacha and Cariñena are the most widely planted grape varieties. They are suited to the extreme conditions as they are late ripening (they do not reach sugar ripeness too quickly) and drought tolerant. A grape grower based in this area may also choose to use a drought tolerant rootstock such as 140R.

Because Priorat's terrain is extremely rugged and the vines are often not trellised, the work in the vineyard, including harvesting, needs to be carried out by hand. Low yields and the need for long hours of manual labour means that the wines from Priorat will never be inexpensive and often sell at premium or super-premium prices.

10.2. Pauillac, Bordeaux

Bordeaux is in south-west France near the Atlantic Ocean, which moderates its climate. It has moderate summers and mild winters, with rain throughout the year. The soils in Pauillac are free draining and poor in nutrients.

Cabernet Sauvignon is the main grape variety. It is medium to late ripening and so can struggle to ripen in Bordeaux's coolest sites and years. It can also lack some body and a diversity of fruit aromas/flavours. However, it can be blended with Merlot, which ripens earlier and adds body and fruit.

The vines are typically trellised to a VSP system. Poor, free-draining soils limit the vigour of the vines. As a result, more complex systems of training for big vines would not be suitable. The vines are usually head-trained and replacement cane-pruned. The VSP system ensures that the canopy is appropriately arranged: the grapes are exposed to the sun, the surface area of the leaves is maximised and air circulation is improved, which helps to reduce onset of fungal diseases, all promoting the production of healthy, ripe grapes. Rain and high humidity in damper years means that producers need to monitor for diseases such as downy mildew and botrytis regularly and take preventive action, such as spraying.

The vines are planted at high densities, for example with spacing of 1 m by 1 m (around 10,000 vines per hectare). Rainfall is high enough for vine competition not to be a problem. The vineyard land in Pauillac is expensive, so maximising the yield per hectare by planting vines closely makes economic sense. Yields often vary depending on vintage conditions, but average yields are generally 50–60 hl/ha (hence yield per vine is small).

Vine trellising means that some vineyard procedures, such as trimming and weed management, can be done by machine. Specialised machines are able to straddle rows of vines and therefore be used despite tight between-row spacing. Harvesting may be carried out by hand or machine.

10.3. Finger Lakes, New York state

The Finger Lakes is an American Viticultural Area (AVA) region located in upstate New York. The deep lakes in the region provide some moderation of temperatures (*V. vinifera* would not be able to grow here without the effect of the lakes), but summers are still moderate and winters are extremely cold.

The vineyards are located around the edges of the lakes. In general, the black grape varieties such as Cabernet Franc are grown on the land nearest the lakes to benefit from the slightly more moderate conditions. This extends the period over which grape growing is viable, providing more chance for the tannins and aromas in these varieties to get ripe.

The main grape variety in the region is Riesling, its winter hardiness means it can survive harsh winters. However, grape growers will also hill up the soil so that it covers and protects the vine graft, which is generally the part of the vine that is most at risk from winter freeze. Riesling is also a late budding variety, which provides protection against spring frosts. A variety of clones of Riesling are typically planted to provide blending options to enhance the quality of the final wine or as one way of providing differentiation between different Rieslings in a winery's portfolio.

The soils of Finger Lakes are nutrient-rich and that, together with plentiful rainfall throughout the year, means that the vines can be vigorous. Scott-Henry trellising systems are used to divide the vine canopies and hence improve light interception in large canopies. Various summer pruning techniques (e.g. leaf stripping) may also be carried out to enhance ripeness.

Rainfall in the growing season means that fungal diseases can be a problem, especially botrytis. The divided canopy of Scott-Henry also improves air circulation through the canopy to reduce the risk, but spraying with fungicides is usually necessary also.

Large vines need sufficient space so that they do not overlap, so vine densities here are low (around 2800-3200 vines per hectare). Between-row spacing is also large to allow for mechanisation because labour availability is low. However, each vine can ripen a large crop, so yields are around 50-60 hl/ha.

10.4. Central Valley, California

Central Valley is an area in California that grows large volumes of grapes for inexpensive, high-volume wines. Because the grapes are used to make inexpensive wines, the key concern of the grape grower will be to maximise the yield of grapes while keeping costs low in order to maximise profit.

Located in inland California, the Central Valley has a warm, dry, sunny growing season. Although rainfall is a limiting factor, irrigation is permitted and provides the vines with their water requirements. Levels of nutrients will vary according to the soil and how the vineyard has been managed in the past, but fertilisers can be added if nutrients are limited. These factors combined mean that vines can grow large and ripen large crops of fruit. This is beneficial as vines are expensive to buy and therefore the most cost-effective option for the grape grower is low density planting (around 1200–1800 vines per hectare) of big, high-yielding vines (approximate yields 180–200 hl/ha).

In such conditions, a large range of grape varieties can ripen. The choice of grape variety will typically be based on market demand and the price per ton that the grape variety can command.

California sprawl is a common trellising technique in this area. A single wire is installed above the cordon and the shoots flop up and over the wire. (The vines are typically spur-pruned and cordon-trained because replacement cane pruning requires more-skilled labour. In this trellising system, the vines are trained relatively high.) This trellising technique is cheap compared to other trellising. The hanging shoots also help shade the fruit from intense afternoon sunshine, reducing risk of sunburn. Complex vine trellising systems such as Lyre system are also sometimes used to manage the vigour of the vines. Summer pruning techniques such as leaf pulling require labour or machinery and therefore are generally not carried out. In particular, green harvesting, which requires dropping fruit, is unlikely, as this would reduce yields. Overall, the lack of passing through the vineyard and attention to individual vines may result in variable ripeness within the crop of grapes, and therefore lower quality.

Harvesting will typically be carried out by machine, which is generally the most cost-effective option for large vineyards. Where possible, the fruit may be picked at night so that the grapes are cool during transportation, reducing chance of oxidation and microbial spoilage. However, if there is a large amount of fruit to pick over a short period, this may not always be possible. The main concern of the grape grower will be providing a crop that is healthy and unaffected by rot; this means that the grapes may be picked relatively early to avoid any risks of rain as autumn approaches. If the grape grower also grows higher quality fruit, this make take preference when deciding when to pick, and therefore the grapes may not be picked at optimum ripeness.

11 Wine Components

Wine is made up of a complex array of compounds, some of which have come directly from the grapes and others which have been formed during the fermentation process or added as part of other winemaking procedures. The main groups of compounds are described below.

WATER

Wine is approximately 85 per cent water by volume depending on the abv, level of residual sugar and other factors. The water is critical for the way a wine flows as a liquid.

ALCOHOL

Ethanol is formed during fermentation and is the predominant alcohol in wine. It has a slightly sweet smell. Ethanol contributes a sense of sweetness and bitterness, and oral warmth. It also makes a contribution to the fullness of the body of a wine and the mouthfeel. Alcohol levels of 14.5% and above reduce the volatility of wine aromas and increase the sense of bitterness. Wines with high alcohol levels must have sufficient fruit concentration to be in balance with the alcohol.

There are also traces of higher alcohols, but these are below the level of perception.

ACIDS

The principal acids of wine, tartaric acid and malic acid, come from the grape itself. Studies in warm climates have shown that these two make up about two-thirds of the total acidity in wine. Other acids (e.g. lactic acid, acetic acid) are produced in fermentation or malolactic conversion.

Volatile acidity mainly refers to acetic acid (vinegar smell), although some other compounds can contribute. It is present in all wines, generally in low concentrations, and is only a fault when in excess (see Faults). Acetic acid in turn reacts with the alcohol in the wine and becomes ethyl acetate (nail varnish remover smell), which is also perceived as a fault when in excess.

Acidity contributes to the structure of wine, makes wine refreshing and should be in balance with the fruit concentration and, if present, residual sugar, depending on the style of the wine. High acid also makes wine appear leaner on the palate. Excessive acid will make wine taste tart. Lack of acid will make wine taste flabby.

The perception of acidity and of dryness is related not just to the level of acidity, but to the balance of acidity and any residual sugar. For example, some German Rieslings taste dry despite having significant levels of residual sugar (up to around 9 g/L) because of the elevated level of acidity.

The levels of individual acids can also affect the taste of wine. For example, high levels of malic acid will give the wine a firm acidity, which contributes to its style; for example, cool climate Chardonnay where the malolactic conversion has been blocked.

In wine, total acidity and pH are linked but not exactly correlated. This is due to the buffering effect of other molecules (e.g. potassium). A wine with high acidity would usually have a low pH, and vice versa.

Acidity can be measured and expressed in several ways, but the most common measure is 'total acidity', which is the sum of all the acids. Although there are many acids present, the result will usually be expressed as the equivalent of grams per litre (g/L) in tartaric acid. Total acidity in wine is typically in the range of 5.5–8.5 g/L. In France, total acidity may be expressed as sulfuric acid (the ratio between sulfuric acid and tartaric acid is 1:1.5).

If total acidity is measured in g/L, pH is a scale of measurement for the concentration of the effective acidity of a solution. Wines typically have a pH in the range of 3–4. This is an inverse scale, so the lower the number, the more concentrated the acidity (the wine will taste more acidic). The scale is logarithmic, so a pH of 3 is ten times more acidic than a pH of 4. pH level affects a range of key parameters in winemaking. A low pH increases the microbiological stability of wine, increases the effectiveness of SO_2, gives red wines a bright red colour and enhances a wine's ability to age well.

WINE AROMATICS

Wine contains many aromatic and non-aromatic compounds. Its aromatic complexity arises from the presence of these molecules and from their interaction with each other. The compounds come from four sources:

Aromas from the Grapes

Examples of aromatic compounds that are found in the grapes include methoxypyrazines and rotundone.

- Methoxypyrazines occur in the Sauvignon Blanc variety and give a grassy, green pepper aroma.
- Rotundone occurs in Syrah and in Grüner Veltliner, producing a pepper aroma.

Aromas created by Fermentation due to the Presence of Aroma Precursors in Grape Must

Aroma precursors are compounds that are not in themselves aromatic but are building blocks which become aromatic during fermentation. For example, many compounds occur in grapes in a form combined with sugar as aroma-less precursors. However, through the process of fermentation they become aromatic.

- Thiols are a category of aromatic compounds that are released during fermentation. An example is 4MMP which gives the box tree aromas in Sauvignon Blanc.
- Terpenes are another category of compounds that are formed in this way. They are widely found in wines, giving fruity and floral aromas. Examples such as linalool and geraniol contribute to the grapey aromas/flavours in Muscat.

Aromas originating from Fermentation and its By-Products

Some aromas do not originate from the grapes but are created from fermentation and its by-products, such as lees.

- Esters are compounds which are formed by the reaction of certain acids and alcohols. The majority are created through the action of yeasts in the fermentation process. Esters are responsible for many fresh and fruity aromas and are therefore essential in the aroma profiles of young wines. They are especially important in the aroma of young white wine. The most common ester is isoamyl acetate, which gives aromas of banana when its concentration is high (for example in Beaujolais Nouveau), but others produce apple, pineapple and many other aromas. Another common ester is ethyl acetate, see Acids. Most esters are unstable and will break down a few months after fermentation.

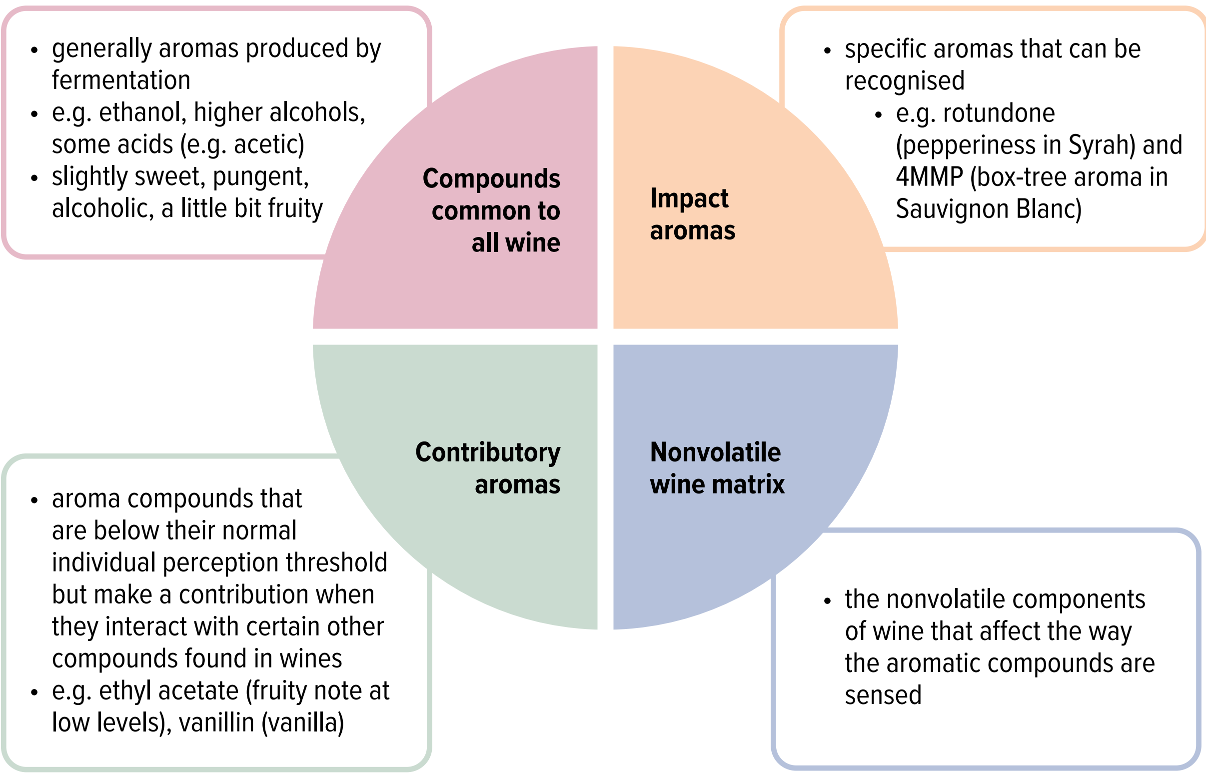
- Acetaldehyde occurs in wines due to the oxidation of ethanol. It is also known as ethanal. It masks fresh fruit aromas and has a stale smell that is regarded as a fault in most wines. However, it is an important component of the distinctive smell of Fino sherry.
- Diacetyl is produced during fermentation and especially malolactic conversion. It contributes a buttery aroma.
- In certain conditions, yeast can produce reductive sulfur compounds during fermentation and lees ageing. Depending on the types of compounds present in the wine and their levels of concentration, aromas can range from struck match, which may be desirable, to rotten eggs, which would be regarded as a fault.

Aromas from Other Sources

There are numerous other sources of aromas found in different wines. For example:

- vanillin, which gives aromas of vanilla, is just one of the aromatic compounds that can be derived by ageing wine in new oak barrels.
- eucalyptol, which can be volatized from eucalyptus trees by heat and absorbed in the waxy layer of the skins of grapes in nearby vines, may be detected in wine.

The aromas in wines have been the subject of intense scientific research in recent years. This is a complex field due to the sheer number of compounds involved, and especially due to the final aroma of a wine being the product of the interaction between aromatic and non-aromatic compounds in wine. This complexity is summarised in the diagram of Vincente Ferreira's model for wine aromas.



Diagrammatic representation of Vicente Ferreira's model for wine aromas[1]

RESIDUAL SUGAR (RS)

Dry wines will usually have a small amount of RS (2–3 g/L), while off-dry to sweet wines will have much more (Sauternes can have 150 g/L, Pedro Ximenez sherry can have up to 400 g/L). In addition to contributing a level of sweetness to wines, RS gives more body to them.

For more information on the processes and choices for making non-dry wines see Specific Options for Producing Wines with Residual Sugar.

The EU Classification of Sweetness Levels

The EU has two classifications of sweetness levels in wine. The one for sparkling wines is covered in the unit on that topic. The classification for still wines is reproduced here. These terms do not have to appear on labels, although some regions (e.g. Alsace) are encouraging their use or bespoke sweetness codes in order to guide customers.

The classification takes into account two factors – levels of residual sugar and optionally higher levels of RS for wine with higher total acidity – in an attempt to guide consumers as to the taste of the final wine.

- **Dry/sec/trocken etc.** – up to 4 g/L RS, or not exceeding 9 g/L provided that total acidity expressed as grams of tartaric acid per litre is not more than 2 g below RS content. For example, a wine with 9 g/L RS can be labelled 'Sec' if it has 7 g/L total acidity.
- **Medium dry/demi-sec/halbtrocken etc.** – more than 4 g/L and not more than 12 g/L RS, or up to 18 g/L provided that the total acidity expressed as grams of tartaric acid per litre is not more than 10 g below the RS content.
- **Medium or medium sweet/moelleux/lieblich etc.** – more than 12 g/L and not exceeding 45 g/L RS.
- **Sweet/doux/süss etc.** – at least 45 g/L RS.

GLYCEROL

Glycerol is the third most abundant part of wine after water and alcohol (in dry wines) and is derived from the sugar in grapes. It occurs in higher levels in wines made from botrytis-affected grapes (e.g. Tokaji) and wines made by carbonic maceration (e.g. basic Beaujolais) although to a lesser extent than those made from botrytis-affected grapes.

Glycerol contributes smoothness to the texture of wine and the perception of the fullness of the body. It has a slightly sweet taste.

PHENOLICS

Phenolics refers to an important group of compounds that occurs in grapes, especially in the skins, stems and seeds. They include both anthocyanins (colour pigments responsible for the red colour – and sometimes blue tints – of red and rosé wines) and tannins.

In broad terms, tannins bind with proteins in the mouth, giving a drying sensation on the palate. However, the exact relationship between the tannin compounds in the grapes, tannin compounds in the wine and the sensation of tannins in the wine is very complex and not well understood. It is thought that the perception of tannins can be influenced by the other compounds in the wine. A little residual sugar can make tannins seem softer, whereas dry wines with high acidity can make tannins appear more astringent. Tannins can also react with other compounds in wine during winemaking and maturation, changing their composition and hence how they are perceived (see Defining Ripeness in Grape Development). Unripe tannins generally taste bitter and are never desirable. The level and nature of the tannins and their role in the balance and structure of the wine as a whole is considered a key part of quality in red wines.

Reference

1. Ferreira, V (2010), 'Volatile aroma compounds and wine sensory attributes', in *Managing Wine Quality. Viticulture and Wine Quality*, Woodhead Publishing, pp. 3–28

Approaches to Winemaking 12

Just as there are a number of approaches to managing the vineyard, there are also different approaches to making wine. The approach that the winemaker takes will influence their winemaking options and choices. This chapter will introduce the approaches of conventional, modern winemaking, organic winemaking, biodynamic winemaking and natural winemaking.

12.1. Conventional, Modern Winemaking

Conventional winemaking builds on a scientific understanding of the processes which convert grape must into wine. The foundational discovery was Louis Pasteur's work in the 1860s identifying bacteria and yeasts. Conventional winemaking now includes:

- **Temperature control** – the ability to control temperature is a factor in the following areas: cold soaking; the ability to control fermentation temperatures with particular outcomes in mind (e.g. a fruity style); and temperature control in the maturation phase
- **Use of additives and/or processing aids of many types** – examples include adding sugar to increase potential alcohol or sweeten the final wine, adding SO_2 to protect wine and the use of cultured yeasts and fining agents
- **Manipulations** – from simple pressing and filtration to high technology such as reverse osmosis

These interventions will be examined in more detail in other sections. The aim is to produce stable wines which reliably show their fruit character and have no faults. This approach is used for wine of all styles, quality levels and prices.

Just because manipulations are possible or additives are available, does not mean they are used in every case. The options employed are dictated by many factors including the style and price point required, the health and ripeness of the grapes, and the particular beliefs/preferences of the winemaker. For example, sterile filtering of wines with residual sugar is usually desirable as the sugar makes them prone to spoilage organisms. By contrast, a number of producers of premium dry wines choose not to filter, believing it may remove some texture and/or flavours from the wine.

12.2. Organic Winemaking

Organic winemaking refers to making wine with certified organically-grown grapes and complying with rules that restrict certain practices from being performed during the winemaking process. These rules allow many common additives and processes used in conventional winemaking, including cultured yeasts and yeast nutrients, and adding tannins. The certification agency Ecocert issues a full list of allowable additives and processes. It indicates where organic raw materials should be used if possible (e.g. organic egg white albumin for fining), and has a short list of excluded practices, e.g. partial de-alcoholisation of wines.

The rules for organic wine with regard to the addition of SO_2 vary across countries. The EU definition of organic wine allows the addition of regulated amounts of SO_2. However, the definition of organic wine in the USA excludes any addition of SO_2 and requires naturally occurring SO_2 (produced in fermentation) to be less than 10 mg/L. In the USA there is also a category of 'wine made from organic grapes' that does allow the addition of SO_2.

Certified organic status can be issued by associations (e.g. by the Organic Winegrowers New Zealand) or it is determined at country level (US Department of Agriculture, USDA) or by the EU.

Certification itself adds a small cost element to organic wines. The wines are sold at every price level. Whether consumers are willing to pay a premium for organic wines compared to non-organic equivalents depends very much on the specific market.

12.3. Biodynamic Winemaking

Certified biodynamic wine must be made from certified biodynamically grown grapes. In the winery, certain processes are required or encouraged by the certifying body. Demeter International is the main certifying association. Although it sets certain global standards, Demeter certifiers in each country determine the specification for that country. Thus, for example, for Demeter-certified biodynamic wine in the UK, natural yeasts are encouraged, but organic or, if unavailable, commercial yeasts can be used. Other stipulations ban the use of measures such as increasing alcohol levels by concentration of the entire must. For Demeter-certified biodynamic wine in the USA, natural yeasts must be used, but certain classes of commercial yeast can be used if a ferment has stuck and then only on a case-by-case basis. Many products are not permitted (e.g. adding tannins or certain fining agents such as isinglass).

Certification adds a small cost element to biodynamic wines. The wines are typically mid-priced and above, reflecting additional costs and usually small-scale production.

12.4. Natural Winemaking

Natural winemakers reject many modern interventions in favour of artisan practices from the past. The overall aim is 'nothing added, nothing removed'. While there is no widely agreed definition for natural wine, in practice it usually refers to wine made with the fewest possible manipulations (this is often termed low-intervention winemaking). Typical practices include fermentation by ambient yeasts and with an absolute minimum of added SO_2 (often only at bottling) or no added SO_2. Most natural winemakers would argue that organic or biodynamic grapes should be used whether certified or not. While any winery can claim that any of their wines are natural, the first nationally recognised certification is France's *Vin méthode nature*. There are also associations that publish their own approach and/or standards. Examples include *VinNatur* in Italy and *L'Association des Vins Naturels* in France.

There is a negligible impact on price as the saving on investment in equipment is offset by the cost of small batch winemaking and, where sought, certification. The wines are typically small batch and mid to premium priced.

Natural winemaking often involves artisan practices from the past, such as the use of amphorae.

Winemakers of natural wines often claim that their wines are more expressive of *terroir* than those made by conventional winemaking. By contrast, other winemakers feel that some level of intervention or addition (e.g. of SO_2) is beneficial to ensure their wines show at their best.

13 General Winemaking Options

This chapter will introduce winemaking options that are common for many styles of wine from transportation of grapes to the winery to post-fermentation adjustments to wine. Winemaking actions for specific styles of wine are covered in chapters 16, 17, 18 and 19.

13.1. Oxygen and Sulfur Dioxide

These two gases play fundamental roles in winemaking and maturation from grape reception until after the wine is packaged. Whether and how the winemaker chooses to use or avoid these gases will have a significant effect on the style and quality of the wine.

OXYGEN IN MUST AND WINE

Oxygen is responsible for a number of reactions that occur between the compounds in grape must or wine and for this reason can have a significant effect on wine style and quality. Although oxygen itself is not very reactive with many compounds in the must and wine, the reactions it does take part in create products that then go on to react with many must and wine compounds. These reactions are oxidation reactions. The timing and amount of oxygen exposure is key, making the difference between a positive or negative effect, and therefore an understanding of the role of oxygen is essential.

Oxygen is generally threatening for the production of fresh, fruity wines. Many of the aroma compounds that give these wines their fruity style, for example the thiols found in Sauvignon Blanc, break down in the presence of oxygen, and this can lead to a loss of fruitiness. Furthermore, the products of oxidation reactions may contribute unwanted aromas to the wine; for example, acetaldehyde (from the oxidation of ethanol) can give a nutty, apple aroma. The colour of white wines can also turn darker, becoming gold and then brown with increased oxidation, and therefore white wines tend to need greater protection. Phenolic compounds in red wines have an anti-oxidative effect, which means that they can absorb more oxygen before such effects are perceptible.

The practice of minimising oxygen exposure during the winemaking process is sometimes called reductive or protective winemaking.

The effect of oxygen on the must or wine can be limited by:

- avoiding ullage in vessels. Ullage is the headspace of air between the wine and the top of the container. It can be avoided by ensuring vessels are filled up to the top. In vessels that are not completely airtight, such as those made of wood, there may be a gradual loss of liquid through evaporation. Therefore, these vessels should be topped up regularly with more wine to avoid ullage.
- use of inert (chemically inactive) gases. Gases such as nitrogen, carbon dioxide and argon can be used to flush out oxygen from vessels, pipes and machinery (such as presses) because these gases do not react with compounds in the wine. Inert gases can also be used to fill the empty headspace of any containers where the wine does not reach the top to prevent oxygen coming into contact with the wine.

- addition of sulfur dioxide, which has strongly anti-oxidative effects (see further below)
- use of impermeable containers. Stainless steel and thick concrete vessels are impermeable to oxygen, whereas wooden vessels allow gentle ingress of oxygen. The use of glass bottles with screwcap can also minimise exposure to oxygen during storage in bottle.
- cool, constant temperatures. Cool temperatures slow the rate of oxidation reactions; hence the reason for maturing wines in relatively cool cellars or picking grapes early in the morning so that the fruit is not warm.

However, controlled exposure to oxygen can be positive for many wines. In fact, oxygen is required at the start of fermentation of all wines to promote growth of a healthy yeast population and, in some cases, lack of enough oxygen in winemaking or storage can lead to reductive off-flavours (see Faults). In the production of some white wines, exposing the must to oxygen before fermentation is thought to lead to greater oxidation stability in the wine, and to result in increased ageing potential (see Hyperoxidation). In red wines, oxygen is essential in the reaction between anthocyanins and tannins that leads to greater colour stability (see Anthocyanins, Tannins and Oxygen in Specific Options for Red Winemaking).

Exposure to oxygen over time also leads to changes in the aromas/flavours of wine. These can give a greater range and diversity of characteristics: fresh fruits become dried fruits and notes such as honey, caramel, coffee, leather and mushroom can develop. A high level of oxidation is vital in some wine styles, such as Oloroso Sherry, Madeira and Tawny Port, but less extreme oxidation also contributes to the complexity of many matured white and red wines.

This system of cap management sprays the must from a height, increasing oxygen exposure.

Oxygen exposure can be increased by:

- use of cap management techniques in red wine fermentation that spray or splash the must or wine (see Cap Management Techniques in Crushed Fruit Fermentations)
- use of small wooden barrels that can only contain a small volume of wine relative to the amount of oxygen that enters through the bung holes and staves (see The Role of Oxygen in Maturation)
- increasing the number of rackings or amount of lees stirring during ageing; any procedures that require the bung of a barrel or lid of a vessel to be removed and the wine to be moved will increase oxygen exposure (see The Role of Oxygen in Maturation)
- allowing ullage in wine containers without the use of inert gases in the headspace
- use of techniques that involve pumping oxygen through the must (e.g. hyperoxidation) or wine (e.g. micro-oxygenation) (see The Role of Oxygen in Maturation).

Oxygen can favour the growth of spoilage organisms, such as acetic acid bacteria and Brettanomyces, especially if other conditions are favourable (e.g. grape must or wine with residual sugar). Therefore, wines exposed to oxygen must be carefully monitored for these microbes and their associated faults.

SULFUR DIOXIDE

Sulfur dioxide is a preservative that is almost universally used in winemaking, where it has the following properties:

- **Anti-oxidant** – SO_2 only reacts with oxygen itself very slowly; it reduces the effects of oxidation by reacting with the products of oxidation reactions, so they cannot oxidise further compounds in the wine. It also inhibits oxidative enzymes.
- **Anti-microbial** – It inhibits the development of microbes such as yeast and bacteria. Different species of yeast and bacteria can vary in their tolerance to SO_2.

SO_2 can be applied in various forms: gas, liquid or solid, as sulfur dioxide, potassium metabisulfite or potassium bisulfite. A small amount of SO_2 (10 mg/L or less) is also naturally produced during fermentation. Maximum concentration levels of SO_2 are defined by local laws as it is a toxic substance. For example, in the EU 150 mg/L SO_2 is the maximum permitted for red wines and 200 mg/L is the maximum permitted for white wines. Sweet wines are permitted to contain higher levels. The maximum permitted SO_2 levels are lower for organic wines than non-organic wines (and in the USA SO_2 additions are not permitted for organic wines). Producers of natural wines may choose not to add any SO_2 at all or use only a very small amount. The concentrations of SO_2 found in wine are far below toxic levels; however, even at these very low levels some people can experience an allergic reaction. If a wine contains over 10 mg/L of SO_2, the label must state that the wine contains sulfites.

SO_2 is generally added soon after the grapes are picked and/or reach the winery. It may then be added at various points during the winemaking process and usually at bottling. When SO_2 is added to must or wine, it dissolves and some of it reacts with compounds in the liquid. This proportion is called ‘bound SO_2’ and it is ineffective against oxidation and microbes. The proportion that is not bound is called ‘free SO_2’. The vast majority of the free SO_2 exists in a relatively inactive form and a small proportion exists as molecular SO_2, which is the most effective against oxidation and microbes.

The pH level of the must or wine has a key effect on the efficacy of SO_2 in that a greater proportion of free SO_2 is in the molecular form at lower pH levels. This means that a greater amount of SO_2 needs to be added to musts and wines with relatively high pH to protect them from oxidation and microbes.

The timing and size of SO_2 additions also influences the effectiveness of the added SO_2. Adding a larger amount when the grapes are crushed, at the end of malolactic conversion and at bottling is considered as more effective than adding smaller amounts throughout the winemaking process.

Judicious additions of SO_2 are beneficial and often necessary to produce unfaulty wines that remain unfaulty once packaged. However, where possible, quality-conscious winemakers will aim to limit additions of SO_2 both because of the legal restrictions listed above and also because high levels of SO_2 can dull wine aromas/flavours and sometimes cause the wine to taste harsh. Good winery hygiene and effective grape sorting can limit the amount of harmful microbes in the wine and the winery. Limiting oxygen exposure (see suggestions in Oxygen in Must and Wine above) and keeping grapes, must or wine at cool temperatures can also reduce the amount of SO_2 needed to protect from oxidation and spoilage organisms.

13.2 Transportation to Winery

Once harvested, grapes will be transported to the winery. At this stage, they are vulnerable to oxidation and to ambient yeasts and acetic acid bacteria (which turn alcohol to acetic acid, i.e. vinegar). All of these threats to quality rise with higher temperatures. Black grapes are less vulnerable to oxidation because they contain more phenolic compounds that have anti-oxidative properties. Measures can be taken to minimise the threats of oxidation and microbial infection:

- Harvesting and transporting grapes at night when temperatures are lower (see Harvesting Options) or harvesting at sunrise if harvesting by hand
- Addition of SO_2 for its anti-oxidant and anti-microbial properties at the time of harvesting (see Sulfur Dioxide in Oxygen and Sulfur Dioxide)
- Reduction of the grapes' temperature by putting them in a cold storage room once received at the winery
- Sanitising harvesting equipment/bins (reduces chance of microbial infection only)
- Collecting and transporting the grapes in small crates to minimise crushing (this may depend on the method of harvesting, see below).

In the vineyard, hand-harvested grapes are typically put in small crates that the pickers can carry. Depending on the scale of operation, the options are:

- To transport the grapes in small crates to the winery. This may be for quality purposes or simply because of small-scale grape growing. For example, in many Italian regions many grape growers will only have one hectare to harvest and will use their own tractor to transport the grapes. Small crates mean minimal crushing of grapes and therefore reduce oxidation of the juice and threat from spoilage organisms.

Hand harvested grapes may be transported in small crates to minimise crushing.

- The small crates are tipped into larger hoppers (large bins) for transport to the winery. Without protective measures, this would involve some crushing of grapes and therefore oxidation and increased threat from spoilage organisms. Some grape growers will add SO_2, generally in the form of potassium metabisulfite, at this point to minimise this (see Sulfur Dioxide in Oxygen and Sulfur Dioxide).

Machine-harvested fruit has already been destemmed and and is typically transported in large containers, with some release of juice.

Again, some grape growers will choose to add SO_2 at this point. (As noted in Harvesting Options, some newer harvesters are able to sort fruit, crush grapes and add SO_2 before transporting the juice to the winery.)

13.3. Grape Reception

On arrival at the winery, a number of options are possible and will depend on the volume of the grapes, whether they have been hand- or machine-harvested and the health and quality of the grapes. Where large volumes of grapes are to be moved on reception, then a conveyor belt or a screw conveyor will be used, the former being gentler with higher quality potential. Smaller volumes of hand-harvested grapes can be moved around manually, often with a pallet truck or forklift. The grapes are conveyed either to the sorting phase or to the destemmer/crusher.

CHILLING

Hand harvested grapes may be chilled in a cold store.

If the grapes are warm when they reach the winery (e.g. they have been picked on a sunny, warm afternoon), the winemaker may choose to chill them to a lower temperature before crushing and pressing begins. Warm temperatures increase the rate of oxidation and therefore chilling can help preserve fruity aromas. Chilling also helps to reduce the threat from spoilage organisms.

Chilling of whole bunches usually takes place in a refrigeration unit. The chilling takes time, which may slow the processing of the grapes (but the refrigeration unit can be a useful place to store grapes if all the sorting tables, presses and other equipment are already in use).

A heat exchanger can also be used for chilling (or heating in cool climates) if the grapes are in a more fluid format (e.g. fruit that has been machine picked, grapes that are destemmed and possibly crushed). Heat exchangers can work very quickly.

Both of these options incur costs in terms of equipment and energy. Where possible, harvesting at night or early in the morning will be encouraged in warm climates to bring in cool grapes and avoid these costs.

SORTING

The level of grape sorting (also known by the French word *triage*) that is required, and indeed whether sorting takes place at all, depends on a number of factors including the ripeness and health of the fruit arriving at the winery, the intended final wine quality and price, whether any sorting has been carried out in the vineyard (e.g. by skilled hand-pickers) and the physical state of the grapes (if grapes arrive in large containers, the bottom grapes will have crushed and released juice; this is too liquid to sort).

The more sorting that is carried out, the higher the cost. This is both due to the labour and time needed for meticulous hand sorting and because greater scrutiny often results in less yield. A judgement has to be made as to the level of sorting that is justifiable in relation to the return expected from the sale of the wine. In poor years and in cool climates a greater of level of sorting may simply be required (for all but the most basic quality wines) to remove mouldy and under-ripe grapes. In very good years, fruit may arrive in near perfect condition and require little sorting. MOG (material other than grapes), for example, leaves, twigs, and insects, may still need to be removed. The grapes for inexpensive wines may not be sorted at all (as sorting costs money and time and requires either expensive machinery or labour). The key determinants are the health of the grapes on arrival at the winery and then the quality of the wine to be made in relation to the price that can be gained for the wine.

These grapes are being sorted by hand to remove MOG and rotten grapes.

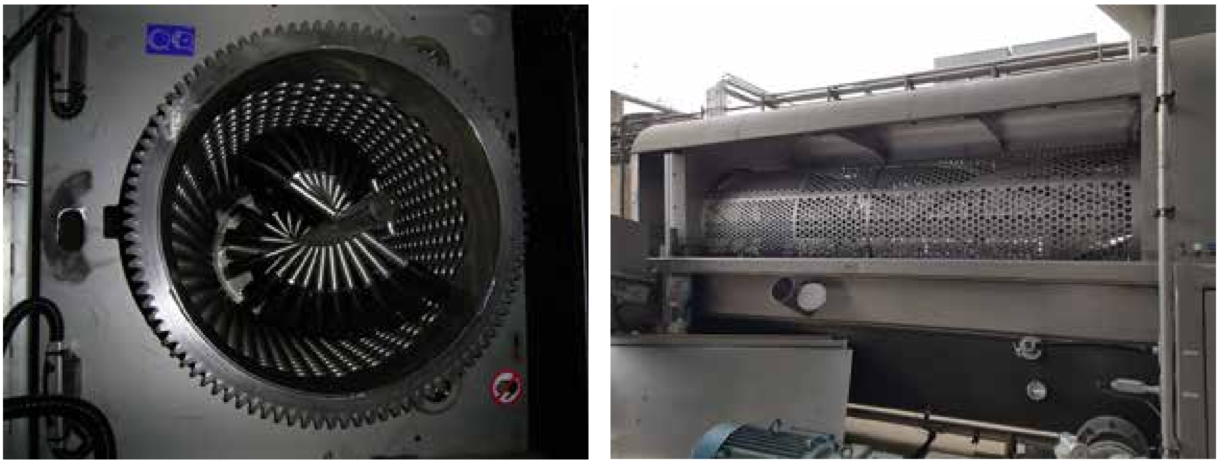
For quality wines there is a range of sorting options:

- Removing unwanted grapes/bunches before picking or during hand-harvesting
- Sorting by hand on a table or a moving or vibrating belt (the latter also removes MOG); this can take place before or after destemming, or occasionally both before and after destemming
- Optical sorting, which is a high-tech, high-cost option that uses digital imaging and software technology to scan individual grapes. The machine scans a 100-grape sample chosen by the grape grower as a reference. The full load of grapes to be sorted is then passed through the machine and it rejects individual grapes that do not conform to the sample and any MOG. This can be done either in a harvesting machine or at reception in the winery. Due to the cost of the machine and high level of selection, this option is typically only used for premium and super-premium wines.

DESTEMMING

Hand-harvested grapes for most white wines and many red wines are destemmed on arrival at the winery. (Machine-harvested grapes are already destemmed because the grapes are shaken from their stems during harvesting.) Destemmers generally work by a series of blades within a rotating drum that remove the grapes from the stems. Destemming is common in wineries around the world.

Stems contain tannins, which can be extracted if the stems are left in contact with the wine. These tannins are not wanted in white wines and are additional to skin/seed tannins in red wines, so can be desirable in some wines and not in others (see Whole Berry/Bunch Fermentations). If stems are not ripe, they can convey unwanted green flavours and bitter tannins to wine.



Destemmers involve a series of blades in a rotating drum. The destemmed grapes fall out through the holes in the drum.

Grapes are not destemmed for wines made in certain ways. Examples include:

- red wine fermentations that use some whole bunches (e.g. with Pinot Noir in Burgundy and many other Pinot-producing regions)
- carbonic maceration (e.g. with Gamay in Beaujolais)
- whole bunch pressing for some white wines (e.g. common for high-quality sparkling wine).

CRUSHING

Crushing grapes, which happens at the beginning of the winemaking process, is the application of sufficient pressure to the grapes to break the skins and release the juice, making it available for fermentation. (It is not to be confused with pressing, which is the separation of the juice or wine from the skins and seeds.) It is important that the pressure applied is gentle enough not to crush the seeds, which would add bitterness. Traditionally, crushing was done by the pressure of human feet.

Many wineries combine these two last processes with a combined destemmer–crusher machine. Using this machine means that sorting can only be done at the level of whole bunches.

The mixture of grape juice, pulp, skins and seeds that comes from the crusher is commonly termed ‘must’. For white wines, must may also refer to the grape juice that is fermented (pressing and clarification means pulp, skins and seeds have been removed). Hence, in winemaking, ‘must’ typically refers to the substance that is being fermented.

13.4. Pressing

In white winemaking, the grapes are almost always pressed to extract the juice from the grapes and to separate the skins from the juice before fermentation. In red winemaking, the grapes are typically crushed before fermentation and pressed after the desired number of days on the skins or at the end of fermentation.

Soft pressing is important in both white and red wines. For white wines, the aim is to crush and press the berries to maximise the release of juice but without extracting tannins from skins and seeds and to avoid excessive amounts of solids. Tannins are not desired in most styles of white wine. Equally, for red wines where pressing is typically after fermentation has been completed, care must be taken not to extract excessive tannin and bitterness from skins and seeds that have been softened by being in the must for periods typically between five days and three weeks.

An important choice is the type of press to use:

Pneumatic Presses
These are currently the most popular type of press used in wineries throughout the world. They are also called ‘air bag presses’. The press is made up of a cylindrical cage with a bladder that runs down the side or middle of it. Grapes are loaded into the tank (on one side of the bladder). The other side of the cage is filled with air and, as the bladder inflates, the grapes are gradually pushed against grates on the side of the cage, separating the juice or wine from the skins. The advantages of the pneumatic press are that it can be programmed to exert different amounts of pressure (light pressure for less extraction, harder pressure for greater extraction, which can provide different blending components if needed) and that it can be flushed with inert gas before use to protect the juice or wine from oxidation. Pneumatic presses are common in wine regions around the world in medium to large-scale wineries that can afford the initial investment.

Pneumatic presses are commonly found in wine regions around the world.

Basket Presses
These are a more traditional form of press, but are still used by some winemakers. They are also called ‘vertical presses’ or ‘champagne presses’. A ‘basket’ is filled with grapes and pressure is applied from above. The juice or wine runs through gaps or holes in the side of the

Basket presses provide gentle pressure but no protection from oxygen.

basket and is collected by a tray at the bottom of the press. A pipe transfers the juice or wine to another vessel. Basket presses are not sealed vessels, and therefore cannot be flushed with inert gases to avoid oxygen exposure. Some winemakers believe these to be gentler than pneumatic presses. However, they generally hold a smaller press load, are much more labour intensive and are therefore most suited to small wineries making premium wines. They are to be found in wine regions around the world.

Though less widely used, other types of presses include the horizontal screw press and the continuous press. The horizontal screw press is similar to a basket press mounted horizontally above a rectangular draining tray. It is less gentle than many other types of press and therefore less popular. This press, as well as pneumatic and basket presses, all require batch processing. A volume of grapes is loaded into the press, they are pressed, the skins are removed, the press may be cleaned and the next batch is then loaded. This can take a lot of time. The continuous press allows grapes to be continually loaded into the press as it works by using a screw mechanism; this allows for quicker pressing of large volumes of grapes. However, it is also less gentle than pneumatic and basket presses and therefore best suited to producing high volumes of inexpensive wines. Consequently, they tend only to be used to produce some inexpensive, high-volume wines.

Most modern presses are computerised. The winemaker can program the pressure and length of the press cycle to obtain the desired results. Applying less pressure will extract less tannin and colour from the skins, but will result in a smaller volume of juice and/or wine. There can therefore be a compromise between the quality of the juice and wine and volume of wine that can be made. A longer press cycle extends the contact between the skins and the juice or wine (in the case of red winemaking), which extracts more aroma/flavour and tannin.

The solid remains of the grapes left after pressing is called pomace. For must clarification, see Specific Options for White Winemaking.

13.5. Must Adjustments

Winemakers can make a number of adjustments to the must. The general aim is to create a more balanced wine, especially if there has been a compromise in achieving optimum ripeness of sugars, acids, tannins and flavours. Adjustments to the must are generally made after must clarification for white wines. (Adjustments can also be made after fermentation.)

ENRICHMENT

It is common practice for winemakers in cooler climates to enrich the must either before or during fermentation to increase the alcoholic content of the final wine. The general EU term 'enrichment' refers to a range of practices: adding dry sugar, grape must, grape concentrate or rectified concentrated grape must (RCGM – manufactured, flavourless syrup from grapes) and the processes of concentration (reverse osmosis, vacuum extraction, chilling).

The common practice of adding dry sugar is also known as chaptalisation (after Jean-Antoine Chaptal, whose name came to be associated with the practice). The source of the sugar can be beet or cane sugar. In the EU this is allowed within limits in the cooler parts of Europe. Warmer areas (broadly southern Europe) are not permitted to add sugar, but they can add grape concentrate or RCGM, again within limits. With rising average temperatures in Europe during the growing season, there may be less need for enrichment.

Wine regions within the EU are split into different zones that determine the level of enrichment (as well as acidification and deacidification) that is permitted. To give two examples of the coolest and warmest regions of Europe:

	Minimum natural potential alcohol	Maximum enrichment	Maximum alcohol level in final wine (if enriched)
Zone A: Germany, excluding Baden, and UK	8%	+3%	11.5% (12% for red wines)
Note: Limits also given for Zones B CI, CII and CIIIa	....	....	....
Zone CIIIb: Most of Portugal, southern Spain, parts of southern Italy and Greece	9%	+1.5%	13.5%

Note: potential alcohol is the amount of alcohol that would be created by fermenting all the naturally-occurring sugar in the must into alcohol.

In practice, adding sugar is done when fermentation is underway because the yeasts are already active and can therefore cope better with the additional sugar in the must.

Sugar levels in musts can also be concentrated by technological means of removing water: reverse osmosis, vacuum evaporation or cryoextraction (freezing the must, or even the final wine, and removing ice from it). The first two of these options are expensive because of the initial outlay on the machines used and therefore are limited to wines that will provide a high return on investment or wineries that produce high volumes of wine. Cryoextraction tends to cost less and so may be used more widely. In all cases, the costs must take into account that after these concentration processes there will be less wine to sell.

REDUCING ALCOHOL

In warm or hot regions where sugar can accumulate in the grapes quickly, it may be desirable to lower the potential alcohol of the wine slightly by adding water to the grape must. This is only legal within some countries or regions (e.g. in California water may be used within the addition of other wine processing additives). However, adding water also dilutes the grapes' aromas/flavours and acids. Other ways of reducing the alcohol content involve removing alcohol from the wine (see Post-Fermentation Adjustments).

ACIDIFICATION

In warm climates without any cooling influences, the malic acid in grapes tends to drop dramatically as the grapes ripen. If the wine is not acidified, it could lack freshness. Acidification can also be used to lower pH (the benefits of low pH levels are covered in Wine Components). Acidification is routine in most warmer parts of the world for inexpensive and mid-priced wines and many premium wines.

Acidification is typically carried out by the addition of tartaric acid, the acid characteristic of grapes. Other options are:

- citric acid (though not permitted in the EU for acidification)
- malic acid (less used as it could be turned into lactic acid by malolactic conversion)
- lactic acid (may be used if adjustments need to be made after malolactic conversion; it tends to taste less harsh than the other acids).

Acidification can take place before, during or after fermentation. However, winemakers typically prefer to acidify before fermentation starts to benefit from the effects of a lower pH and because they believe that the acidity added at this stage integrates better within the profile of the wine as a whole. However, total acidity and pH can both be affected during the various winemaking processes, including malolactic conversion (if allowed to occur) and tartrate stabilisation (see Stabilisation in Finishing and Packaging); therefore, the winemaker must take this into account when deciding the amount of acid to add.

In the EU, just as with enrichment, the amount of permitted acidification is controlled within the bands of countries organised according to climate. In the coolest zone, only deacidification (see below) is allowed. In the warmest zone, acidification is allowed. To use the same two examples as before:

	Acid adjustment
Zone A: Germany, excluding Baden, and UK	−1 to 0 g/L expressed as tartaric acid
Note: Limits also given for Zones B, CI, CII and CIIIa	....
Zone CIIIb: Most of Portugal, southern Spain, parts southern Italy and Greece	0 to +2.5 g/L

In the moderate-climate zone CI, which includes Bordeaux, Spain's cool north Atlantic coast and Italy's Trentino-Alto Adige, winemakers can deacidify or acidify according to the season (−1 to +2.5 g/L).

Within the EU, winemakers are not allowed both to chaptalize and to acidify musts. This is to prevent wines being 'stretched' by the two additions.

DEACIDIFICATION

In cool climates where grapes may have to be picked before they are fully ripe (e.g. due to the threat of poor weather), it may be necessary to deacidify the must or wine. Any calculation of the desired final level of acidity will need to take account of the lowering of acidity brought about by malolactic conversion. Deacidification is carried out by adding calcium carbonate (chalk) or potassium carbonate, and it lowers acidity by the formation and precipitation of tartrates (see Stabilisation in Finishing and Packaging). A high-tech option is deacidification by ion exchange. This last option requires considerable investment or hiring expensive machinery. The producer will need to check that this option is legal in the intended country of sale. Producers in the EU will need to ensure that they only deacidify within the legal limits set by EU law.

ADDING TANNINS

Powdered tannins may be added to help to clarify musts and, in the case of red wines, to help to stabilise the colour of musts and improve mouthfeel. Tannins may either be added to the must before fermentation or to the wine before maturation.

13.6. Alcoholic Fermentation

Alcoholic fermentation is the conversion of sugar into ethanol (also known as ethyl alcohol) and carbon dioxide carried out by yeast in the absence of oxygen ('anaerobically'). This conversion also produces heat, which has to be managed.

YEAST

Yeast is the collective term given to the group of microscopic fungi that convert sugar into alcohol and affect the aroma/flavour characteristics of wines. Initially, yeast need oxygen to multiply quickly, but once any oxygen is used up by the yeast (in aerobic respiration), they switch to fermentation. The yeast species that are most often used in winemaking convert the sugars in the must to produce alcohol if given the right conditions: a viable temperature range, access to yeast nutrients, especially nitrogen, and the absence of oxygen. As well as alcohol, carbon dioxide and heat, the process also produces:

- volatile acidity (vinegar and nail polish remover smell); in standard fermentation, not enough is produced to be perceptible
- very small amounts of naturally-produced SO_2
- wine aromatics (see Wine Components)
  - from aroma precursors: aroma precursors are compounds that have no flavour in the must, but are released by the action of yeast and create aromas in wine. Examples include thiols (e.g. 4MMP, which gives aromas of boxwood/gooseberry in Sauvignon Blanc), and many terpenes (e.g. linalool and geraniol, which give Muscat its floral, grapey aroma).
  - created by yeast: for example, esters, which give many fruity flavours (e.g. banana flavour in wines made with carbonic maceration and recently released – for instance, Beaujolais Nouveau). The action of some species or strains may also produce detectable levels of undesirable reductive sulfur compounds (rotten eggs, rotten cabbage) and acetaldehyde (bruised apple, paint thinner).
- glycerol, which increases the body of the wine.

Saccharomyces cerevisiae is the most common species of yeast used in winemaking. It can withstand well the high acidity and increasing alcohol level of the must as it ferments and, hence, it reliably ferments musts to dryness. It is also fairly resistant to SO_2 in comparison to other yeast species.

For any one fermentation vessel, the winemaker must choose between using ambient or cultured yeast.

Ambient Yeast

Ambient yeast (also called wild yeast) is present in the vineyard and the winery. It will include a range of yeast species (e.g. *Kloeckera* and *Candida*), most of which will die out as the alcohol rises past 5 per cent. Typically, *Saccharomyces cerevisiae* quickly becomes the dominant yeast, even in ‘wild fermentations’.

Advantages:

- Ambient yeast can add complexity resulting from the presence of a number of yeast species producing different aroma compounds.
- It costs nothing to use.
- Some studies have shown that the yeast population in a must can be unique to a place or region, especially where widely available cultured yeast has not been used.
- Using ambient yeast may also be used as part of the marketing of the wine.

Disadvantages:

- Fermentation may start slowly. This can be dangerous for the build-up of unwanted volatile acidity and the growth of spoilage organisms (such as Brettanomyces) and bacteria, potentially leading to off-flavours.

- Fermentation to dryness may take longer, which may not be desirable in a high volume winery. There is also increased risk of a stuck fermentation (fermentation ceases or slows) leaving the wine in a vulnerable state to spoilage organisms.
- A consistent product cannot be guaranteed, which can be a drawback, especially for producers looking for consistency over many large vessels or across vintages.

Cultured Yeast

Cultured yeast (also sometimes called selected yeast or commercial yeast) are yeast strains that are selected in a laboratory and then grown in volumes suitable for sale. Commercially available cultured yeasts are often single strains of *Saccharomyces cerevisiae*.

To use cultured yeast, the must may be cooled down to prevent fermentation by ambient yeast and then the cultured yeast added, which quickly overwhelm the natural yeast population. Another option is to add SO_2 to the must to suppress ambient yeasts. A starter batch, made up of fermenting grape must which has been activated with the cultured yeast, is then added to the tank of must to be fermented.

Advantages:

- Cultured yeast produces reliable, fast fermentation to dryness.
- Cultured yeast produces low levels of volatile acidity and, given its speed and reliability, there is less danger from spoilage organisms and bacteria. Many winemakers report that the reason they use cultured yeast is for the security of a clean, completed ferment.
- Cultured yeast also helps to produce a consistent product from one vintage to another.
- With a large selection of cultured yeast strains available commercially, the winemaker's choice can also affect the style of wine created. For example, the winemaker may choose to use a neutral yeast for a sparkling wine base or a strain of yeast to boost the aromatic character in Sauvignon Blanc (e.g. for mid-priced Marlborough Sauvignon Blanc).

Other species of yeast are used for particular wines, for example, Saccharomyces bayanus is sometimes used for must with high potential alcohol or for re-fermenting sparkling wine.

When using cultured yeast a small starter batch must be made and this is then added to the main vat.

Disadvantages:

- Some believe that using cultured yeast leads to a certain similarity of fruit expression (and hence the charge of 'industrial wine').
- Using cultured yeast adds the cost of using a commercial product.

While the fermentation itself does not require exposure to oxygen, this is needed at the early stages to enable yeast to multiply rapidly at the beginning of fermentation. Winemakers may also add yeast nutrients, particularly if nitrogen levels in the must are low. Low levels of nitrogen can stress the yeast causing them to produce undesirable sulfur compounds (giving a rotten egg smell) or even to stop fermenting (resulting in a stuck fermentation). Diammonium phosphate (known as DAP) or thiamine (vitamin B1) can be added as yeast nutrients.

TEMPERATURE

The speed of fermentation is related to the temperature of the must, which in turn affects the style of wine being produced. Winemakers may prefer a relatively warm start to fermentation (e.g. 25°C / 77°F) to get the yeast population established, and then monitor it regularly and cool or warm the must as required.

As stated, the fermentation temperature helps to define the wine style (see more in Specific Options for White Winemaking and Specific Options for Red Winemaking). These temperatures are merely a guide and winemakers make individual choices.

Cool: 12–16°C / 54– 61°F	Fresher, fruitier white wines and rosé Cool temperatures promote the production and retention of esters that give fruity aromas and flavours
Mid-range: 17–25°C / 63–77°F	Easy-drinking fruity red wines to retain fruit aromas and for low tannin extraction Middle of this temperature range for less fruity white wines, top of this range for barrel-fermented white wines
Warm: 26–32°C / 79–90°F	Used for red wines with pronounced flavour concentration and high tannins Maximum extraction of colour and tannins, but can result in some loss of fruity flavours

Above 35°C (95°F) the fermentation may slow down and stop as yeasts struggle to survive, with risk of a stuck fermentation. Hence, the temperature must be controlled to prevent this from happening.

Options for Temperature Control

At the most basic level, fermentation temperature can be affected by the temperature of the cellar and adjusted to some extent by changing that temperature. Sluggish ferments can be moved to a warmer room and over-heating ferments to a cooler one, if they are available and if the fermentation vessels are small enough to move. However, modern wineries typically have fermentation control installed in many vessels. These use either water or glycol in jackets that surround vessels (typically stainless steels tanks) or in inserts that can be put into vessels. Most wineries will monitor and control these systems by computer. Temperatures can also be reduced by pumping over/*délestage*, which releases heat.

FERMENTATION VESSELS

A wide variety of vessels are in use for fermenting wine and, in the case of red wines, the maceration process.

Stainless Steel

This is the modern standard as it is easy to clean, comes in a large range of sizes and enables a high degree of control over the temperature of the must or wine. These are neutral vessels and so are very good at protecting the wine from oxygen, and they also do not add any flavours. Stainless steel tanks are the most common type of vessel used in modern, high-volume wineries due to price, hygiene and a very high level of mechanisation possible (automatic pump-over, temperature control, automatic emptying, etc.). They can require substantial initial financial investment in the tanks themselves and in computerised temperature-control systems.

Stainless steel vessels are very common as they are easy to clean and to control temperatures.

Concrete

Concrete vats were an inexpensive option in the last century, with the vats being built in situ on a large scale. They are now coming back into fashion because of their high thermal inertia: they maintain an even temperature much more efficiently than stainless steel. Smaller, egg-shaped vessels in concrete, which are very expensive, are said to set up convection currents that mix the fermenting must and mix the lees during maturation (see The Role of Lees in Still Wine Maturation).

Concrete eggs are thought to permit natural lees stirring.

Old concrete vessels

Concrete has come back into fashion with a number of wineries investing in new concrete vessels.

Wood

Some areas of Europe have retained their traditional large wooden fermentation casks (e.g. 1,000 litres or above in Alsace, Germany or Italy). Wood retains heat well and some winemakers value the small amount of oxygen that fermenting red wine in oak provides. However, great care has to be taken with hygiene as the pores in wood can harbour bacteria and spoilage organisms.

They can be reused many times and so are inexpensive over the long term. However, they require capital investment when new large oak casks are bought. White wines may also be fermented in small wooden barrels. This is relatively rare for red wines due to the need to manage the cap of skins. For further details on wooden vessels, see The Role of Wood in Maturation.

There are also a number of alternative options. Plastic vessels are light, versatile and useful for small-batch fermentations. However, plastic is permeable to oxygen and it can be difficult to control the temperature in plastic vessels. Terracotta has been used historically (e.g. for amphorae) and is in use in small-scale production today. Pots made from terracotta are known by various names. These include amphora, qvevri (Georgia) and tinaja (Spain).

Large old oak vessels in Tuscany

13.7. Malolactic Conversion

Malolactic conversion, often called malolactic fermentation (MLF, 'malo'), is the result of lactic acid bacteria converting malic acid into lactic acid and carbon dioxide, and it produces heat. It typically happens after alcoholic fermentation and occasionally during it. Certain conditions encourage it to happen: 18–22°C (64–72°F), a moderate pH (3.3–3.5) and low total SO_2. Historically, it often happened spontaneously in the spring following harvest as temperatures rose in the cellar. Now the process can be started by adding ('inoculating with') cultured lactic acid bacteria and making sure that the optimum conditions are available.

Certain conditions inhibit or prevent malolactic conversion taking place: temperature below 15°C (59°F), a low pH and moderate levels of SO_2. If winemakers want to ensure that it is less likely to happen, they can add the enzyme lysozyme, which kills lactic acid bacteria, or move any batch of wine going through malolactic conversion to another part of the winery to avoid the spread of lactic acid bacteria. Alternatively, lactic acid bacteria can be filtered out to avoid malolactic conversion taking place.

Red wines routinely go through malolactic conversion. It is a winemaker's choice for white wines. The outcomes of malolactic conversion are:

- **Reduction in acidity and rise in pH** – This is because lactic acid is a weaker acid than malic acid. This may be desirable in overly acidic wines (e.g. Chardonnay grown in a cool climate such as Chablis) but not in wines that are already relatively low in acidity. It results in a softer, smoother style of wine.
- **Some colour loss in red wines** – This is not a problem except in very pale red wines.
- **Greater microbial stability** – If the wine goes through malolactic conversion during or after alcoholic fermentation, this then prevents malolactic conversion from spontaneously happening later (e.g. when the wine is in the bottle) when it would be undesirable.

However, in cases where the pH of the wine is high, raising the pH slightly makes the wine more vulnerable to spoilage organisms.

- **Modification of the flavour** – A slight loss of fruit character may occur with the addition of buttery notes (notably in white wine). The process will also increase volatile acidity.

Some winemakers choose to conduct malolactic conversion in barrels for both white and red wines rather than in larger batches in tanks. The advantages are the ability to be able to stir the lees at the same time and promote better integration of the flavours.

However, this is more work because barrels may be at different temperatures and so will need monitoring individually. Some winemakers prefer to promote malolactic conversion at the same time as alcoholic fermentation. Some studies have shown that this can increase fruity characteristics (or alternatively reduces the loss of fruit character from the final wines) and shortens production times, saving money as wines can be finished and sold earlier.

13.8. Post-Fermentation Adjustments

After fermentation is completed, there are still options for the winemaker to adjust the wine before it is matured, finished and/or packaged. The acidity, pH and tannins can be adjusted in the same ways as before fermentation (see Must Adjustments). The winemaker should aim only to be making small adjustments post-fermentation in order not to upset the balance of the wine. For sweetening wine at this stage, see Specific Options for Producing Wines with Residual Sugar. In addition, the following techniques are possible.

REMOVAL OF ALCOHOL

It may be desirable to remove alcohol either to produce a reduced alcohol wine (e.g. below 5.5 per cent) or to adjust the level of alcohol marginally. The simplest solution for marginal adjustment (where permitted) is to add water to the must. However, adding water also reduces the intensity of flavour. High-tech solutions that remove alcohol from the wine include:

Reverse osmosis – A form of cross-flow filtration that removes a flavourless permeate of alcohol and water, which can be distilled to remove the alcohol. The watery permeate is then blended back to recreate the wine. This is the most common high-tech option. The equipment can be rented or bought, but is generally costly.

Spinning cone – A device that first extracts volatile aroma compounds from wine and then removes the alcohol. The aroma compounds are then blended back into the wine of the desired alcohol level. This technology is only financially viable for large volumes of wine. Within the EU, alcohol reduction by these last two means is legal, but within specified limits.

COLOUR

Winemakers may wish to reduce unwanted colour tints, for example by fining the wine (see Fining in Post-Fermentation Clarification) or, when making some high-volume red wines, enhance colour intensity by adding very small amounts of the grape-derived colouring agent, MegaPurple. This is not permitted within the legislation of some regions (e.g. Ribera del Duero).

14 Maturation

Once alcoholic fermentation and malolactic conversion (when allowed to occur) have been carried out, the wine can either be finished and packaged relatively quickly or it may be matured for a period of time before it is bottled.

Young, fruity or aromatic styles of wine that have been protected from oxygen throughout the winemaking process (such as many examples of New Zealand Sauvignon Blanc or Veneto Pinot Grigio) are likely to be kept protected from oxygen at this stage to best retain their primary aromas. They may be stored in vessels that are impermeable to oxygen, such as those made from stainless steel, and kept protected by use of SO_2 and/or blanketing with inert gas. They are likely to be finished and packaged shortly after the end of fermentation.

Some winemakers making these styles of wines choose to bottle only when an order from a customer has been placed (hence the wine is stored in bulk), or they choose to ship the wine in bulk. Storing the wine in bulk means the winery has more flexibility when it comes to selling the wine through the year (depending on demands it can be packaged with different labels, sold in bulk or blended with other wines). Storage in bulk is often more efficient in terms of winery space than the same volume of wine kept in stacks of bottles, and it also means wine labels are less likely to get dirty or become ruined (e.g. by humidity). The advantages and disadvantages of bulk shipping can be found in Transportation of Wine.

By contrast, for many winemakers the period of maturation after fermentation is essential in determining the style and quality of wine. The key factors that may have an influence on the wine during maturation are oxygen, new wood and yeast lees; not all of these are always used, depending on the style of wine that is being aimed for.

Blending can have a significant impact on the style, quality and price of the wine, and although it may take place at any point in the winemaking process, it is often carried out at the end of maturation process.

Post-Bottling maturation can be found in the chapter on Finishing and Packaging.

14.1. The Role of Oxygen in Maturation

Oxidation reactions play a significant role in the way aroma and phenolic compounds evolve in the wine, and therefore have a marked influence on the style and quality of the wine.

Generally, oxidation leads to a gradual reduction in many primary aromas and a development of tertiary aromas, such as dried fruits and nuts. If the primary aromas develop into pleasant tertiary aromas, and the wine has a structure suitable for extended ageing, this can maintain or enhance the quality of the wine. If the primary flavours fade and are not replaced by positive tertiary characteristics, this can result in a reduction in quality.

Additionally, oxidation can influence the colour of wines. With exposure to oxygen, white wines become darker, gradually becoming gold and then brown. Exposing a young red wine to oxygen can result in greater colour stability and intensity. In this reaction, anthocyanins bind with tannins, which, in turn, protects anthocyanins from being bleached by SO_2 additions or adsorbed by yeast lees (i.e. the anthocyanins are not held as a thin layer on the lees, which would reduce the colour of the wine). This is particularly important for light-coloured red wines such as Pinot Noir. After much more prolonged exposure to oxygen, all red wines gradually become paler and browner.

For red wines, oxidation reactions also seem to result in the softening of tannins, which may be positive for quality. This area of science is not yet well understood but may at least in part be linked to anthocyanin and tannin bonding.

The speed of oxidation is influenced by the amount of oxygen exposure, the compounds in the wine and temperature, among other factors. Wine that is fully exposed to the air (and hence oxygen) will generally oxidise quicker than when oxygen exposure is more gradual (e.g. wine kept in a large oak vat). That said, red wines can withstand a higher level of oxygen exposure than white wines before any signs of oxidation are apparent due to their higher content of anti-oxidative phenolic compounds (e.g. tannins). This is why red wines are often matured for longer than white wines, with 12–24 months pre-bottling maturation being common for red wines and 6–12 months more common for white wines. Temperature is also important with warm temperatures increasing the speed of oxidation reactions.

A high level of oxidation is a key part of the style of some wines (such as Oloroso Sherry), the oxidation evident from the brown colour of the wine, and lack of fresh fruit on the palate instead replaced by nuts and dried fruits. In this case, the wine is stored for a number of years in barrels that are not filled to the top, allowing oxygen within the headspace of the barrel (ullage). More commonly, for un-fortified red and white wines, the exposure to oxygen is limited and therefore has a much slower, subtler effect. Too much oxidation in these wines is usually considered a fault.

WOODEN VESSELS AND OXYGEN

The traditional, and still commonly used, method of gaining a slow, gradual exposure to oxygen is to store the wine in small wooden vessels. Some oxygen is released from the pores in the vessel within the first month that the vessel is filled with wine. A very small amount of oxygen also continues to pass through the gaps between the staves and the bung hole. (Note that there are different schools of thought on how wine in barrel is exposed to oxygen. Some state that oxygen only enters through the bung hole, while others suggest oxygen passes through the wood itself.) However, the times when the wine is most exposed to oxygen in this process is during any transfer of the wine, such as during racking, lees stirring or topping up in which the bung is removed.

Some wine is generally lost during the maturation process in wooden vessels. Water and alcohol in liquid form impregnate the wood. Within the staves of wood, the water and alcohol turn to vapour (evaporate) and diffuse, along the concentration gradient, to the air outside the vessel. This leads to a gradual concentration of the other components of the wine. Small vessels, such as barrels, have a large surface area to volume ratio, increasing the rate at which wine is lost. This means that barrels frequently need to be topped up with more wine to keep them full (and hence avoid ullage and excessive oxidation). The frequency of topping up leads to more oxygen exposure in these vessels than in much larger vessels. The amount of oxygen that enters the barrel relative to the volume of wine is also larger for small vessels compared to larger vessels, also leading to quicker (but not extreme) oxidation.

MICRO-OXYGENATION

However, maturing wine in barrels is costly for a number of reasons (see The Role of Wood in Maturation) and therefore micro-oxygenation is a technique that can provide a cheaper alternative. Micro-oxygenation involves bubbling oxygen through wine. The dose of oxygen is typically in units of mg/L per month. Micro-oxygenation is generally carried out in stainless steel tanks for a number of months post alcoholic fermentation. Initially, it was generally used on inexpensive and mid-priced wines; however, a growing number of wineries producing premium and super-premium wines are using the technique.

Micro-oxygenation is thought to increase colour stability and intensity, soften tannins, improve texture and reduce the presence of any unripe, herbaceous flavours. Additional benefits are that it provides the effects of gentle exposure to oxygen more quickly than barrel ageing without needing expensive barrels, and the rate of oxygen exposure can be controlled much more tightly than it could be in a barrel. If used in conjunction with oak alternatives (such as chips or staves), it can also help to integrate the influence of the oak.

However, care must always be taken because the increasing oxygen levels in the wine can provide a more favourable environment for spoilage organisms such as acetic acid bacteria and Brettanomyces. This is a relatively new technique and therefore research into which grape varieties or types of wines benefit from micro-oxygenation and how wines made by micro-oxygenation age in bottle over the long term (and whether there is any difference compared to the same wine matured in barrel) is lacking.

TEMPERATURE AND HUMIDITY

Wines are usually matured in stable, cool temperatures to slow down the rate of oxidation and the threat from spoilage organisms. White wines tend to be stored at 8–12°C (46–54°F), whereas red wines are stored a little warmer at 12–16°C (54–61°F) as they are less susceptible to the effects of oxidation. Stable, cool temperatures give a slower maturation than warm temperatures (e.g. 20°C / 68°F and above) due the effect of temperature on the various chemical reactions that happen between compounds within the wine. However, warmer temperatures do not simply speed up the ageing. The temperature determines what reactions can occur and how quickly various reactions will occur. Unfortunately, many of the reactions that benefit from warm temperatures are undesirable in terms of wine quality.

Some wine is generally lost through the maturation process in wooden vessels. Low humidity and warm temperatures increase the rate of wine loss. This is undesirable as it reduces the volume of wine to sell; barrels need topping up more often (greater cost through labour requirement) and risk of oxidation is increased (harmful for quality). Conditions of low humidity (under approximately 70 per cent) cause water to be lost at a greater rate than alcohol and, over time, this can lead to a higher alcohol concentration in the wine, which in many instances may be seen as undesirable.

For these reasons, wines are usually matured in cool cellars of constant temperature and humidity. Temperature- and humidity- control systems are common in modern cellars. Many traditional cellars were built underground for this same reason.

14.2. The Role of Wood in Maturation

Wooden vessels permit a slow exposure to oxygen during the wine's maturation (for more details see The Role of Oxygen in Maturation). However, a newly-made wood vessel also contains various extractable compounds, including tannins and many aroma compounds, which can have a significant influence on the wine. The level and type of compounds extracted from wood vessels depend on the following features of wooden vessels:

Age of the Vessel

New wood contains various extractable compounds. Each time the barrel is used, the amount of extraction decreases because fewer extractable compounds remain. (A barrel loses about 50 per cent of its new oak flavours during the first year of use.) By the time the vessel is on its fourth usage, it will contribute very little at all (but still allow ingress of oxygen). The flavours of new oak may be too dominant or clash with the flavours of some wines (particularly aromatic grape varieties) and a number of winemakers choose to use entirely pre-used barrels. Where new oak is used, it is typically as a proportion of the blend with wine that has been stored in pre-used barrels.

Size of the Vessel

Small vessels, such as *barriques* (225 l), hold a relatively small volume of liquid compared to the surface area of the vessel. This means that any extraction from the wood and exposure to oxygen is greater in small vessels than in large vessels, such as *foudres*.

Extraction of wood compounds and exposure to oxygen is greatest in small vessels.

Type of Wood

The most common type of wood used for winery vessels is oak. It can easily be shaped into a barrel and, importantly, makes containers that are watertight. Oak is also prized for its positive effects on the aroma/flavour and structure of the wine. Different species of oak have different characteristics, but it is possible for the same species of oak to show different characteristics depending on where it is grown.

Most winery oak vessels are made from European oak (typically French, but also Hungarian, Russian or Slavonian) or American oak. They are different species. Both European and American oak have significant levels of vanillin, which contributes aromas of vanilla and is usually a key part of the aroma/flavour of oaked wines. However, one of the key differences is that American oak has been found to contain much higher levels of lactones, which give aromas of coconut. In general, American oak tends to impart a greater intensity of aromas/flavours than European oak, which is often said to be subtler. By contrast, European oak tends to impart more tannin.

Another variable related to the type of wood is the tightness of the grain. A more tightly grained wood is the result of slower growth of the tree. For example, oak trees grown in continental climates, particularly Russia and Hungary, tend to grow slowly and therefore have the tightest grains. Wood with a tight grain slows down the extraction of compounds compared with more coarsely grained wood, and can alter what particular compounds are most extracted. For example, Hungarian oak, which tends to have a tight grain, is gaining popularity in New York State as an option that allows very gradual extraction of oak aroma compounds and tannins for their red wines (many of which are medium in alcohol, body, tannins and flavour intensity) so that they are not dominated by oak-derived characteristics.

The production process for barrels made from European oak is more expensive than that for American oak and this is part of the reason why French oak vessels are more expensive to buy than American oak vessels. The cost of American oak barrels tends to range from €300–€600, whereas that for French oak barrels tends to range from €600–€1200. European oak must be split to create staves, whereas American oak can be sawn. The ability to saw American oak means more vessels can be made from the same amount of oak. American oak also grows significantly quicker than European oak.

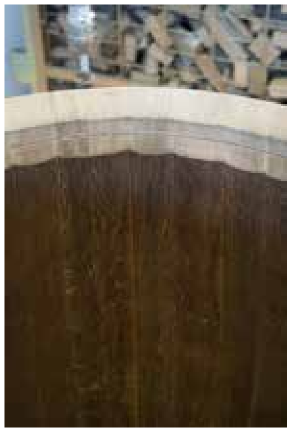
Although oak is by far the most commonly used wood in wine production, other types of wood such as chestnut, cherry and acacia, are occasionally used.

Production of the Vessel

The way in which the vessel is made has a vital influence on how it will affect the wine, at least for new or nearly new vessels. Before the vessel is constructed, the wood needs to be seasoned. This typically takes place outside and lasts 2–3 years. This lowers the humidity levels in the wood, reduces bitter flavours and increases some aroma compounds, such as those that give flavours of cloves. The barrel production process involves heating the staves so that they can be bent into shape. This heating process also transforms the tannins and aroma compounds in the oak. The temperature and length of heat exposure is referred to as the level of toasting, and barrels are typically categorised as either light-, medium- or heavy-toasted. Toasting contributes notes of spice, caramel, roasted nuts, char and smoke. Many of these characteristics are more pronounced at heavy levels of toasting. Many cooperages produce their vessels to a house style (including how long they season the wood, exactly how long and how intensely or gently they heat the wood for the different toast levels), and it is common for wineries to use barrels from a range of coopers to increase blending options.

Oak staves during seasoning. The darker staves have been seasoned for longer.

Fires are generally used to toast the inside of barrels so they can be bent into shape.



A newly toasted barrel

LENGTH OF TIME IN WOOD

The level and type of compounds extracted from wood vessels will also depend on the length of time that the wine is aged in the vessel. Very broadly, the longer the wine is aged in a wooden vessel the greater the extraction of compounds from the wood and the greater the exposure to oxygen. However, the rate at which various aroma compounds and tannins are extracted from the oak is not constant throughout the ageing process. Indeed some compounds are extracted more or less quickly at different periods of time and therefore longer ageing in wood can lead to a greater diversity of wood-derived aroma compounds. Extraction from wood is also highly dependent on other factors, for example the size of the vessel, type and age of wood, and environment in the cellar etc.

COST OF MATURATION IN WOOD

Barrel maturation is expensive for several reasons and therefore is typically only used for wines that are mid-priced, premium or super-premium. First, barrels are expensive to buy. Small barrels, such as *barriques*, do not hold much liquid, which means that hundreds of these vessels may be necessary, even in modest-sized wineries. Second, monitoring the wine in each separate barrel and performing any winemaking operations, such as lees stirring or racking, is labour intensive. Spoilage organisms such as Brettanomyces like to live in wood and therefore meticulous cleaning and sanitation is also needed. Finally, barrel maturation is a slow process, and therefore it is not uncommon to store the wine for 1–2 years or even longer. In most cases the wine is only sold when it is packaged and reaches the market, therefore return on investment is slow.

Wood chips

OAK ALTERNATIVES

For these reasons, producers of inexpensive and mid-priced wines may choose to use alternatives to barrels when the flavours of oak are desired. Alternatives include oak chips and oak staves. Oak staves can be attached to the inside of the stainless steel or concrete vessel, or they can float in the wine. Oak chips are generally placed in a permeable sack, which is left to soak in the wine. For both options it is possible to purchase different species of wood and different seasoning and toasting levels. They are much cheaper than purchasing a barrel, can be added to a large tank of wine (therefore less labour intensive) and their large surface area means they are quick to have an effect. The amount needed for the desired stylistic effect can also be finely tuned. Some winemakers use micro-oxygenation alongside oak alternatives to replicate the gentle oxidation of barrel maturation as this helps integrate the oak flavours.

It is difficult to define the influence of oak alternatives on wine style and quality compared to that of oak vessels. The precise effects depend, among other factors, on the source, size and toasting level of the wood, and whether micro-oxygenation is used alongside the addition of oak alternatives.

14.3. The Role of Lees in Still Wine Maturation

Lees describes the sediment that settles at the bottom of a wine vessel. It is made up of dead yeast, dying yeast and bacteria, grape fragments, precipitated tannins, nutrients and other insoluble compounds. The sediment that forms quickly after the end of fermentation (within the first 24 hours) is called gross lees. This is made up of the larger, heavier particles. Smaller particles may settle more slowly, and when they gradually form a sediment they are known as fine lees. The lees may be removed by racking (for more detail, see the box below, ‘Racking’). The first racking after fermentation generally removes the gross lees, and then subsequent periodic racking helps to manage the levels of fine lees. Some winemakers choose to keep the wine in contact with the lees. This has several effects.

After fermentation, the yeast cells die very slowly and break down (autolysis), releasing compounds that contribute flavours, body and texture to the wine. Some of these compounds bind with phenolic compounds in the grapes, reducing colour and softening tannins. Compounds from the lees also bind with certain extractable components of the wood, such as wood tannins and flavours, and can therefore reduce astringency and modify the flavours from the wood. The precise aromas/flavours that lees contribute are hard to define. A range of compounds are

Racking: maturing wine is moved from the top barrel to the clean barrel at the bottom.

released from the yeast, and these compounds can react with aroma compounds already in the wine. In white wines, where the effects of lees are generally more significant, descriptors can include yoghurt, dough, biscuit or toasted bread.

Lees ageing helps in the stabilisation of white wine against unstable proteins that can cause hazes. They also help to protect the wine from oxygen, helping to maintain a slow, controlled oxidation during maturation and lowering the need to use SO_2 during this time. However, if the layer of lees is too thick, particularly a problem for gross lees, it can produce volatile, reductive sulfur compounds. At certain concentrations, some of these compounds can add complexity (e.g. giving aromas of struck match and smoke). However, if not controlled, these compounds may contribute unpleasant aromas, such as the smell of rotten eggs, a fault termed reduction (see Faults). Lees provide nutrients for microbes, and therefore can assist the growth of lactic acid bacteria for malolactic conversion, but also encourage the development of spoilage organisms such as Brettanomyces.

For stirring of the lees, also as known as *bâtonnage*, see Specific Options for White Winemaking.

Lees ageing may increase the time the wine is stored at the winery before release, and this can increase the cost of the final wine. Wines aged on lees (particularly gross lees) need to be monitored regularly and may be stirred to agitate the layer of lees, which incurs a labour cost. For example, acceptable to good, inexpensive Rueda wines are finished, packaged and released from the winery shortly after the end of fermentation. Those of higher quality may be aged in tank on their lees for a few months before bottling, and generally are sold at slightly higher prices.

If the wine is being matured in barrels, there is unlikely to be any significant additional cost to lees ageing on top of that for barrel maturation. Lees stirring may be costly in terms of labour if large numbers of barrels need to be opened and individually stirred.

RACKING

Racking is the process of transferring wine from one vessel to another with the aim of removing sediment from the wine. This sediment may be gross lees, fine lees or other solid material in the wine that has fallen to the bottom of the vessel over time (e.g. tiny fragments of grape skin or tartrate crystals). The wine is removed from the original vessel through a valve near the bottom of the vessel (above the top of the sediment) and pumped or poured into the top of a new, clean vessel.

Racking can be an oxidative process. Some makers of red wine will increase the oxygen exposure by deliberately splashing the wine. It is also feasible to protect the wine from oxygen during this time, which may be preferential for aromatic or fruity wines, by using pressure from inert gas to push the wine out through a hose into the new vessel, which would have been flushed with an inert gas.

Racking may be carried out once or several times during the maturation process, depending on how long the wine is stored, whether it is stored with or without lees and whether the winemaker wants to increase oxygen exposure by racking.

14.4 Blending

In winemaking, the term ‘blending’ usually refers to the mixing together of two or more batches of wine, as opposed to the blending of two different substances (e.g. mixing *Süssreserve* into the wine to sweeten it). Blending can take place at any time during the winemaking process, but is most often carried out just prior to finishing and packaging. Blending may involve combining wines:

- from different grape varieties
- from different locations (from different vineyards, different regions or even different countries)
- from different grape growers or businesses that sell grapes, must or wine
- from different vintages
- that have been treated differently in the winery (e.g. white wine made from free run juice and white wine made from press juice, or wine matured in oak with wine that has been stored in stainless steel or concrete)
- that have been treated equally in the winery but are in different vessels for logistical reasons (e.g. unless a wine is made in very small quantities, wine fermented or matured in barrels will need to be blended together to make up the required volume).

What can and cannot be blended and in what proportions often depends on local legislation. For example, in the EU, for a wine to be labelled with a Protected Designation of Origin (PDO), 100 per cent of the grapes must come from the defined geographical area. Equally, Brunello di Montalcino DOCG must be made from 100 per cent Sangiovese, whereas in Chianti Classico DOCG, Sangiovese can be blended with other specified grape varieties.

There are several key reasons for blending wines, and one or more of these reasons may play a role in blending decisions:

Balance

Blending may help to increase or moderate the levels of certain characteristics of the wine to produce a wine that is better balanced, and in this way enhance quality. For example, a batch of wine from a warmer vineyard or that has been picked late may be blended with a batch of wine from a cooler vineyard or that has been picked early to fine tune acidity levels. The use of different grape varieties is a common way to enhance the balance of the wine, and there are many well-known blending partners. For example, Merlot

Blending trials in the production of rosé wines

provides body and ripe, plummy fruit to a blend with Cabernet Sauvignon, which, when not fully ripe, can be too astringently tannic on its own.

Consistency

Significant variation among bottles of a single product in a single vintage is usually seen as a fault. Therefore, blending can be necessary to ensure a certain volume of a consistent product. There are some wine styles where consistency is needed across different years. This includes most styles of Sherry and non-vintage sparkling wine, but also many inexpensive wines where the consumer may not expect nor accept significant vintage variation.

Style

Blending is also often fundamental in reaching a desired style. Even where vintage variation may be accepted and promoted, winemakers often make their wines to a certain 'house style' or want to create wines of certain quality levels within their range (e.g. a premium or super-premium wine for bottle ageing and a lower-priced wine (e.g. mid-priced) for earlier consumption). Equally, some rosés are made by blending red and white wine, and this method allows very precise control over colour and flavour profile (how much contribution the red wine makes).

Complexity

The blending of two or more parcels of wine may lead to a greater range of flavours, and in this way enhance the complexity and therefore quality of the final wine.

Minimise Faults

Blending may also be carried out to help reduce the presence of a wine fault. For example, if wine in one barrel is showing significant volatile acidity (see Faults), that wine may be sterile-filtered to remove acetic acid bacteria and then blended into a larger volume of un-faulty wine to lower the concentration and sensory perception of acetic acid.

Volume

In areas with small vineyard holdings, winemakers are likely to need to blend the wines from different vineyards to produce viable volumes of certain wines. Similarly, in poor vintages or in cases where the producer has minimal vineyard holdings, grapes, must or wine may need to be bought in to satisfy the needs of their customers.

Price

Many wines, especially those that are inexpensive or mid-priced, will be made to be sold profitably at a certain price point. In this case, blending different parcels of wine can help to create a certain style and quality. For example, Chardonnay is sometimes blended with grape varieties such as Trebbiano and Semillon. The latter two grapes are generally cheaper to buy than Chardonnay, keeping the price point of the wine low. As one of the most recognised grape varieties internationally, the inclusion of Chardonnay in the blend helps the wine to sell.

Of course, there are also reasons why a winemaker might choose not to blend certain grape varieties or parcels of wine. For example, a winemaker may choose to produce wine that comes from a single vineyard to maintain the character of the fruit and/or quality of wine coming from that particular vineyard. The term ‘single vineyard’ on the label can also make the wine seem more rare and distinctive from a marketing point of view. Additionally, some grape varieties have pronounced and distinctive aromas (such as Sauvignon Blanc and Riesling) and blending with other grape varieties may dilute the character of these grape varieties.

The blending process generally starts with blending trials using measuring cylinders and small volumes of wines to distinguish the proportion of each wine in the favoured blend before conducting on a much larger scale. This is a process that requires a high level of skill and experience. The blending process can be extremely challenging, especially when blending young wines that are destined for long ageing; the winemaker needs to estimate how the blend will develop in the future. Logistics and business also play a part; money is lost if volumes of wine are not used or sold on to other producers.

Blending is best carried out before stabilisation in case any instabilities arise from the blend; for example, tartrate stability is dependent on pH level, and this can be affected by blending wines with different pH levels.

Finishing and Packaging 15

Finishing a wine is preparing it to be put in its final packaging (glass bottle or other format) ready for sale. For the overwhelming majority of winemakers, the aim is to produce a clear and stable wine. To achieve this, the wines will be clarified and stabilised before being bottled and packaged. Finishing may also include other checks and actions; for example, to correct the level of dissolved oxygen or sulfur dioxide in a wine.

This chapter will explore the key techniques for clarifying and stabilising wine and examine packaging and transportation options. Common wine faults, and the importance of hygiene and quality control are also addressed.

Simplified check list: Getting your wine ready for bottling day

TIME	ACTION
4 months to 8 weeks ahead	Assemble final blend Full chemical analysis – alcohol, residual sugar, free SO_2, etc.
8 weeks ahead	Final adjustments: alcohol, acidity, tannins if desired
6 weeks ahead	Protein stability trial and if necessary fine with bentonite
4–6 weeks ahead	Test for tartrate stability and, if necessary, treat
4 weeks ahead	Check protein stability and tartrate stability again, treat as necessary
1–2 weeks ahead	Add sweetening agents e.g. grape concentrate, if using
72–48 hour ahead	Test filterability of wine
24 hours ahead	Adjust free SO_2
Bottling day	Adjust dissolved oxygen and CO_2
During bottling	Check dissolved oxygen (to ensure no pickup) and SO_2 levels regularly and keep samples of bottled wines for quality assurance purposes

(Source: Wine Business Monthly[1])

15.1. Post-Fermentation Clarification

In this book the term 'clarification' is used for all the processes, physical and chemical, that are used to make wine clear. The processes used to clarify grape must – particularly sedimentation and centrifugation – are also used to clarify wine. In addition, wine may be fined and filtered.

SEDIMENTATION

If wine is stored in cool cellar conditions, it will begin the process of clarification naturally, with suspended matter precipitating over time. The wine is allowed to stand and the particles with higher density than wine will form a sediment at the bottom of the container. The wine can then be racked off, leaving the sediment behind (see Racking in The Role of Lees in Still Wine Maturation).

The number of rackings required depends on shape of the container, the volume of wine and the available labour. The larger the storage vessel, the greater the number of rackings required to avoid a thick layer of sediment.

Some premium wines are clarified only in this way. Some winemakers believe that clarification by sedimentation avoids the potential loss of texture and flavour that may occur if the wine is fined or filtered.

As sedimentation takes time, this has a cost as the wine cannot be sold until it is clarified and ready to be released. This means that sedimentation is usually only suitable for premium or super-premium priced wines. However, if a wine is to be barrel-aged, then sedimentation will happen as part of the barrel ageing process.

In many cases, the winemaker will accelerate the process of clarification. In high volume production where the speed of processing wine is financially important, the wine will be clarified by a combination of the following options.

CENTRIFUGATION

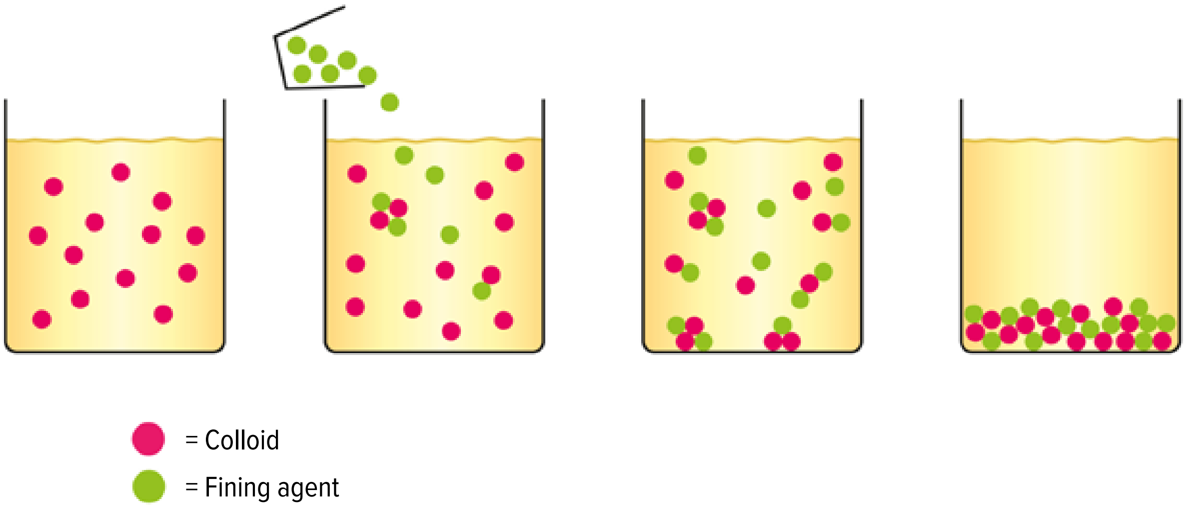
This is a rapid process that spins the wine at high speed to clarify it (see Clarification of Must). It can replace depth filtration and allow early bottling. It is very effective with wines with a lot of matter in suspension. It is only practised in high-volume wineries to spread the considerable cost of buying the machine.

FINING

Fining is a procedure in which a fining agent is added to speed up the process of the precipitation of suspended material in the wine. Fining agents can be of protein or mineral origin. Fining removes a small proportion of unstable colloids (microscopic particles too small to be removed by filtering) from the wine. It helps to clarify the wine and to stabilise it against the formation of hazes later in the bottle.

Winemakers conduct laboratory trials before using fining agents to ensure that the minimum effective amount is used. They then compare the fined sample with the original wine before proceeding. Many fining agents can remove desirable compounds from wine or make the wine unstable when too much is added (over-fining) and therefore it is important to add only the minimum effective amount.

In addition to clarifying the wine, many fining agents are able to offer solutions to other problems, such as the removal of harsh tannins in red wines or browning in white wines. The fining agent must have the opposite charge from the wine colloid to be removed. The fining agent and the colloid attract each other and form a solid large enough to be removed by racking or by filtration.



The opposite charges of the fining agent and colloid mean they attract each other and, as heavier particles, fall to the bottom of the liquid.

There are three categories of common fining agents:

- those that remove unstable proteins
- those that remove phenolics that contribute undesirable colour and bitterness
- those that remove colour and off-odours.

Fining Agent that Removes Unstable Proteins
Must and wine contain grape-derived proteins. It is not necessary to remove these in red wines as they bind with tannins, precipitate naturally and are removed when the wine is racked. However, the proteins in white and rosé wines can agglomerate into a visible haze if warmed up (e.g. in transit). This would be seen as a fault. As a result, these wines are often fined with bentonite.

Bentonite – A form of clay that adsorbs unstable proteins and unstable colloidal colouring matter. It has a minimal effect on the flavour and texture of wine. It does lead to some colour loss in red wines and produces large amounts of sediment, and so wine is lost when it is racked off. Bentonite can be used to fine must as well as wine.

Fining Agents that Remove Phenolics that Contribute Undesirable Colour and Bitterness
The fining agents listed in this section may be used in conjunction with bentonite for their own properties and to avoid risk of over-fining (which in itself could make the wine unstable).

Egg white – Due to its protein content, egg white is often used in fresh or powdered form. It tends to be used for high-quality red wines because of its ability to remove harsh tannins and clarify wine. It is gentle to the wine. As it is an allergen, it must be declared on the label if the wine is sold in the EU and other territories if present above a specified limit. It is also not suitable for vegan wines.

Gelatine – A protein collagen extracted from pork that aids clarification, removes bitterness and astringency in red wine and browning in white wine pressings. It must be added in the smallest effective amount as it is easy to over-fine with gelatine, stripping flavour and character, and creating the risk of a protein haze forming later. It is not suitable for vegetarian or vegan wine as it is derived from animals. Gelatine can be used to fine must as well as wine.

Casein – A milk-derived protein that removes browning from white wines and clarifies wines to some extent. It must be declared as an allergen on the label in a number of countries and is not suitable for vegans as it is derived from milk. Casein can also be used to fine must as well as wine.

Isinglass – A protein collagen that very effectively clarifies white wines, giving them a bright appearance. The smallest effective amount must be added to avoid potential for the formation of a protein haze later and the creation of a fishy smell. It is not suitable for vegetarian or vegan wines as it is derived from fish bladders.

Vegetable protein products – These are derived from potato or legumes and are suitable for vegetarian and vegan wines.

PVPP – Polyvinylpolypyrrolidone is an insoluble plastic in powder form that removes browning and astringency from oxidised white wine. It is a gentler fining agent than charcoal. It is rarely used on red wines, but can reduce astringency and brighten the colour.

Fining Agent that Removes Colour and Off-Odours

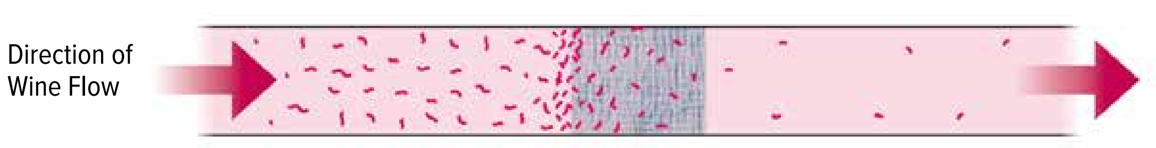
Charcoal – This removes brown colours and some off-odours. Care has to be taken as charcoal over-fines easily removing desirable aromas and flavours. One option is to treat only one batch of the affected wine and then blend it with the rest of the wine to reduce this effect.

FILTRATION

Filtration is a physical separation technique used to eliminate solids from a suspension by passing it through a filter medium consisting of porous layers that trap solid particles, thus making the liquid clear. Filtration is the most common way of clarifying wine.

There are two main types, depth filtration and surface filtration.

Depth Filtration
This method of filtration traps particles in the depth of the material that forms the filter. It can cope with fluid with many particles in it; for example, wine that has just been pressed or lees. Small particles are trapped within the many irregular channels through the filter. This type of filter does not block easily; however, it is not absolutely reliable because, if too much pressure is applied or if the filter is used for too long, some particles will make their way through the filter. In other words, it is not an absolute filter.



Diatomaceous earth – The most common form of depth filtration uses diatomaceous earth ('DE', also known as Kieselguhr), which, once it has been processed, is pure silica and inert. The DE is wetted and used as a filter medium. Wine is sucked by vacuum from the outside of a rotary drum, through the DE, to the inside of the drum.

Rotary vacuum filters use this method to filter very thick and cloudy wine (e.g. wine mixed with lees). It is an oxidative process as the drum is exposed to air. Enclosed DE filters do the same job, but can be flushed with an inert gas (e.g. nitrogen) to avoid oxidation taking place. DE comes in a range of particle sizes and thus can remove large or very small (e.g. yeast) particles.

Initial investment in machinery is an important consideration with DE, though the per litre cost after that is small. Used DE must be disposed of responsibly, which adds an additional cost.

Sheet filters – These are also known as 'plate and frame' or 'pad' filters. The wine is passed through a sheet of the filtering material. The more sheets there are in the filter, the quicker the

Diatomaceous earth

A rotary vacuum filter in action. The earth is stained red with wine.

A portion of wine flows through each sheet of the filter

wine can be filtered because any portion of wine only passes through one sheet. Very fine graded sheets can be used to remove any remaining yeasts at bottling.

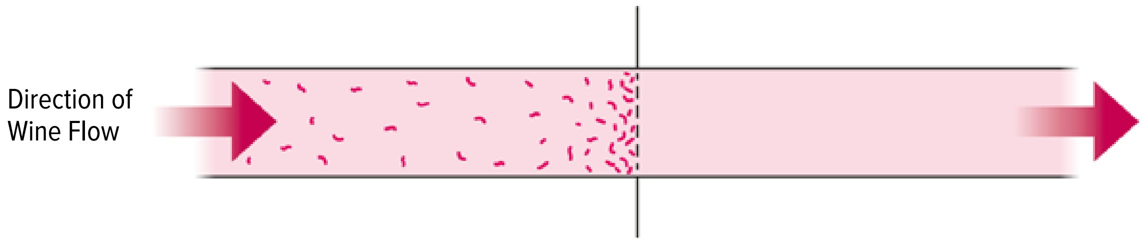
Sheet filter systems require investment initially (the frame must be very robust to withstand the pressures involved), although the cost of filter sheets is low. Trained personnel must operate them to work properly.

Surface Filtration

A surface filter stops particles that are bigger than the pore size of the filter from going through. They are often termed absolute filters. There are two types of surface filter:

Membrane filters are often used for sterile filtration, the removal of any yeast and bacteria.

Membrane filters – These filters, sometimes also called cartridge filters, catch particles that will not go through the pore size of the filter. They are slower than using a depth filter as the pores are smaller, often less than 1 micron. For the same reason, wine must be pre-filtered first (e.g. by depth filtration) as, otherwise, membrane filters can easily get blocked. They are usually used as a final precaution immediately before the wine is bottled to ensure that the wine is completely clear and microbiologically stable. This is sometimes called sterile filtering, but this is not entirely accurate (as the filter size can be over 1 micron); the point is that yeasts and bacteria have been removed and therefore the wine is microbiologically stable. In contrast



to depth filters, the initial investment is small, but the cartridges are expensive and an ongoing cost. This is a very common form of filtration during the bottling/packaging process.

Cross-flow filters – These are also known as tangential filters. They allow wine to pass through the filter while uniquely cleaning the surface of the filter as it works. Solid particles cannot pass through the filter. Cross-flow filters can filter wine with a high load of particles or lees very quickly. There are no replacement sheets, cartridges or earth to buy or dispose of. However, the machines are expensive, making them more suitable for large and/or well-funded wineries.

Cross flow filters do not clog as quickly as membrane filters.

As with fining, some wine critics and winemakers believe that filtration can negatively affect a wine's character, especially by stripping it of texture. For this reason, some wines are bottled unfiltered. However, others reject this view. They also argue that the wine will recover from the shock of filtration after some months and, further, that there is much less chance of wines developing faults as bacteria and yeasts have been removed. The argument continues that the fruit and the *terroir* express themselves better in a correctly fined and filtered wine.

15.2. Stabilisation

The term 'stabilisation' is used to refer to several winemaking interventions which, if not carried out, could lead to undesired effects in the finished wine. This includes tackling the potential for unwanted hazes, deposits in the bottle and rapid changes in the wine (browning). Tartrate stability, fining and filtering all contribute both to clarification and stabilisation. For fining and filtering see Post-Fermentation Clarification.

PROTEIN STABILITY

Fining with bentonite is the key procedure to ensure protein stability (for more details see Fining in Post-Fermentation Clarification).

TARTRATE STABILITY

Tartrates, principally potassium bitartrate and, less frequently, calcium tartrate, are harmless deposits of crystals that can form in the finished wine. As many customers will regard these crystals as a fault, all high-volume winemaking and many smaller scale operations will seek to prevent this from happening. There are several options for the winemaker:

Cold Stabilisation

Traditionally, the problem of tartrates was dealt with to some extent by the wine being kept in a cold cellar for months through the winter. More reliably, wine can be held at –4°C (25°F) for around eight days so that the crystals form before bottling (because tartrates are less soluble at cold temperatures) and can then be filtered out. Cold stabilisation requires the equipment and the cost of energy to refrigerate the wine. Colloids must be removed by fining (see Fining) before this process as they could prevent the crystals from forming at this stage. This process only removes the more common potassium bitartrate, not calcium tartrate.

Frost on a tank that is undergoing cold stabilisation

Contact Process

This is a quicker, continuous, more reliable and cheaper form of cold stabilisation. Potassium bitartrate is added to the wine and speeds up the start of the crystallisation process. Wine is usually cooled to around 0°C (32°F) and after one or two hours the resulting crystals are filtered out.

Electrodialysis

This process uses a charged membrane to remove selected ions. After high initial investment, the total costs are lower than cold stabilisation and the process uses less energy and is faster. It removes both potassium and calcium ions and, to a smaller extent, tartrate ions. It is allowed in the EU and other territories for tartrate stabilisation.

Ion Exchange

This process does not remove tartrates, but, instead, it replaces potassium and calcium ions with hydrogen or sodium ions, which will not drop out of solution. This process is not allowed in some territories as it replaces the potassium with sodium, which is not conducive to health. However, the resulting levels in wine are well below the legal limit.

Carboxymethylcellulose (CMC)

This cellulose is extracted from wood and prevents tartrates from developing to a visible size. CMC is widely used on inexpensive white wines, but is not suitable for red wines as it reacts with tannins (rendering it ineffective) and causes haze. It is much cheaper than chilling. CMC keeps wines stable for a few years.

Metatartaric Acid

Adding this compound prevents the growth of potassium bitartrate and calcium tartrate crystals, reducing the need for cold stabilisation. However, the compound is unstable, and its positive effect is lost over time, especially when wine is stored at high temperatures (25–30°C / 77–86°F), meaning it is best used for wines designed for early consumption. It is a quick and easy process that tends to be used more for red wines as for white wines CMC is more effective and long-lasting.

MICROBIOLOGICAL STABILITY

Wines with residual sugar are potentially liable to start to re-ferment in the bottle. This can be dealt with by removing yeast through sterile filtration (see Filtration in Post-Fermentation Clarification). The alternative is to add sorbic acid and SO_2, which inhibits yeast from growing. A drawback is that some people can smell the effects of sorbic acid at very low levels. (This has become less prevalent as a method since the widespread availability of sterile filtering.)

Very few microbes can live in wine with its low pH and high alcohol levels. Exceptions include lactic acid bacteria, acetic acid bacteria and Brettanomyces (a spoilage yeast). Wines with lactic acid bacteria where malolactic conversion has not been carried out or completed are liable to malolactic conversion starting up again in the bottle. (This would result in cloudiness in the bottle.) The solutions here are to ensure that malolactic conversion has been completed or to filter the wine to remove the bacteria. If Brettanomyces is a problem, wine can be treated by filtering or with DMDC (dimethyl dicarbonate, commercial name: Velcorin) before bottling, which inactivates Brettanomyces (for more details on Brettanomyces see Faults).

15.3. Finishing Options

Before final finishing options are carried out, the winemaker will make a full chemical analysis; this will measure, at least, alcohol, residual sugar and free SO_2. In the light of this analysis, final adjustments will be made. Within the last few hours before bottling levels of dissolved oxygen and CO_2 will also be checked.

ADJUSTING THE LEVEL OF SULFUR DIOXIDE

Winemakers routinely check the level of SO_2 and adjust it before bottling. They must ensure that the level of SO_2 is within legal limits. Both the total SO_2 and the free SO_2 are measured, the latter being the part that contains molecular SO_2, which is the effective part.

Many factors will affect the levels of SO_2 in wines at the point of filling, including winemaking approach (see Approaches to Winemaking), wine style (white, red, sweet), pH and intended drinking period (early consumption vs cellar ageing). However, in general, the amounts of free SO2 are:

- white wine – 25–45 mg/L (lower than for red wines due to lower pH)
- red wine – 30–55 mg/L
- sweet wine – 30–60 mg/L

REDUCING DISSOLVED OXYGEN

Oxygen dissolved in wine can accelerate the speed of ageing of the wine and thus reduce its shelf life. If the levels of oxygen are found to be too high, it can be removed by flushing the wine with an inert gas to remove it, a process called sparging.

ADDING CARBON DIOXIDE

A small amount of CO_2 may remain in wine after finishing and packaging. However, especially for inexpensive youthful white and rosé wines, some winemakers will prefer a tiny bit of spritz from CO_2 in the bottled wine for added freshness. If desired, CO_2 is added just before bottling.

15.4. Faults

Most present-day wine is technically fault-free because of the care taken at every stage of the production process – sorting to exclude damaged or mouldy fruit, exclusion of oxygen at key points in the process, temperature control, scrupulous hygiene in wineries, stabilisation, final adjustment of SO_2, fining and filtering and care over bottling. Nonetheless, some wine faults continue to be seen.

CLOUDINESS AND HAZES

Wines can be less than perfectly clear for several reasons. This can be due to the growth of yeast or bacteria in wine coupled with failure to filter adequately. The remedy is better hygiene in the winery, pre-bottling chemical analysis and, as necessary, filtering wine to remove yeast or bacteria before bottling. Alternatively, cloudiness may be due to poor filtering of wine (e.g. pumping wine at too high a pressure through a depth filter so that some unwanted molecules pass through the filter).

Cloudiness can also be due to a protein haze where fining is not effective, where the wrong type of fining agent has been used or the wine has been over-fined (see Fining in Post-Fermentation Clarification). This results in unstable proteins remaining in the wine, causing it to go hazy after the wine has left the winery or is with the final consumer. The remedy is to fine correctly and conduct analysis after fining.

TARTRATES

Tartrates are colourless or white crystals in the bottom of bottle that can be mistaken for fragments of glass. This can be seen as a fault by consumers, while knowledgeable drinkers may know that this is a natural process triggered by low temperatures and is completely harmless to health and wine quality. Most inexpensive and mid-priced wines are stabilised before release from the winery (see Stabilisation), but occasionally this is not entirely successful.

RE-FERMENTATION IN BOTTLE

Consumers may regard visible bubbles or spritz in wine as a fault. If it is accompanied by cloudiness, it would indicate unwanted re-fermentation in the bottle, which points to a failure to stabilise and clarify/filter the wine adequately. Some wine styles purposely include a low level of spritz (e.g. Muscadet sur lie or Vinho Verde). Some inexpensive and mid-priced white wines will have a small amount of CO_2 added before bottling to preserve and enhance freshness.

CORK TAINT

This is associated with a very unattractive, mouldy, wet cardboard smell, and additionally reduces the fruit character and shortens the finish of wines. For approaches to reducing or eliminating cork taint, see Packaging and Closures.

OXIDATION

This is the result of excessive exposure to oxygen either in the winemaking process or once in bottle or other container. The latter can be due to faulty bottling, poor quality corks or plastic closures, or simply keeping wine for too long if it is not of a quality to age. The effect is that the wine becomes prematurely brown in colour with a loss of primary fruit and then a vinegary smell.

VOLATILE ACIDITY

All wines have volatile acidity, but excessive amounts give a pungent smell of nail varnish and/or vinegar. This is due to the activity of acetic acid bacteria, inadequate levels of SO_2 and excess exposure to oxygen. The threat can be reduced by sorting fruit to exclude damaged grapes, scrupulous hygiene in the winery, keeping vessels topped up, careful racking (to avoid excessive exposure to oxygen) and maintaining adequate SO_2 levels.

REDUCTION

Reduction is associated with sulfur-like odours that range from onion to rotten eggs. The smells are caused by high levels of volatile, reductive sulfur compounds. Depending on the sulfur compounds present and concentration of these compounds some of their aromas (e.g. struck match and smoke) can give complexity to wines. However, at higher concentrations they produce undesirable aromas (e.g. rotten egg) that will always be regarded as a fault. These sulfur compounds can be produced by yeast under stress (due to low nitrogen levels) in the winemaking phase. Reduction also can be due to the near complete exclusion of oxygen during ageing in closed vessels, especially when lees ageing. Sometimes these odours evolve when wine is closed with the impermeable type of screw cap.

Reduction can be avoided by making sure yeast is not stressed. This is done by ensuring it has sufficient nutrients and oxygen, and that the must is at an adequate temperature. SO_2 may need to be lowered, especially if the closure used allows very little oxygen ingress (see Options for Closures).

LIGHT STRIKE

Light strike is caused by UV radiation and certain wavelengths of visible light reacting with some compounds in the wine to form volatile sulfur compounds, giving odours such as dirty drains. Wines that are left in direct sunlight are most at risk, but wines that are placed near fluorescent lighting e.g. in displays in retailers are also at risk. Choice of packaging can also be a factor. Wines packaged in clear glass are most likely to be affected, whereas dark glass (green, and particularly brown) provides more protection.

BRETTANOMYCES

The activity of Brettanomyces yeast produces a range of off-aromas including animal, spicy or farmyard smells. Some tasters think it can add complexity to red wines if at a low level. At higher levels it is clearly a fault in which the off-flavours dominate, fruity flavours are reduced and the acidity or tannins of wine becomes more prominent.

Once a winery is infected by Brettanomyces, it is difficult to eradicate, especially as wood can host the organism and be very difficult to clean effectively. It can be present in old or new barrels.

The key ways to avoid Brettanomyces are:

- excellent hygiene
- maintaining effective SO_2 levels
- keeping pH levels low and keeping the period between the end of alcoholic fermentation and malolactic conversion as short as possible so that SO_2 can be added as soon as possible.

If wine has been affected by Brettanomyces if can be treated either by filtration or with DMDC (dimethyl dicarbonate, commercial name: Velcorin) before bottling, which inactivates Brettanomyces.

15.5. Packaging and Closures

Glass bottles finished with cork remains the most popular package and closure for wine. However, the winemaker must pay particular attention to oxygen management when packaging and choose the packaging and closure for the finished wine.

Considerations include its place in the market (intended for early sale and consumption or as a wine that potentially may have a long life ahead of it) and the markets in which it will be sold.

OXYGEN MANAGEMENT WHEN PACKAGING

In addition to maintaining high standards of hygiene, the most important consideration when bottling or filling other containers is oxygen management. This is because the amount of oxygen in the final container will determine the shelf life and expected development of the wine. Too much oxygen will lead to premature browning and oxidised characters (loss of fruit, development of off-flavours including bruised apple). Too little oxygen may lead to reductive characteristics (e.g. onion, rotten eggs).

Because of all these factors, winemakers are paying increasing attention to limiting oxygen uptake in filling bottles or other containers (e.g. by flushing the head space with an inert gas before closing the bottle) and to the oxygen transmission rate (OTR) rates of the closures chosen.

Winemakers measure what is referred to as the total package oxygen. This is the combination of:

- the amount of dissolved oxygen in the wine
- the oxygen in the head space (below the cork or other closure) – usually the greatest contributor
- the amount of oxygen in the cork or other closure
- the OTR of the cork or closure.

OPTIONS FOR PACKAGING

In most markets glass bottles are still the overwhelmingly preferred option for the packaging of wine. The two main exceptions would be:

- producer markets (e.g. France) where inexpensive plastic (PVC) containers are used to collect wine from a local winery for short term storage and early drinking
- the dominance of bag-in-box in some markets, such as the Swedish market (nearly 60 per cent)[2].

Different glass (left) and plastic (right) bottling formats

Glass

The advantages of glass are:

- It is inert and conveys no taint to the wine.
- Bottles can be delivered to wineries in a near sterile condition, having been shrink-wrapped when still hot.
- It is inexpensive to manufacture and comes in a range of colours.
- In principle it is 100 per cent recyclable, but some colours are easy to recycle, others less so.
- Glass remains the best packaging option for the ageing of wine as it is impermeable to oxygen.

However, there are significant disadvantages too:

- Glass has a high carbon footprint initially because of the heat needed to manufacture it.
- It is heavy to transport, again contributing to its carbon footprint, especially if it is transported thousands of kilometres/miles to its final market.
- It is fairly fragile.
- Glass bottles are rigid; therefore, once a bottle of wine has been partly drunk, air fills the headspace and the wine is subject to rapid oxidation.
- Wine packed in clear bottles can be spoiled by light strike from fluorescent (e.g. in supermarkets) and natural light, producing sulfur-related off-aromas. Green bottles give better protection and brown still better.

Plastic

PET (polyethylene terephthalate) is a form of plastic that is light (about 1/8th the weight of glass), tough, inexpensive and, in principle, recyclable. It must be lined with a barrier to reduce the ingress of oxygen and therefore give a reasonable shelf life. PET can be used for range of sizes, including standard bottle size or the single serve RTD ('ready to drink'). It is well suited to wines with a limited shelf life and for quick consumption and in informal settings (outdoor eating, travel) or on planes where breakage is a hazard. Special filling equipment is required as the PET bottles are inflated at filling.

Bag-in-box

This consists of a cardboard box that houses a flexible bag inside. It is usually made of a very thin aluminium foil (which acts as a barrier to oxygen) covered on both sides by a suitable plastic. Alternatively, the bag can be made from a plastic that gives some protection from oxygen and is resistant to cracking, unlike aluminium foil.

The advantages of this packaging include flexible pour size (one or more glasses), good protection from oxygen after wine has been poured (the bag collapses inside the box) and the availability of a range of sizes from 1.5–20 litres, making it suitable for home and commercial use. The boxes are easy to store (they are less fragile than glass and can easily be stacked) and have low environmental impact (light to transport, can be recycled).

The wine must have a slightly higher SO_2 level than in glass to counter oxidation, a low dissolved oxygen level, no head space and low carbon dioxide (the last to avoid the bag bulging). Producers must use a high- quality tap as this is where most oxygen ingress occurs.

From left to right: bag-in-box, ‘brick’ and pouch

Shelf life is in the range of 6–9 months depending on the quality of the manufacture, although the best may protect wine for up to a year. As noted, this is very successful in certain markets: Australia, where it was pioneered, and in Sweden.

‘Brick’

Often referred to as a Tetra Pak, after the leading manufacturer, this is made of paper card with plastic layers and an aluminium foil layer that excludes oxygen and light. The package can be entirely filled with wine, thereby excluding oxygen. It has been accepted by consumers at lower price points and does well in markets where price is a major driver (e.g. Germany). More attractive contemporary designs are appearing. The filling equipment is a big investment, and some producers outsource the filling of bricks.

Pouch

Pouches are similar to the bags inside bag-in-boxes. They are available in larger (e.g. 1.5 litre) and single serve sizes.

Can

The ring-pull can offers many advantages as a package for wine to be consumed early: it is light weight, robust, easy to open, impermeable to oxygen and recyclable. The aluminium has to be lined with a plastic to avoid being attacked by the acidity of the wine. Packaging companies continue to experiment with cans which may prove attractive in the RTD market. The filling equipment is a big investment, and producers will generally outsource the filling of cans. Currently, producers are mainly using this packaging option for inexpensive and mid-priced wines.

OPTIONS FOR CLOSURES

All containers used for wine need a closure. The ideal closure would combine the following properties:

- protect the wine from rapid oxidation
- be inert so that it does not affect the quality of the wine adversely
- be easy to remove and to re-insert
- be cheap, recyclable and free from faults.

Cork continues to be the most popular closure (at around 60 per cent of wine bottles), but it now has several competitors. The most common closures for bottles are:

Natural Cork

Cork is light, flexible (while requiring a specialised tool to remove it), inert (but can house harmful fungi) and comes from a renewable, natural resource. It mainly has a very positive image in the eyes of consumers and opening a bottle with a corkscrew is seen as part of the enjoyment of wine.

Cork comes in a range of length and quality, and a winemaker must decide what is appropriate to the wine and its intended price. Shorter, lower-grade corks are cheaper and may be used for inexpensive wines intended for short term consumption; better quality, longer corks are used for higher-priced wines that may be aged in bottle.

There have been two issues about natural cork. First, corks can taint wine through the creation of TCA (2,4,6-trichloroanisole) and other related compounds, resulting in an unpleasant smell of mould or wet cardboard that also suppresses the fruit character. The estimate is that this affects 3–5 per cent of bottles closed with cork.

Second, while cork is generally a good oxygen barrier, natural corks have variable rates of oxygen ingress. As a result, the same wine bottled in cork-sealed bottles ages at different rates in the medium to long term due to the variable rate of oxygen ingress of the individual corks.

Natural cork is cut from the bark of a cork tree

The incidence of cork taint has led to two developments: the creation of alternative closures, and efforts by the cork industry to reduce or eliminate the incidence of cork taint. Approaches to the latter include:

- cleaning corks with steam extraction (championed by Amorim, the largest world producer of cork products)
- creating closures from recomposed cork particles that have been cleaned and reconstituted with a plastic; the result is a closure that looks and behaves like natural cork (championed by Diam) (This is a form of a technical cork.)
- much more rigorous quality control during cork production, including high-cost high-tech solutions (e.g. gas chromatography) to check for the presence of TCA
- introducing an inexpensive polymer barrier between the cork and the wine. This is an impermeable membrane between the cork and the wine that gives a wrinkled appearance on the end of the cork and excludes any aromas reaching the wine from the cork.

Technical Corks

These are made from cork that has been subjected to a manufacturing process and are designed to address the issues of cost and avoiding cork taint. The cheapest option is the agglomerated cork in which cork granules are glued together. These are only suitable for inexpensive wines intended to be drunk quickly after purchase. A further development of this is a one-plus-one cork, in which the largest, central, section is inexpensive agglomerate, but it is finished with a disc of natural cork at both ends. Diam corks have already been described. They are available with different oxygen-ingress rates so that a winemaker can choose a closure for wines to be drunk in the short term or for ageing.

Synthetic Closures

Popularly known as plastic corks, synthetic closures are made of food- grade plastic with a silicone coating. The cheapest are moulded closures; however, their relative rigidity makes

A selection of technical and synthetic corks

them more difficult to re-insert in the bottle. Extruded closures addressed this issue and are more elastic, being made by an external firm layer of plastic covering a plastic foam.

Moulded closures offer limited protection from oxygen ingress and therefore are only suitable for wines for consumption within months of bottling. Extruded closures now come in a range of oxygen-ingress rates, with leading producer Nomacorc claiming that its top line is suitable for extended ageing in bottle.

A further issue with plastic closures is flavour scalping, the loss of some flavour intensity because plastic absorbs some flavour molecules. This process has been demonstrated in laboratory conditions, but it is not known if it occurs to an extent that would be perceived by a consumer.

All the options reviewed thus far are 'in bottle' closures. They can be implemented on traditional bottling lines set up for natural cork and traditional bottle sizes and shapes. There is therefore no additional cost or logistical issues (having the right type of bottle available) in switching between them. This is not the case with screwcap or glass stoppers.

Screwcap

The screwcap is an aluminium closure rolled onto the outside of a bottleneck that has been specially designed for this purpose. It therefore requires different closure equipment from in-bottle closures. The seal with the wine is a wad of either tin (impermeable to oxygen) or Saran (a form of plastic with low permeability to oxygen, better known for its use as cling film).

An issue with screwcaps, especially with tin linings that permit almost no oxygen ingress, has been that wines can become reductive after bottling, with an unpleasant onion-like smell on first opening. To avoid this issue, winemakers using screwcaps need to adapt the final wine to have slightly lower SO_2 levels.

From a consumer's point of view, a screwcap can be opened without a special tool and screwcaps eliminate the possibility of taint from corks. (TCA can be picked up from other sources, e.g. infected barrels, although this is far less prevalent than from corks.)

Consumer attitudes towards the screwcap are markedly different between those countries where this closure has a high degree of acceptance for all but the finest wines (e.g. Australia, New Zealand, UK) and those where the screwcap is still seen as synonymous with inexpensive wines (USA, although attitudes are beginning to change there, China). The winemaker therefore must take the intended market into account when making decisions about closures, and for this reason many larger wineries offer the same wine with both screwcap and cork.

Glass Stoppers

Often referred to by the Vinolok brand name, glass stoppers are a closure made from glass, but where the actual seal is formed by a plastic ring. Wine can be stored for similar lengths of time as under closures such as natural cork;[3] however, special bottles must be used to ensure a perfect fit. The stoppers look attractive and are as expensive as top-quality cork, and therefore are only suitable for premium and super-premium wines.

15.6. The Packaging Operation

If a finished wine is to be transported any distance, it has to be packaged in a bottle, bag-in-box, can or other container before it can be sold. This operation is referred to in this study guide as packaging.

Before packaging, pre-filling analysis is carried out to check that the wine:

- is stable;
- meets any technical specification set by the winemaker or the client (the details of a typical specification are set out below);
- conforms to the required legal standards such as limits on SO_2 and trace metals (e.g. copper and iron).

The analysis will include testing for issues that have been addressed already, e.g. protein instability. However, if the pre-filling analysis shows any remaining issues, the wine will be treated again. Within the last few hours before filling, levels of dissolved oxygen and CO_2 will also be checked and corrected if necessary.

The technical specification is a list of the wine's main measurable chemical parameters. If the wine is being made for a retailer, for example for a private label for a supermarket chain, it will form part of the purchasing contract. This ensures that the wine remains the same—or within the limits specified—from year to year. The specification will typically include limits or ranges for:

- free and total SO_2
- volatile acidity
- alcohol content
- residual sugars
- total acidity
- pH
- malic acid and lactic acid
- total dry extract
- tartrates and proteins (stability analysis)
- turbidity (the amount of particles in suspension and therefore how clear a wine is)
- various minor acids: sorbic, ascorbic, metatartaric, citric
- trace metals such as copper, iron, potassium, calcium, sodium
- dissolved oxygen
- CO_2
- microbial populations (various strains of yeast, bacteria)
- taints, e.g. TCA

These analyses may be done in the winery if it has invested in the necessary laboratory equipment. Larger producers increasingly have installed expensive high technology options such as High Performance Liquid Chromatography (HPLC) and Fourier Transform Infrared Spectroscopy (FTIR) as results can be returned in a matter of minutes. Alternatively, samples may be sent to an external laboratory and a fee paid.

If the wine is to be transported in bulk, e.g. in an ISO tank or flexitank, for long-distance travel, the analysis also provides a standard against which the wine can be checked on arrival.

OPTIONS FOR FILLING BOTTLES

Bottles are typically delivered to the winery shrink wrapped with the plastic that was applied while the bottles were still warm from the production process. As a result, the bottles arrive in a near sterile condition.

Traditional Bottling

For centuries, wine has been bottled with minimal treatment. Provided a wine is fermented to dryness, the acid, alcohol and lack of nutrients creates a hostile environment for microbial growth. Where wines have been matured over an extended period of time (6–12 months) in a cool cellar, they will normally become clear by natural processes. Producers then siphon the wine directly to bottle and seal it with a cork.

Modern Bottling Techniques

On a modern bottling line, before being filled with wine, the bottles are rinsed with sterile water and steam-cleaned (i.e. subject to being heated to 82°C/180°F for 20 minutes).

Modern bottling is often referred to as 'aseptic bottling' (free from microorganisms). This involves the elimination of any potentially harmful yeast and/or bacteria from a wine either by:

- sterile filtration, which physically removes the microorganisms. This may be referred to as cold bottling as no heat is applied to the wine and the bottling is carried out at ambient temperature.
- heat treatments, which kill the micro-organisms. For example, one option is flash pasteurisation in which the wine is heated to a high temperature (80°–90°C/175°–195°F) for a few seconds and then cooled rapidly. The wine is then bottled.

While heat treatment was typical of large volume winemaking in the past, today the great majority of large wine companies use sterile filtration to remove microorganisms from the wine immediately before bottling. The advantage of cold bottling is that no heat is applied to the wine and therefore there is no deterioration of quality or premature ageing of the wine. The disadvantages are the considerable amount of investment required (in comparison to flash pasteurisation) and the need to employ the highly-trained staff to supervise the technology used. In both sterile filtration and flash pasteurisation, care has to be taken to sterilise the bottling line (pipes, fillers, etc.) to avoid microbial spoilage after filtration or heat treatment and also to ensure no oxidation takes place during the filling operation.

FILLING OTHER CONTAINERS

Bag-in-box and pouches require their own dedicated filling lines. The slight permeability of these packaging options to oxygen means that particular attention is paid to minimising oxidation during packaging to maximise the limited shelf life of these products. Due to the need to avoid re-fermentation (and especially if the wine has any residual sugar), the wine is sterile filtered and sterile packed. The bags are put under vacuum before filling. The wine must have a slightly higher SO_2 level than in glass to counter oxidation, a low dissolved oxygen level, no head space and low carbon dioxide (the last to avoid the bag bulging). For 'bricks', the packaging material is sterilised with UV radiation and the filling takes place in a sterile enclosure. Packaging in cans is a specialist operation typically done by an external partner.

15.7. Post-Bottling Maturation

Many wines, usually those based on fresh, fruity flavours, are best consumed within a year of bottling as maturing them results in a loss of their primary fruit flavours. However, there are many wines that can develop positively in bottle for several years and are not at their best in the years immediately after bottling. Some notable examples include Vintage Port, premium German Rieslings and *crus classés* Bordeaux. Some PDOs (e.g. Chianti Classico Riserva DOCG) specify a minimum length of bottle maturation before the wine can be distributed and sold. Post-bottling maturation at the winery may increase costs, as the winery must have/build suitable storage conditions and pay insurance while the wine is in their ownership.

Glass bottles are the standard packaging used for wines that are intended for further ageing. Other types of packaging, such as plastic bottle or bag-in-box, are slightly permeable to air and therefore are only suited to wines intended to be drunk young. Glass bottles are impermeable to air; however, it is possible for a small amount of air to ingress through the closure.

A lot of research has been carried out on different closures and rate of transmission of oxygen through the closure and it is now possible to select a closure (natural and technical corks and screwcaps) based on the oxygen transmission rate (OTR) desired. However, the number of variables (different grape varieties, different winemaking practices, etc.) that could affect how oxygen influences the wine, and how much oxygen is positive or negative, are issues that are still not fully understood. Equally, the amount of oxygen trapped in the headspace of the bottle at the time of bottling and the amount of oxygen dissolved in the wine at the time of bottling both have significant impact on the development of the wine in the bottle. Generally, a wine that has a high level of dissolved oxygen, is bottled with a large headspace of oxygen and/or with a high OTR closure is likely to oxidise more quickly than those more protected from oxygen.

Similar to pre-bottling maturation, a small amount of oxygen can be positive, allowing the wine to develop slowly in bottle. Primary aromas become tertiary aromas, tannins soften, any aroma compounds from oak become better integrated and the colour moves towards brown and becomes paler in red wines and darker in white wines. However, rapid or excessive oxidation is perceived as a negative. By contrast, if the wine has been exposed to too little oxygen before bottling, this can lead to the formation of volatile, reductive sulfur compounds in the bottle. At low levels these compounds can give some aromas that may be perceived as positive, such as struck match and smoke. At high levels they give rotten egg and other unpleasant aromas (see Reduction in Faults).

It is widely agreed that any ageing time should be spent undisturbed in a cool dark place, with a constant temperature, ideally around 10–15°C / 50–59°F. There should also be constant humidity and, if sealed with cork, the bottles should be stored lying on their side, so that the corks remain moist and an optimum seal is maintained.

15.8. Quality Control Procedures

HYGIENE IN THE WINERY

Virtually all modern wineries regard hygiene as a very high priority. High standards of hygiene give the winemaker the maximum chance of producing sound wine and of avoiding contamination from organisms that could spoil wine.

New wineries are designed to facilitate cleaning. This includes the use of easy-to-clean stainless steel, hard non-porous floor surfaces that slope to aid drainage and equipment being located so that it can be reached to be cleaned. Particular attention must be paid to hard-to-reach areas: underneath equipment or dead-ends of pipes. Pores in oak continue to be a potential source of spoilage organisms.

There are three procedures for hygiene:

- **Cleaning** – the removal of surface dirt
- **Sanitation** – the reduction of unwanted organisms to acceptably low levels, typically with water and a detergent or other sanitising agent and/or steam; it is reckoned that for every litre of wine produced, 10 litres of water are used, most of this for hygiene purposes
- **Sterilisation** – the elimination of unwanted organisms; for example, from high risk areas such as the filler heads of bottling lines – these can be sterilised with high strength alcohol or with steam.

Wineries have a detailed schedule setting out a programme of daily, weekly and monthly actions for cleaning, sanitation and, where applicable, sterilisation.

Quality control during the transportation of wine is dealt with under Transportation of Wine.

QUALITY CONTROL AND QUALITY ASSURANCE

'Quality control' in a winery is the set of practices by which the company ensures a consistently good quality product. 'Quality assurance' is a broader concept that includes quality control. It is the complete way a business organises itself to deliver a good product consistently and to protect itself from legal challenge. This includes planning, management systems and the monitoring and recording of key standards from vineyard to bottling of wine. By having a comprehensive system in place, a producer can show that they have taken all reasonable precautions to produce a safe product for the consumer – and have the documentation to be able to demonstrate it.

HACCP

HACCP (Hazard Analysis of Critical Control Points) is a common approach to quality assurance regarding significant threats to the safety of consumers and to the reputation of a wine company. It is a process in which the company identifies all the possible hazards that could affect final wine quality; in effect, everything that could go wrong. For each hazard, the HACCP document will state how serious it is, how it can be prevented and how it can be corrected.

To give an example, in a bottling line there is a possible hazard of glass breaking and ending up in a bottle of wine, a threat to the health of the consumer. In a highly mechanised winery, the preventive action plan would be to have a system in place to detect a broken bottle and to push out the next three neighbouring bottles automatically to remove bottles that could have been affected by shards of glass.

HACCP is carried out by the company producing the wine with no checking or auditing by a third party. However, the HACCP plan itself and the actions taken to implement it are available for inspection. The creation of the HACCP plan, implementing it and keeping the records are a considerable time investment and therefore a cost.

Producers may also choose to have an external audit of their quality processes. Further, commercial customers may require a supplying wine company to have external quality certification. One very important example of this is auditing to ISO standards.

As the last stage in the production process, wineries typically have very detailed quality assurance procedures in place for bottling.

Certification to ISO standard

Wine companies seeking external verification of their quality standards can be audited against the standards of a recognised external body such as the ISO (International Organization for Standardization). The purpose of this is to give assurance to all the parties down the supply chain: the wholesaler and the retailers who will sell the wine and, finally, the end consumer.

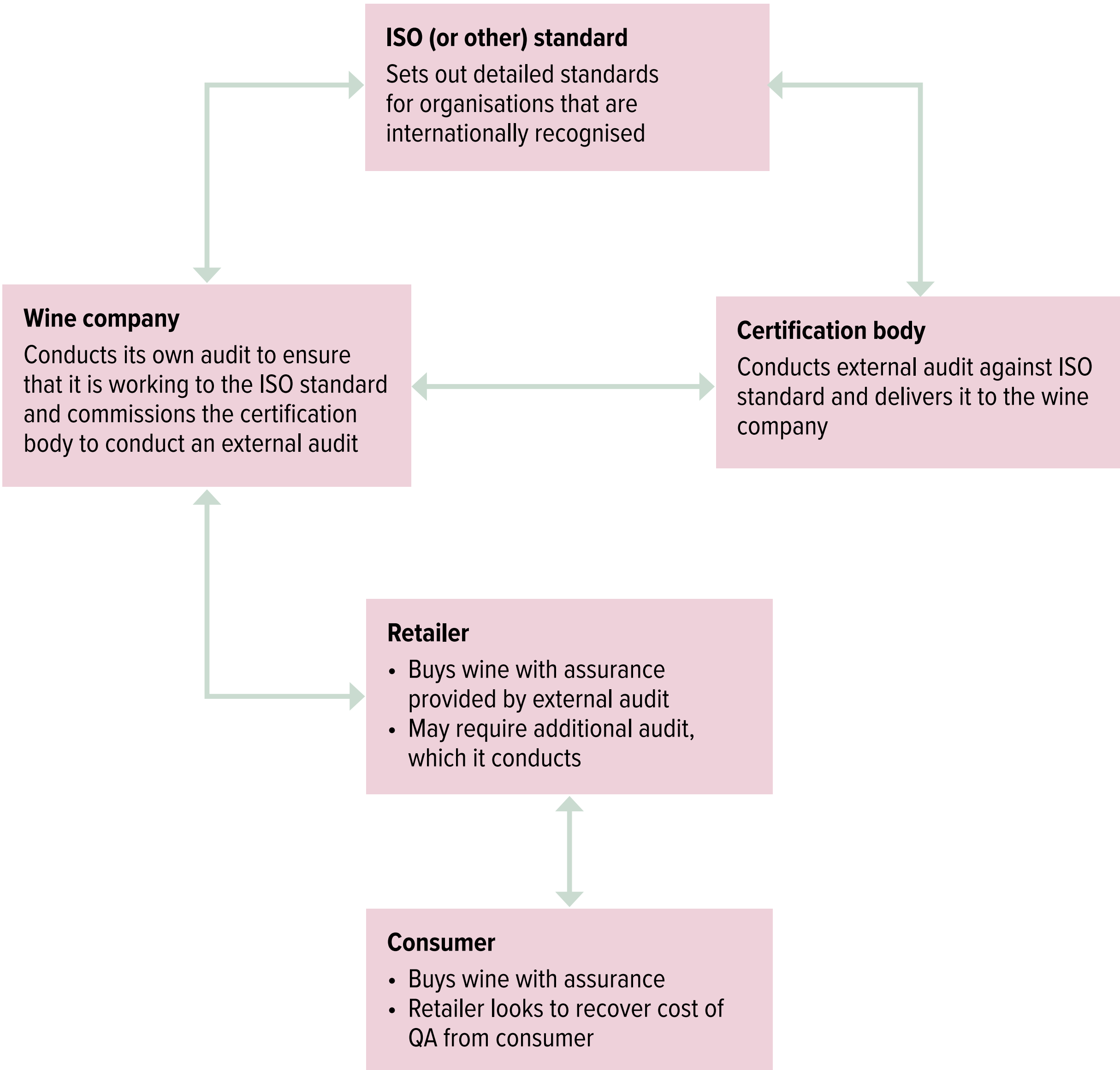
The ISO sets the standards (ISO 9000 and 9001) and separate certification bodies carry out the audits. External auditors from the certification body will review the company's own quality management system, management structure, physical and human resources and how it measures, analyses and improves its performance. This is a rigorous process for which a professional fee must be paid.

In addition, many large retailers require a higher level of audit, which might also look at issues such as environmental policy or ethical trading. Multiple audits add further cost, both in terms of fees paid and in staff time.

Traceability

A formal system for traceability is necessary if a wine company is to:

- respond to and investigate complaints about its wine. Complaints can come from any point of the supply chain, including the final consumer
- improve its practice so that similar problems do not occur in the future.



Each consignment of wine is given a lot number, which appears on the bottle. This is a requirement in the EU and many other markets. The lot number enables a company to trace back where the grapes came from, what additives have been used and what processes the wine went through. The winery must keep records of its activities at every point of its production, from the vineyard, through the winery and then in the transportation of the wine. Larger firms and those concerned about traceability will keep samples of every batch so that they can investigate what has gone wrong and compare returned bottles with their library of samples. Common problems include cork taint, tartrate crystals and faulty or missing labels.

15.9. Transportation of Wine

Historically, wine has been transported in animal skins, terracotta and, for centuries, in barrels. Bottling wine in the winery became an important means of quality control in Bordeaux, followed by other fine wine regions, starting in the 1920s. By this means, the producer could guarantee that the final wine was as the producer intended, rather than being at the mercy of possible blending or adulteration if shipped in barrel to the final market.

Today, the main options are transport in glass bottles or in larger containers, i.e. in bulk. Premium and super-premium wines continue to be bottled in the winery and transported in cases of individual bottles. However, for inexpensive to mid-priced wines there has been a rapid increase in transportation in bulk and bottling in or near the final market. This is particularly the case where very long journeys are involved.

Road and rail are used to move wine in containers of 24,000 litres from southern Europe to markets in northern Europe. Container ships carry wine from Australia, New Zealand, South Africa, Chile and Argentina to final markets in the northern hemisphere. This has given rise to very large scale and very high-quality bottling plants in or near final markets. The majority of exported wine is transported in bottle, however, wine transported in bulk makes a significant minority (currently 40% of volume).[4] However, by value, bottled wine continues to dominate.

There are two types of container for the bulk shipping of wine: the more common flexitank, a single-use, recyclable polyethylene bag that fits into a standard container; and the ISO tank, a stainless steel vessel built to the ISO standard that can be reused many times and may have additional insulation. The flexitank bag is coated with a barrier to prevent taint from an external source and to reduce oxygen ingress. Insulated tanks with temperature control, known as reefers, are available, but at an additional cost.

The advantage of shipping wine in bottle is that the entire product – the wine, the bottling, the labelling and any external packaging – is controlled by the producer. The disadvantages are:

- the smaller amount of wine that can be shipped in one container and therefore a higher cost
- the financial and environmental cost of shipping the weight of glass as well as the wine
- potential damage to the wine due to high and fluctuating temperatures in transit, and potential spoilage of labels and packaging in transport
- the shorter shelf life of inexpensive wine because it is bottled earlier than if it were bottled in or close to the final market.

The advantages of shipping wine in bulk are:

- it is more environmentally friendly as one container can hold the equivalent of 32,000 bottles in liquid rather than 12,000-13,000 filled bottles, reducing the carbon footprint of the wine; it is cheaper, for the same reason

A flexitank makes most efficient use out of the space available in this container.

- the greater thermal inertia of a whole container filled with wine, which means there is less fluctuation of temperature; this reduces the effects of high temperatures in transport and therefore reduces the risk of loss of fruit and oxidation of wine in transit, which is particularly relevant for slow, long distance journeys that go through the tropics
- strict quality control: the key parameters of a wine (residual sugar, SO_2, etc.) can be measured at the point of filling the container and again on emptying it
- the wine can be adjusted (e.g. level of SO_2 can be adjusted) at the point of bottling close to the final consumer
- the shelf life of a wine can be extended as this is calculated from the time of bottling (e.g. shipping wine from Australia to northern Europe takes around eight weeks); this is particularly relevant for bag-in-box with its relatively short shelf life.

The main disadvantages of shipping wine in bulk are the loss of the direct relationship with the producer and the transfer of business and employment opportunities from producer countries to the countries close to the final market. There have been protests, in particular from South Africa, complaining about the loss of business and of jobs. Shipping in bulk is only commercially viable for larger brands, for example those that will sell three or more containers per year.

Reference

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Specific Options for White Winemaking 16

White wines can be made in a large variety of styles. The choice of style will depend on factors such as the grape variety and the climate (the ripeness of the grapes influences the structure and flavours of the wine). The desired consumer and market for the wine will also be considered. The common processes and choices involved in making wines are explained fully in General Winemaking Options, Maturation, and Finishing and Packaging. This chapter purely focuses on options that are significant in the making of white wines and the influence that these options can have.

16.1. Transportation to Winery and Grape Reception

For options regarding transportation, chilling, sorting, destemming and crushing of grapes see Transportation to Winery and Grape Reception in General Winemaking Options.

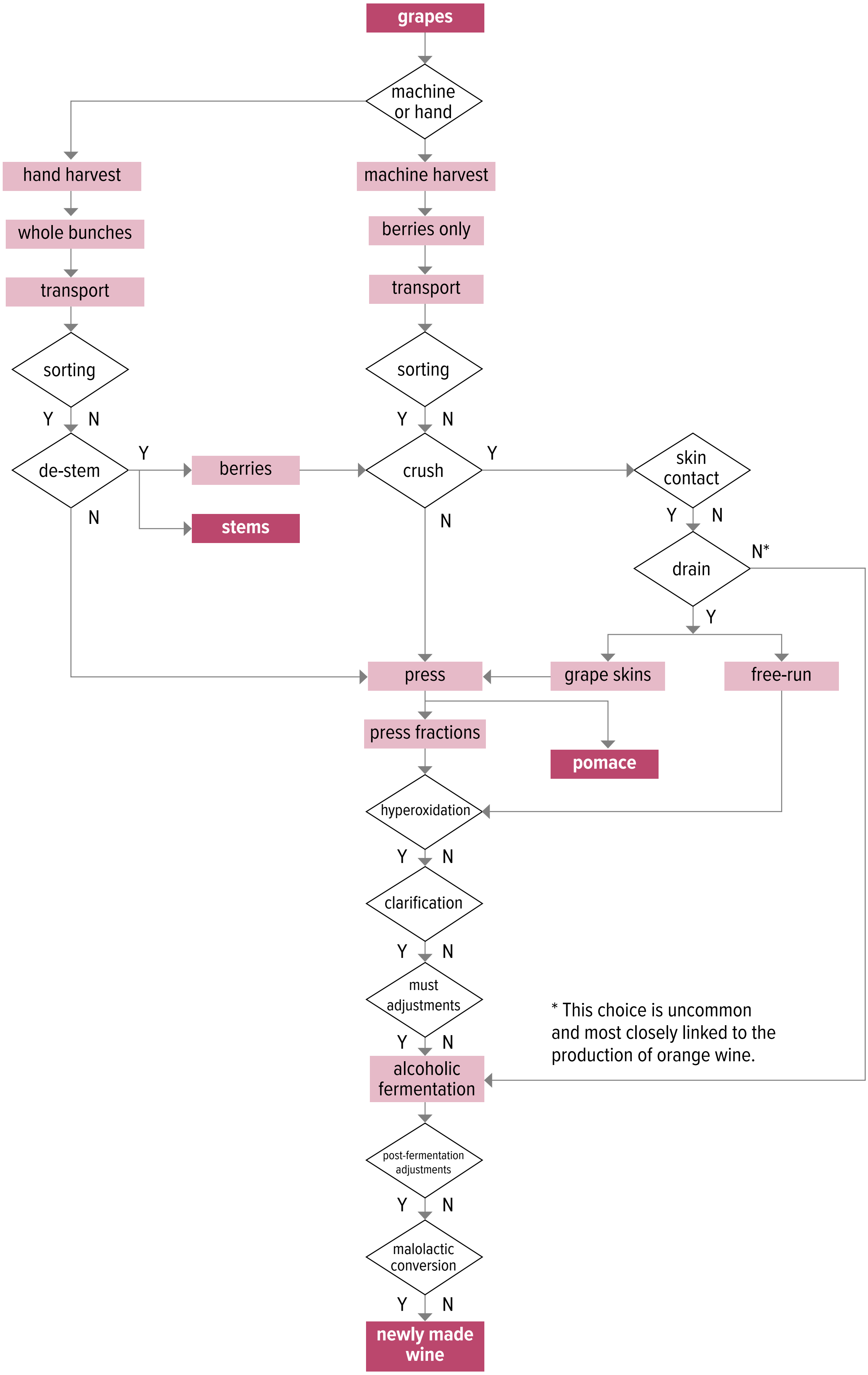
SKIN CONTACT

Skin contact is the process of leaving the juice in contact with the skins to extract compounds from the skins (similar to cold soaking in red winemaking). When carried out on (crushed) white grapes, the main purpose is to enhance the extraction of aroma and flavour compounds and precursors, and to enhance the texture of the wine by extracting a small amount of tannin. However, it is not a technique that is suited to all styles of wines and, if used too excessively, it can make white wines taste bitter and feel coarse in the mouth.

The majority of white wines are made with zero or very minimal skin contact. The grapes are crushed and then pressed immediately. This is because the principal aroma and flavour compounds of white grapes that are desirable in white wines are in the pulp. To further limit the contact between the juice and the skins, and reduce risk of oxidation, some winemakers choose to load the press with whole bunches of uncrushed grapes (see further in Pressing the Grapes).

Minimal skin contact is typical for wines where delicate fruity flavours, minimal colour and a smooth

Chenin Blanc grapes fermenting on their skins



Specific Options for White Winemaking (Processing and Fermentation)

mouthfeel are desired. It is also typically the choice for wines that are designed to be drunk early because the tannins that would be extracted during skin contact would not have time to soften. In addition, keeping skin contact to a minimum is the usual choice if fruit is at all under-ripe, as skin contact in this case could extract bitter flavours and astringent tannins. A period of skin contact also slows processing and is another winemaking procedure that requires use of equipment and labour. It is therefore less likely to be carried out on inexpensive wines from a logistics and cost perspective.

Skin contact maximises flavour extraction and therefore it is most effectively used on aromatic grape varieties that have lots of aroma compounds that can be extracted, such as Riesling, Gewurztraminer, Viognier, Muscat and Sauvignon Blanc. In these aromatic varieties that are seldom matured in oak, it is also a way of enhancing texture. However, there are some winemakers that feel that the technique leads to homogenisation, reducing the variations between grape varieties and different vineyard sites.

Time and temperature are the two key factors that can influence extraction during skin contact. Skin contact times can range from around an hour to 24 hours and over, with greater time on skins leading to greater extraction of flavour and tannins. Chilling the juice during this time reduces the rate of extraction of flavours and tannins, permitting more control, and also reduces the rate of oxidation and the threat from spoilage organisms, including likelihood of a spontaneous fermentation. Juice is typically chilled down to below 15°C (59°F). The wine is usually pressed to separate the skins and juice before fermentation begins.

Although less common, white grapes can also be fermented on their skins, as with red grapes. The resulting wines are usually termed ‘orange wines’ or ‘amber wines’ due to their orange or amber colour. Their taste profile can be markedly different to typical white wines, as different aromatic and phenolic compounds are extracted from the skins. Orange wines can have notable levels of tannin and characteristics such as dried fruit, dried herbs, hay or nuts.

Winemakers who make orange wines are often those who work with traditional methods and minimal intervention (i.e. producers of natural wine), hence it is common that these wines are fermented with ambient yeasts, without temperature control or additions of SO_2.

16.2. Pressing the Grapes

In white winemaking, the grapes are almost always pressed to separate the skins from the juice before fermentation. Typically, pressing will be as gentle as possible to avoid the extraction of unwanted compounds from the skins and seeds of the grapes, such as tannins and colour. On the choice of the press to be used, see Pressing in General Winemaking Options.

An important choice involves whether to destem the grapes before pressing. Usually, grapes are destemmed and crushed before being loaded into the press (see Grape Reception). However, it is also possible to press whole bunches of grapes. This reduces the chance of oxidation before and during pressing, especially if inert gases, such as nitrogen, carbon dioxide or dry ice (carbon dioxide in solid form), are used within the press. It is also one of the gentlest forms of pressing, providing juice that is low in solids (grape skin, stem and seeds), tannins and colour. The stems also help to break up the mass of grape skins, providing channels for the juice to drain.

However, this method of pressing is only an option if the grapes have been hand-harvested. Additionally, the whole bunches take up a lot of room in the press, therefore fewer grapes can be loaded within each press cycle. Whole bunch pressing may be suitable when making smaller batches of premium wines, but is less likely to be an option when making large volumes of inexpensive and mid-priced wines where grapes need to be processed quickly and efficiently.

If grapes are destemmed and crushed, the juice that can be drained off as soon as the grapes are crushed is called the free run juice. This is typically the juice that is lowest in solids (see Clarification of Must below), tannin and colour. It is also lower in pH and higher in acidity. The winemaker may choose to make wine from entirely free run juice, especially if looking to make a lighter bodied style of wine and minimise any colour or tannin. However, using only this proportion of the juice reduces the final volume of wine that can be produced and therefore has a cost implication.

The juice that runs off through the pressing is called the press juice. At the start, the press juice will be similar to the free run juice, but, as the pressing continues and more pressure is applied, more solids, tannin and colour are extracted. The press juice also has lower acidity and less sugar than the free run juice. The winemaker may decide to separate the press juice into different fractions (called 'press fractions') as the pressing continues. Different press fractions may be blended with the free run juice in the winemaking and/or maturation process (see Blending), and can increase body and texture. The last press fractions are likely to be too astringent or bitter (due to tannins from the skins, seeds or stems) and therefore will be discarded.

16.3. Hyperoxidation

Hyperoxidation is the technique of deliberately exposing the must to large quantities of oxygen before fermentation. This targets the compounds in the must that oxidise most readily. As they oxidise, these compounds turn the must brown. However, during fermentation the compounds precipitate, returning the wine to its normal colour. The main aim is to produce wines that are more stable against oxidation after fermentation. This process can also help to remove bitter compounds that can come from unripe grape skins, seeds and stems. Hyperoxidation can destroy some of the most volatile aroma compounds found in the must and therefore is typically better suited to less aromatic grape varieties such as Chardonnay. For example, hyperoxidation can reduce the levels of volatile thiols and methoxypyrazines found in Sauvignon Blanc, and therefore would not be carried out if an aromatic fruity or herbaceous style of this wine was desired.

The equipment required for hyperoxidation is not particularly expensive, but it is an extra step in the winemaking process that requires labour to set up and monitor, and therefore overall it may have some small impact on costs.

16.4. Clarification of Must

Between pressing and fermentation, the juice of white grapes may be clarified. (Clarification may also occur after fermentation and this is covered in Post-Fermentation Clarification in Finishing and Packaging.) The aim of clarification is to reduce the amount of suspended solids within the must. These solids include particles of grape skin, stem and seeds.

Winemakers will generally aim for the proportion of solids in the must to be 0.5–2 per cent. Levels below 1 per cent can only be achieved by using pectolytic enzymes or centrifugation (see below). Some winemakers choose to retain between 1–2 per cent or marginally higher because this can add to the texture of the wine, giving a subtle astringency (particles of skin and stem will add tannins). Relatively high levels of solids can also give a greater range of aromas from fermentation, which could give greater complexity; however, lower levels of solids are better for obtaining fruity aromas. Therefore, a relatively high level of solids may be desirable for a premium-priced Chardonnay, but would be less suitable for an inexpensive Pinot Grigio. Fermentations with a high level of solids need careful monitoring and management as the various compounds within the solids and their reactions can lead to off-flavours. For example, high solids fermentations can give reductive sulfur compounds that at low levels may be desirable (struck match, smoke), but at higher levels are very negative for quality (aromas of rotten eggs). The close monitoring of the fermentation means it is a technique better suited to small-volume production of premium wines.

However, a small amount of solids is beneficial in that it provides nutrients for yeast, and over-clarifying the must can lead to stuck fermentations. Fermentations with a very low level of solids also need careful management, and yeast nutrients (such as DAP) may need to be added (see Alcoholic Fermentation in General Winemaking Options).

There are many different options for the clarification of grape must.

SEDIMENTATION

Sedimentation is the simplest form of clarification. It is also sometimes called ‘settling’. The suspended solids in the must are left to fall over time with gravity. The must is commonly chilled to around 4°C (39°F) to reduce the rate of oxidation and the threat from spoilage organisms, and to avoid a spontaneous fermentation. The rate of sedimentation will also depend on the size and shape of the vessel; it takes longer in large, tall vessels than in smaller, shorter vessels due to the depth over which the solids need to fall. Sedimentation at low temperatures (e.g. below 15°C / 59°F) slows microbial activity and reduces oxidation but takes longer, tying up tank space. Sedimentation times of 12–24 hours are not uncommon. The clear juice is transferred to the fermentation vessel, leaving the sediment of solids at the bottom of the sedimentation vessel (a process called racking, see The Role of Lees in Still Wine Maturation). The solids left behind after sedimentation will often be filtered by cross flow or depth filters to extract extra juice.

Sedimentation can be used to clarify wines as well as must. Sedimentation is the cheapest method in terms of equipment required and is the most traditional way to clarify must or wine in that it requires no extra equipment or additives. However, it takes the most time and there is a cost to the energy used in chilling. It is also a batch process, which is costly in terms of labour and time. For these reasons, it is most commonly used for small-volume production of premium wines.

FLOTATION

Flotation involves bubbling gas up through the must. As the bubbles of gas rise, they bring with them the solid particles. The solid particles are then skimmed off the top of the vessel. Compared to sedimentation, flotation speeds up the rate of clarification. Inert gas such as nitrogen is typically used. If oxygen is used as the gas, this is a method of hyperoxidation. Fining agents must be added to the must for this technique to be successful (to help bind the particles together), and it can only be used on must, not wine. This technique is a little more expensive than sedimentation in terms of the equipment needed. The technique requires gases, fining agents and equipment for bubbling the gas through the liquid. However, it is effective and quick, and can either be used as a continuous or a batch process. Also, the must does not need chilling, and therefore there is a saving on energy costs.

CENTRIFUGATION

A centrifuge is a machine that comprises a rapidly rotating container which uses centrifugal force to separate solids from liquids. The advantage of centrifuges is that they clarify the must quickly. They are used continuously (rather than as a batch process) which also saves time and labour costs. However, they are expensive to buy, and therefore are typically only used in wineries needing to process large volumes of must quickly. They also increase the must's exposure to oxygen unless the machine is flushed with inert gas, but that has an implication on costs. Centrifuges can be used on wine as well as must.

A centrifuge can be used to speed up the clarification of juice or wine.

CLARIFYING AGENTS

A number of different compounds can be added to the must as processing aids to speed up the rate of sedimentation. Pectolytic enzymes break down pectins in the must. Pectins are naturally found in plant cell walls (in jam-making they are the compounds that turn liquid juice into gel). Breaking down the pectins allows a more rapid separation between the liquid juice and solids. Pectolytic enzymes only aid the clarification of must, not wine. Some fining agents can aid clarification of both must and wine (see Fining in Post-Fermentation Clarification). There is a cost of purchasing these agents, but this may be justified against the time and energy saved compared to sedimentation (where the wine would need to be chilled to low temperatures for several hours).

16.5. Fermentation Temperatures and Vessels for White Wines

Fermentation temperatures for white wines are typically cooler than those used in red winemaking. This is because the volatile aroma and flavour compounds that are desired in many white wines, for example, many esters, are best produced and retained at cool temperatures (around 15°C / 59°F).

In some styles of white wines, fruity aromas are not particularly desired; for example, where oak is going to be used to provide flavours. In these cases, the fermentation can be slightly warmer (17–25°C / 63–77°F and sometimes higher) to promote yeast health and avoid the production of certain esters, such as isoamyl acetate (banana-like smell).

Stainless steel tanks. The control panel on the front allows the winemaker to monitor and adjust the tank temperature.

Stainless steel tanks are the most popular choice for the production of fruity, floral white wines, such as many styles of Sauvignon Blanc and Veneto Pinot Grigio, due to the ability to control temperatures easily and hence maintain the cool fermentation conditions needed to enhance these aromas. Concrete and old oak vats (as well as stainless steel tanks) may be used for white wines fermented at slightly warmer temperatures, where maximising the fruity and floral aromas from fermentation is not the aim (for example, some styles of Chablis and white Rioja).

Small oak barrels (sometimes new oak) are a popular choice for some styles of white wine, particularly premium and super-premium Chardonnay. However, this adds costs due to the need to buy the barrels and the large number that may be required (e.g. barriques only hold 225 L each). For a full introduction to the use of oak in fermentation, see Fermentation Vessels in General Winemaking Options. Monitoring fermentation in these small vessels is more labour intensive than monitoring a single large vessel. However, it is thought that wines that have been fermented in small oak vessels have a deeper colour and fuller body, due to the oxidative environment, and more integrated oak-derived aromas, due to the action of the yeasts during fermentation (compared to wines that are fermented in steel or concrete and later transferred to an oak barrel for maturation). The small size of these vessels also increases the contact between the wine and yeast lees, and this is also thought to contribute texture. These vessels can also provide more blending options because the wine in each barrel may be slightly different after the fermentation process.

As with oak maturation, small barrel fermentation is less likely to be used for wines made from aromatic grape varieties such as Riesling where the winemaker is usually looking to preserve primary aromas and flavours from the grapes and avoid the characteristics of oak.

For further details on fermentation in general, see Alcoholic Fermentation.

16.6. Malolactic Conversion for White Wines

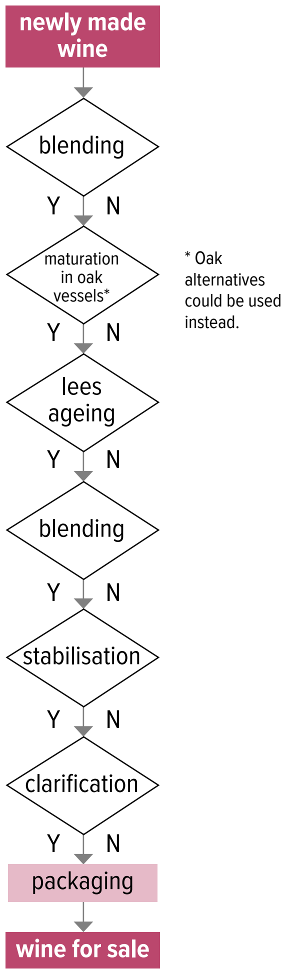
The effects of malolactic conversion are a reduction in acidity, increase in microbiological stability and a modification to the flavours of wine. In white wines, the winemaker typically makes a conscious choice whether or not to put the wine through malolactic conversion because the effects on the final wine make a significant difference to the style. See General Winemaking Options for a full introduction to malolactic conversion.

With a low-aromatic variety such as Chardonnay, there is a choice between the perceived greater complexity of wines that have been through malolactic conversion and the primary fruit character of those that have not. By contrast, with aromatic varieties such as Riesling or Sauvignon Blanc, malolactic conversion is typically avoided to preserve the primary aromatics, despite these being high acid varieties. In this way, the distinctive aromas of these individual varieties are maintained.

Malolactic conversion will decrease the acidity and increase the pH of the wine. It is possible to adjust the acidity of the wine as necessary (this adjustment can also be made at the must stage). It is also possible for winemakers to reduce the alcohol of the wine at this stage. For more details see Post-Fermentation Adjustments.

16.7. Barrel Maturation for White Wines

Whether to mature the wine in wood and the details of this process will have a significant impact on the style and price of white wines. The options regarding maturation in wood can be found in The Role of Wood in Maturation. Premium and super-premium wines, particularly those made with low-aromatic varieties such as Chardonnay, are likely to be aged in small oak barrels for the texture and complexity of flavours this can bring. However, for wines made from aromatic grapes, such as Riesling, the vanilla and toasty flavours from the oak and nutty flavours from slow oxidative ageing are often not desirable. Maturation in oak barrels is usually too costly for inexpensive wines and therefore, if any flavours from oak are wanted, this may come from oak alternatives such as staves.



Specific Options for White Winemaking (Maturation, Finishing and Packaging)

16.8. Lees Ageing for White Wines

The aims of ageing on the lees are to give more body, soften the mouthfeel and help to stabilize the wine. They also protect the wine from oxygen and may introduce some reductive sulfur compounds, which, at low levels, some winemakers and consumers consider desirable (aromas such as struck match, smoke). The impact of lees is thought to be more significant in white wines than red wines. It is common for a range of white wine styles and prices, but is less practiced on inexpensive wines, which will usually be released from the winery for sale as soon as possible. For more details, see The Role of Lees in Still Wine Maturation.

The lees may or may not be stirred to unsettle it from the bottom of the vessel and mix it in the wine. Lees stirring is sometimes referred to by the French term, *bâtonnage*. Lees stirring can increase the release of yeast compounds into the wine. The most traditional method of lees stirring for wine stored in small vessels such as barrels, is to use a rod and manually stir the lees into the wine. Due to the need to remove the bung from the vessel, this method increases oxygen exposure and can result in an increase in the effects from the dead yeast and a decrease in fruity flavours. The introduction of oxygen and disturbing of the lees also reduces the development of reductive sulfur compounds and the off-aromas that they can introduce if not appropriately managed. However, there are other options that now agitate and/or mix the lees without needing to open the vessel (for example, barrel racks that permit easy rolling of the barrels). This can give the winemaker more options and therefore more control over the impact of lees and oxygen. Lees stirring on large numbers of large barrels is labour intensive and can therefore add to the cost of production.

A rod is used to stir the lees in a barrel

16.9. Blending, Finishing and Packaging for White Wines

Explanation of the final stages in the wine production process can be found in Blending and Finishing and Packaging.

17 Specific Options for Producing Wines with Residual Sugar

Wines with residual sugar encompass a large range of styles. Some inexpensive wines contain low to moderate levels of residual sugar to make them more appealing and palatable to a larger consumer audience. At the other end of the spectrum, the sweetest wines have residual sugar levels of a few hundred grams per litre (g/L) and are syrupy in texture.

As will be seen in this chapter, the key ways of producing wines with residual sugar are by concentrating the sugar in the grape must, stopping the fermentation before dryness or blending in a sweetening component to the wine. The choice of method will be determined by the style, quality and price of the wine that the winemaker wants to make, the climate of the vineyard site (for different methods of concentrating the grape must) and the local wine legislation. The objective is to produce a wine with balanced residual sugar and acidity, and with flavour concentration appropriate for the level of sugar.

17.1. Concentrating the Grape Must

This is the method used to produce many sweet and luscious styles of wine. The concentration of sugars in the grape must may be sufficient to stop the fermentation before reaching dryness; yeast struggle in very sugary environments, especially when alcohol is also present, and naturally stop fermentation even at relatively low levels of alcohol. However, the fermentation can also be stopped prematurely by chilling and/or adding SO_2 and then filtering to remove yeast (see Stopping the Fermentation), giving the winemaker greater control over the balance of alcohol and sweetness.

The grape must is concentrated by the reduction of the water content in the grape, and hence this process not only concentrates sugar, but also other grape components such as acidity and flavours. The increase in acidity and flavours helps to keep these wines in balance so that sweetness does not become too dominant, and is a key reason why many of the wines made by such methods tend to be very good or outstanding in quality. The method of removing the water to concentrate the sugars can sometimes add its own flavours. For example, drying grapes off the vine can lead to flavours of dried fruits; therefore, these wines can have more complexity than those simply made by stopping the fermentation by chilling or adding a sweetening component.

Because water is depleted, the volume of juice obtained from the grapes is low. The very sugary pulp is also often hard to extract during pressing. These factors can add to the cost of production of these wines, which means they often sell for premium and super premium prices.

Methods of concentrating the grape must include the drying grapes on and off the vine, the development of noble rot and the freezing of grapes.

DRYING GRAPES ON THE VINE

As seen in Grape Development in the Vine Growth Cycle, the grape goes through four stages of ripening. If left on the vine, the grape will enter stage four of ripening in which the grape starts to shrivel. Water is lost by grape transpiration and the sugars concentrate. The flavours in the grape also continue to develop, giving very ripe flavours. For example, Pinot Gris may develop from stone fruit when ripe to tropical fruits and dried stone fruits as it becomes extra-ripe. Dry autumns are needed for this option to avoid the development of grey rot, which would give off-flavours. The wines produced in this way are sometimes labelled as 'Late Harvest' (or a local equivalent) and include *Vendanges Tardives* from Alsace and *Spätlese* from Germany or Austria.

There is another method of drying grapes while they are still attached to part of the vine. In this method, the cane of the vine is cut or broken off from the vine a short time before harvest. (The cane usually remains attached to the trellis at this point.) The grapes shrivel more quickly than they would if they were still attached to the rest of the vine. This concentrates the sugars, acids and flavours within the grapes. The reduced hang time lowers, but does not eliminate, the risk of grey rot and also means it is possible to obtain grapes with very high levels of sugar without extra-ripe flavours. The technique is used to make sweet wines in Jurançon, south-west France, and is also sometimes used in Australia.

Shrivelled grapes that have been left on the vine

DRYING GRAPES OFF THE VINE

In this method, grapes are picked and then dried. This can last from days to months depending on the extent of drying required and the speed of the drying process. Bunches of grapes may be laid out to dry in the sun in warm climates, such as southern Italy or Spain,


Corvina grapes drying in racks for Recioto di Valpolicella

or dried in a temperature- and humidity-controlled room in cooler climates, which gives the ability to speed up drying and avoid the development of grey rot, for example in Valpolicella. (A humidity-controlled room is clearly more expensive to build and maintain than drying grapes outside.) This drying process causes water to evaporate, making the sugars, acids and flavours become more concentrated. This method is often referred to by the Italian term, *appassimento*. Wines made in this way include Recioto di Valpolicella and Vin Santo.

NOBLE ROT

This method involves the action of the fungus *Botrytis cinerea*. This is the same fungus that causes grey rot; however, under certain conditions it can be used beneficially in sweet wine production. In these circumstances, it is often termed noble rot.

First, the grapes must be fully ripe before the development of the rot. Second, the grapes must be grown in a region that provides humid, misty mornings followed by sunny, dry afternoons. Damp conditions in the morning allow rot to develop on the grapes. The fungus punctures the grape skin with microscopic filaments, leaving tiny holes in the skin. The warm sunny afternoons slow the development of the rot and cause water to evaporate from the grape, concentrating its sugars, acids and flavours. The fungus can also modify some of the aroma compounds in the grape and generate its own unique flavours. Wines made from grapes affected by noble rot have distinctive honey, apricot, citrus zest, ginger and dried fruit aromas.

This method is used in the production of many premium and super premium sweet wines, including Sauternes, *Beerenauslese*, *Trockenbeerenauslese* and Tokaji. It is much more typical to use this technique on white grapes rather than black grapes. Although *Botrytis cinerea* is

Noble rot punctures the skin of grapes and during sunny afternoons water evaporates, shrivelling the grapes.

the cause of both noble and grey rot, the term ‘botrytis’ is frequently used as a synonym for noble rot, and the term ‘botrytised’ is often seen on sweet wine labels.

The spread of noble rot is never uniform and several pickings by hand may be needed to select the best grapes. This is an expensive process as it requires skilled labour over a prolonged period of time. This selective picking and the fact that water has evaporated from the grapes means that the volume of juice obtained is low. Furthermore, in some regions the ideal conditions for noble rot do not occur every year, making these wines relatively scarce and therefore expensive. If conditions are too damp, the fungus will develop too rapidly and cause grey rot, splitting the grapes and encouraging infections.

Furthermore, grapes infected by noble rot are not easy to process in the winery. The fungus contributes an enzyme (called laccase) that is capable of oxidising a number of components in grape must and wine, and is relatively resistant to SO_2. Chilling, high doses of SO_2 and use of inert gases are all options to minimise the oxidation of the must. The thick, high-sugar-content must is also difficult to press, clarify and ferment.

These wines are often matured in oak (either old or new) especially if relatively neutral grape varieties are used, for example Semillon. Oak can give a broader texture to these wines (the oak contributes some tannins), with new oak adding flavours such as vanilla.

However, wines made from more aromatic grape varieties tend to be stored in stainless steel or concrete to retain their more pronounced varietal aromas.

FREEZING GRAPES ON THE VINE

This method requires healthy grapes to be left to hang on the vine into the late autumn or winter months. When freezing temperatures arrive, the water in the grape pulp turns to ice. When the grapes are picked and pressed, this ice remains in the press and the sugar content of the resulting juice is concentrated. This technique is used to produce Eiswein in Germany and Austria and Icewine in Canada. These are protected labelling terms, and winemakers must follow various regulations to be able to use them. For example, Canadian Icewine grapes must be harvested at −8°C (18°F) or below.

Grapes left on the vine into the winter to make Icewine

The vines used for these styles of wine need to be winter hardy and have grapes with resilient skins that can offer protection from disease and can withstand the strain of freeze–thaw cycles. The most popular grapes are Riesling and Vidal. Black grapes such as Cabernet Franc are occasionally used. These wines are often fermented and stored in stainless steel to retain the primary aromas and flavours of the grape variety. Oak maturation is sometimes used to add extra flavours (vanilla, clove, etc.).

The conditions for producing wine by this method are very specific. It can only be produced in a few regions where and when weather conditions allow. Freeze–thaw cycles are thought to be important for the development of typical ice wine character. The highest quality but lowest yielding grapes are picked late in the winter season, for example in late January. Similar to other wines made by the concentration of sugars, juice yield from the grapes is also very low. There is also considerable risk that the unpicked grapes may become infected by disease or eaten by pests further reducing yields (netting against birds is an important cost in ice wine production). All of these factors mean these wines command premium or super premium prices.

A similar effect can be created by picking grapes in the autumn (at the same time as those for dry wines) and then freezing them at a winery. This is called cryoextraction. This technique can be used by winemakers in regions that would not get the typical climatic conditions required for Eiswein and Icewine. It also does not entail the risks of leaving the grapes on the vine into late autumn or winter and perhaps losing yield to disease or pests. It is not permitted in the production of Eiswein and Icewine and therefore wines made by cryoextraction cannot use these terms on the label. The method requires energy to freeze the grapes, but overall is cheaper than traditional Eiswein and Icewine production.

17.2. Stopping the Fermentation

Fermentation is the process by which sugars in the grapes are converted to alcohol by yeast, and therefore stopping this process before all the sugars have been converted results in a wine with residual sugar.

The advantage of this method is that the winemaker has control over the level of sugar in the final wine. The earlier the fermentation is halted, the higher the level of residual sugar that will remain, but also the lower the level of alcohol. For example, White Zinfandel is produced in this way (without any concentrating of the sugar in the grapes beforehand) and contains around 35 g/L and 10% abv. These wines taste off-dry to medium-sweet, rather than fully sweet. This process is relatively quick, simple and low risk (compared to many methods of concentrating grape sugars) and so it is often used to produce wines that are inexpensive or mid-priced. It is rare, however, to find the same intensity and/or complexity of the wines produced by concentrating the grape sugars, and they tend not to reach outstanding levels of quality. (The exception would be some fortified wines that may undergo long periods of ageing and be extremely complex.)

The most common way of interrupting the fermentation is by chilling to below 10°C (50°F) and/or adding a high dose of SO_2 to inhibit the yeast. The wine is then racked off its sediment and sterile filtered to ensure fermentation does not start again at a later stage. Fortification, the addition of alcohol to kill the yeast, is also an option, but this radically changes the style of the wine. The winemaking for Fortified Wines is covered in D5: Fortified Wines.

17.3. Blending in a Sweetening Component

Adding a sweetening component is the easiest way of producing a wine with residual sugar. The dry wine can be stored until it is ready to be bottled and then the sweetening component blended in. The benefit of this is that dry wines are less susceptible to spoilage organisms than wines with residual sugar.

The winemaker is also able to trial, measure and add the amount of sweetener that is needed to produce the style of wine desired. This method therefore allows a high level of control, enabling high volumes of a consistent product to be made.

Also, compared to methods of concentrating the must where the volume of the wine that can be produced is reduced, adding a sweetening component will maintain or possibly slightly increase the volume of the final wine (depending upon the sweetness required) and therefore does not add to costs in this way.

These factors mean that this technique is suited to the production of high volumes of inexpensive wines. The quality of the wine being sweetened and balance of the sweetness against other components in the wine will affect the quality of the final product, but because this method tends to be used for inexpensive wines, quality is likely to be acceptable to good.

Sugar, rectified concentrated grape must (RCGM) and unfermented grape juice (often referred to by the German term, *Süssreserve*) are common sweetening components. While unfermented grape juice will contribute a grape-juice-like character, RCGM is processed so that it just contains the sugar from the grape. It is therefore neutral (not adding any additional flavours to the wine), and smaller amounts are required to sweeten the wine. All of these additions are inexpensive. The substance that can be used for sweetening is sometimes determined by local wine regulations. For example, the use of sugar is not permitted in the EU. Furthermore, for Protected Designation of Origin (PDO) wines, the unfermented grape juice must come from the same wine region as the wine being made.

18 Specific Options for Red Winemaking

The common processes and choices involved in making wines are explained fully in General Winemaking Options, Maturation, and Finishing and Packaging. This chapter purely focuses on options that are significant in the making of red wines and the influence that these options can have.

Many of the choices involved in red winemaking are focused on the extraction of anthocyanins, tannins and flavours from the grape skins. The levels and nature of each of these components have a defining influence on the style of the wine. The general aim is to extract these compounds so that the wine is suitably concentrated and balanced, but not to extract too much.

Factors that affect extraction are:

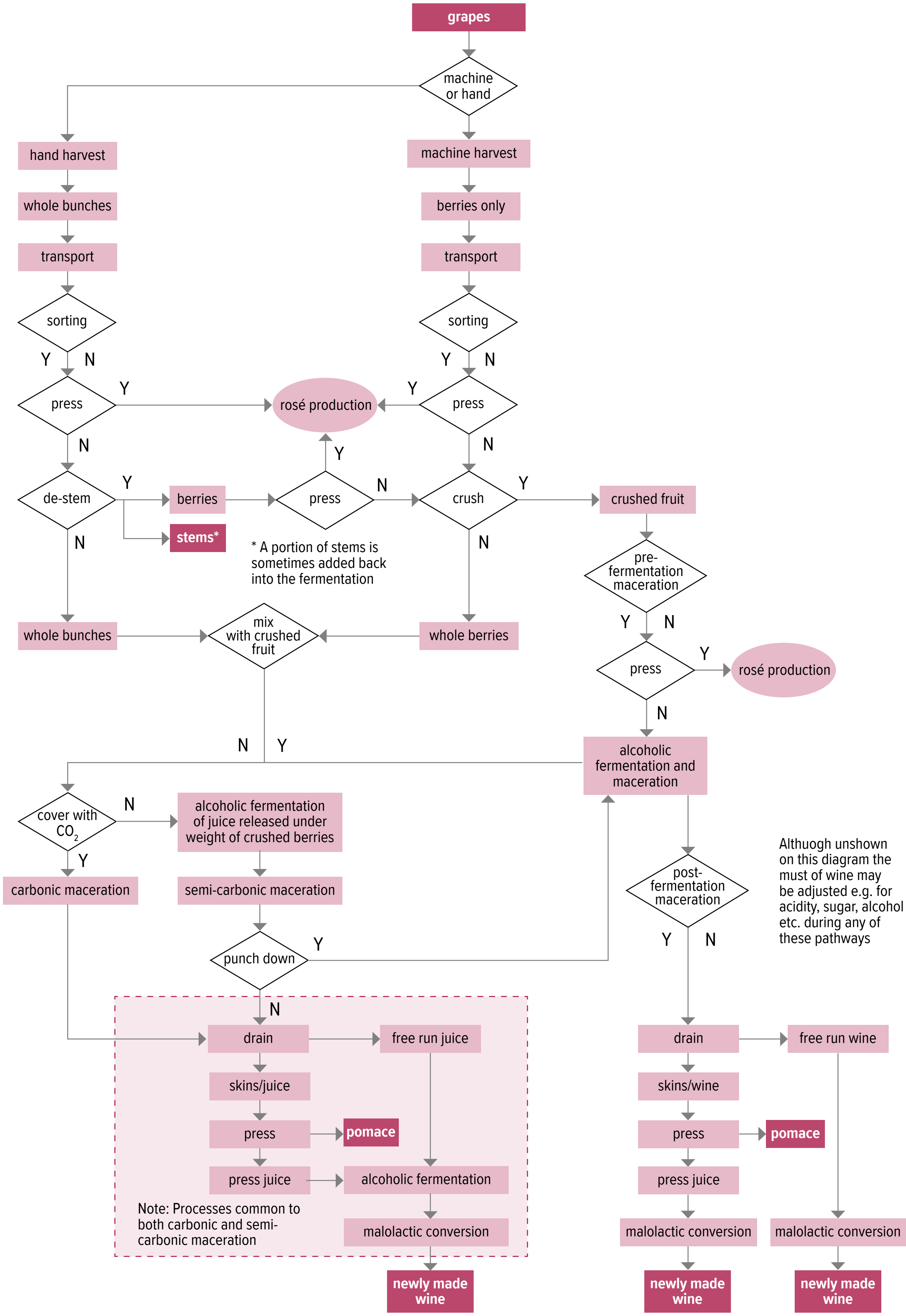
- **Temperature** – higher temperatures result in greater extraction
- **Time on skins** – generally, the longer the juice/wine remains in contact with the skins the greater the extraction management of the skins and juice – the more the skins are mixed through the juice, the greater the extraction
- **The medium in which the extraction is taking place** – for example, tannins are most soluble in alcoholic solutions (e.g. wine), whereas anthocyanins are most soluble in aqueous solutions (e.g. grape must).

ANTHOCYANINS, TANNINS AND OXYGEN

Anthocyanins are the source of colour in young red wines. However, as single molecules they are not very stable and the colour they provide can be altered or lost in the process of different winemaking procedures, such as lees ageing or additions of SO_2. The anthocyanins become more stable when they combine with tannins, resulting in greater colour stability. Oxygen facilitates this reaction and therefore winemaking processes that encourage the gentle oxygenation of the wine (e.g. micro-oxygenation and barrel ageing; see Maturation) can help to promote colour stability. Both, anthocyanins and anthocyanin-tannin compounds change in composition over time and the wine becomes paler and gradually changes from ruby through to brown. However, this change is slower for anthocyanin-tannin compounds than anthocyanins.

18.1. Transportation to Winery and Grape Reception

For options regarding transportation, chilling and sorting of grapes, see Transportation to Winery and Grape Reception in General Winemaking Options. Although the phenolics found in the skins of black grapes make them less vulnerable to oxidation than white grapes, chilling still helps to slow down oxidation, as well as reducing the threat from spoilage organisms. Grapes may also be chilled now if cold soaking is planned (see Crushed Fruit Fermentations).



Specific Options Red Winemaking (Processing and Fermentation)

18.2. Crushed Fruit Fermentations

The vast majority of red wines are made by destemming and crushing the fruit before fermentation. In these cases, the winemaker has the options set out below. In crushed fruit fermentations, pre-fermentation adjustments can be made to the acidity, sugar and tannin levels in the must as needed (see Must Adjustments).

MACERATION BEFORE FERMENTATION

The key aim of maceration before fermentation is to extract colour and flavours, without extracting tannins. As stated, anthocyanins are most soluble in grape must, whereas tannins are more soluble in alcoholic liquids and are therefore not readily extracted at this point in the winemaking process.

Cold Soaking

Cold soaking is also known as cold maceration or pre-fermentation maceration. The juice and skins are typically chilled (to around 4–10°C / 39–50°F) to reduce the rate of oxidation, the threat from spoilage organisms and the risk of a spontaneous fermentation starting. It is typical for pre-fermentation maceration to last 3–7 days, usually with the use of punching down and/or pumping over to mix up the skins and juice, aiding extraction (see Maceration During Fermentation below). This also avoids the growth of spoilage organisms that need oxygen, such as acetic acid bacteria, on the top of the cap of skins. Cold soaking is a gentle technique, suitable for premium wines. The cold temperatures result in a slow extraction, which can easily be monitored and controlled to achieve the level of extraction desired. It is very commonly conducted on Pinot Noir to promote colour intensity, because this grape variety has a low level of anthocyanins but is also used for other grape varieties if the winemaker wants to promote colour extraction without risk of extracting high levels of tannin. There is a cost to cold soaking in the energy required to chill the wine. Also, time taken for cold soaking (tying up valuable tank space) means that it is often not suitable in the production of high-volume, inexpensive wines.

Macerations Using Heat

As previously stated, higher temperatures lead to greater extraction, and therefore the following techniques are designed to extract high levels of anthocyanins and flavours quickly. (Some tannins may also be extracted, but to a lesser extent.) Two key techniques are *flash détente* and thermovinification. Thermovinification involves heating the must to around 50–60°C (122–140°F) and sometimes higher. The time spent macerating at this heat can range from a number of minutes to several hours; generally, the higher the temperature, the shorter the maceration. In *flash détente*, destemmed grapes are quickly heated to 85–90°C (185– 194°F) and then rapidly cooled under a vacuum. This takes place in as little as two minutes. The process bursts the cells in the grape skins, allowing a very rapid extraction of anthocyanins and flavours. The short time at high temperatures limits the risk of 'cooked' flavours developing. However, the vacuum system is expensive to buy, and it therefore tends only to be used at high-volume wineries where the large throughput may justify its cost.

With both techniques, the juice may be pressed off the skins before fermentation if a low tannin, fruity style is desired. However, the wines produced in this way tend to have issues with colour instability. This is because there is not enough tannin to bind with the anthocyanins and form more stable compounds. This option is therefore best suited to inexpensive or mid-priced wines that are going to be consumed shortly after production. It may also be used as a blending component in higher quality wines, bringing juicy, fruity flavours to the blend. Alternatively, the juice may be fermented for a period of time on the skins if a style with more tannin is required.

Both *flash détente* and thermovinification can be particularly beneficial if the grapes are affected by botrytis (grey rot), as the high temperatures denature oxidative enzymes (called laccase) produced by the rot. *Flash détente* can also be used as a treatment for smoke taint. Both techniques are said to intensify the fruitiness of the wines, but critics of these techniques feel that this can lead to a reduction in more subtle varietal characters.

MACERATION DURING FERMENTATION

Cap Management Techniques

The vast majority of red wines are fermented on the skins. It is important to mix the skins with the juice or wine during fermentation for a number of reasons. In a tank of fermenting must, the grape skins rise to the top of the liquid and remain there, buoyed by carbon dioxide. This forms what is known as a cap. Without mixing, this would mean that the skins spend the fermentation macerating in the same small volume of liquid that surrounds them. This liquid would become saturated with colour, tannins and flavours and therefore dissolution of these compounds into the liquid would gradually stop. Additionally, a dry cap would allow bacteria to convert alcohol into unwanted acetic acid. Most of the techniques used to move the cap also aerate the must, helping to avoid the production of reductive sulfur compounds. Mixing also helps to distribute the heat produced during fermentation and is therefore essential for temperature monitoring and control (see the effects of temperature in Alcoholic Fermentation).

Choices regarding cap management have a key influence on the style of the wine. First, there are many different techniques for mixing the skins with the liquid, as outlined below. Second, the winemaker can alter the frequency of the mixing and the duration of the mixing (e.g. pumping over the must three times a day for 15 minutes will extract more than 10 minutes of pumping over once a day). Third, the timing of the mixing within the fermentation can influence what compounds are extracted. For example, more mixing at the start of fermentation with less mixing at the end will extract more colour and less tannin, whereas mixing more at the end of the fermentation will extract a greater amount of tannin.

Temperature also has a role. Warmer fermentations will extract more than cooler fermentations. With temperature-controlled vessels, temperature during different stages of fermentation can be adjusted. Therefore, tannin extraction can be reduced by cooling the wine near the end of the fermentation at the time when tannins are most likely to be extracted.

Punching down – A plunger is used to submerge the cap of grape skins in the liquid. This can either be carried out by hand or by a mechanised plunger. Carrying out this procedure by hand is labour intensive (with the expense that this entails) and is therefore best suited to low-volume production of premium wines. It is also only physically possible to punch down the cap manually and ensure adequate mixing of the skins in relatively small, open top vessels. It is a gentle process and used on several grape varieties. Punching down is often referred to by its French name '*pigeage*'.

Mechanical punching down is needed in large vats where punching down by hand would be too difficult.

Pumping over – In this system, juice/wine is taken from near the bottom of the vessel and sprayed over the cap of skins. Usually around one-third to one-half of the liquid in the vessel is pumped and sprayed over. The liquid extracts colour, tannins and flavours from the cap of skins as it passes through. Because this technique sprays the liquid over the cap, rather than breaking up the cap, the extraction is very gentle and usually punching down or rack and return is also required to extract enough colour, flavour and tannin.

This technique can be carried out aerobically, for example by splashing the wine against the inside wall of the open vat. This exposes the must to oxygen, which can be beneficial for yeast health and avoidance of reductive off-flavours such as rotten eggs. It is also possible to carry out pumping over anaerobically in closed vessels by attaching the hose to a tap at the top of the vessel or simply by keeping the hose close to the cap of skins in an open vessel. It is commonly used on all black varieties, for wines of all price points and qualities and is suitable for use on

Pumping over in a large vat

large vessels. Modern wineries have pumps and hoses installed at each tank, and pump-overs can be pre-programmed to occur at certain times and for certain durations, reducing the need for labour. Pumping over is often referred to by its French name '*remontage*'.

Rack and return – This is similar to pumping over; however, the juice is pumped from one vessel into another vessel. As the juice is being pumped out of the vessel, the cap of skins falls down the vessel. The juice is then pumped from the new vessel in through the top of the original vessel and is sprayed over the skins. This breaks up the cap and mixes the juice and skins thoroughly. It is more extractive than pumping over or punching down. For this reason, rack and return may be used only 1–3 times during the fermentation, alongside punching down and pumping over. It is most commonly used for red wines where medium to high levels of flavour, colour and tannin are desired (e.g. Cabernet Sauvignon- or Syrah-based wines). Rack and return cannot be fully automated and requires labour to set up and monitor the process. It also requires a clean vessel to be available, which can be an issue in wineries that are operating at peak capacity. Rack and return is often referred to by its French name '*delestage*'.

Ganimede® tanks – These specialised tanks bubble CO_2 up through the must/wine. Pressure builds up under the cap, until finally the cap bursts. This technique breaks up the cap quickly and therefore, like rack and return, it is relatively extractive and suited to producing wines with medium to high levels of colour, tannins and flavour intensity, such as Cabernet Sauvignon- or Syrah-based wines. This is a relatively new technique, but one that is becoming increasingly common because it can be fully automated and is therefore less labour intensive than rack and return. However, these specialised tanks are slightly more expensive than standard stainless steel tanks. Oxygen can be used instead of CO_2 if the winemaker wants or needs to expose the must/wine to oxygen during the fermentation.

Rotary fermenters – Rotary fermenters are horizontal, closed, stainless steel tanks. The whole tank rotates and internal blades break up the cap and ensure adequate mixing. The horizontal orientation of the tank increases the surface area between the grape skins and the

In rotary fermenters the cap is mixed in a rotating tank

juice. Rotary fermenters are very effective at extracting and are therefore best suited to the production of wines with medium to high levels of colour, tannin and flavour intensity, such as Cabernet Sauvignon- or Syrah-based wines. The tank can be programmed to rotate at certain times and for a certain amount of time, so labour requirements are low. This type of fermenter is commonly used for high-volume, inexpensive or mid-priced wines that are acceptable or good in quality. They are very effective at extracting, and techniques that are gentler or allow a bit more precision are usually preferred for very good to outstanding, premium-priced wines. These tanks are relatively expensive compared to standard stainless steel tanks and therefore large volumes of wine need to be fermented in them to make them cost effective.

Other Maceration Options During Fermentation

There are some less common ways that winemakers can choose to increase the colour, flavours and/or tannins in their wines. The following techniques would be used in addition to cap management techniques.

Must concentration – Although not strictly a way of increasing extraction, the levels of colour, flavours and tannins of the wine can be increased by drawing off some of the juice just after crushing and before the start of the ferment, concentrating the remaining must. This lowers the volume of red wine that will be made from a set weight of grapes, which has implications for the price of the wine; however, the juice that is removed is typically light in colour, flavour and tannin and can be used to make rosé. This method is often referred to by the French term '*saignée*'. (More information on rosé wines can be found in Specific Options for Rosé Winemaking.)

Co-fermentation – This is the process of fermenting different grape varieties together in the same vessel. The term most commonly refers to the practice of fermenting a small proportion of white grapes (typically up to 5 per cent) within a red wine fermentation. The latter technique is reported to take advantage of some of the phenolic compounds found in white grape varieties that can increase colour intensity and stability through binding with anthocyanins. The white grapes can also contribute aroma compounds (e.g. the terpenes in Viognier give floral and fruity characteristics). However, research into this area shows mixed results, and adding too much of the white grape variety can lead to dilution, and hence lower colour intensity. This technique originated in the Rhone Valley, with the Côte-Rôtie appellation particularly famous for the co-fermentation of Syrah and Viognier. It has since been imitated in many other regions and countries both with Syrah/Shiraz and Viognier, but also a range of other black and white grape combinations. (However, in some cases these are just blends of red and white wines, to benefit from the fruity or floral notes of the white variety, and so the influence on colour stability is diminished.) This technique does not incur any particular costs.

18.3. Whole Berry/Bunch Fermentations

It is also possible to use uncrushed fruit in fermentation. Winemakers can either choose to use whole bunches of grapes or whole destemmed grapes ('whole berries'), and to use either entirely uncrushed fruit or just a small proportion in a crushed fruit fermentation.

If the winemaker intends to use whole bunches, the grapes must be hand harvested. It is very important that the stems of the bunches are fully ripe. Stems can add flavours that are sometimes described as 'spicy' or 'herbal' and can also add some tannins. However, unripe stems can add unpleasant green flavours and bitter tannins. Winemakers can also choose to add stems (left over from the destemming process) to crushed fruit fermentations to provide some tannins and spicy flavours. It is not common to include stems when fermenting grape varieties with naturally high tannins, such as Cabernet Sauvignon.

The objective of whole berry/bunch fermentations is to create an oxygen-free environment for the uncrushed fruit. The lack of oxygen has several outcomes. The grapes change from aerobic respiration to anaerobic metabolism. In the anaerobic process, some of the sugar in the grapes is converted to alcohol. This occurs without the involvement of any yeast and is referred to as intracellular fermentation. Malic acid within the grape is also broken down to create ethanol. This can reduce the malic acid levels by up to 50 per cent, lowering the total acidity and raising the pH of the must/wine. Glycerol levels increase, which can add texture, and a range of distinctive aromas is created inside the grape, commonly including kirsch, banana, bubble gum and cinnamon.

These techniques themselves do not have a significant impact on costs, and it is more likely that other parts of the production process (e.g. hand-harvesting, sorting of fruit, use of oak if desired) will have greater impact on the price of these wines.

There are three forms of whole berry/bunch fermentation:

CARBONIC MACERATION

This involves placing only whole, uncrushed bunches into vessels that are filled with CO_2 to remove all the oxygen. This causes the intracellular fermentation to start, producing about two per cent alcohol by volume. At this point, either the grapes are crushed in the normal way or the grape skins start to split and the grapes release their juice. Normal fermentation commences. The juice is generally drained immediately (no further maceration on the skins), and the grapes are pressed at this stage to separate the juice from the skins. The free run juice and press juice are typically blended. Yeast then complete the fermentation off the skins.

Importantly, this method extracts colour from the grapes, but little tannin (the alcohol is only around 2 per cent when the grapes are pressed, and tannin is most easily extracted in the presence of alcohol). The resulting wines typically have low tannins with distinctive notes from intracellular fermentation, alongside the fruit notes from the grape variety. The flavours of oak are usually not a desirable addition to the fruity, candy-like flavours of these wines, which can keep production costs relatively low.

These wines are defined by their fruity, low tannin profile and are best consumed within a year after harvest. The flavours created are distinct, but not especially complex. However, in some cases they may improve grapes that have been grown at high yields or that have not reached full ripeness. This technique therefore tends to be used for acceptable or good, inexpensive and mid-priced wines. Beaujolais is a region famous for using this technique on some of its wines, particularly Beaujolais Nouveau.

SEMI-CARBONIC MACERATION

This is a similar but slightly different technique that does not involve filling the vessel with CO_2. The vessel is filled with whole bunches. The grapes at the bottom of the vessel are crushed under the weight of the grapes above and some juice is released. Ambient yeast start to ferment the juice (cultured yeast can also be added). This fermentation produces CO_2, which fills the vessel and the remaining intact grapes undergo carbonic maceration. As the intact grapes begin to split and release their juice, the grapes are pressed and the yeast complete the fermentation off the skins.

If the winemaker wants to make a wine with slightly more concentration, body and tannin, and hence a longer ageing capacity, the alcoholic fermentation may continue on the skins and involve some punching down or pumping over. An ever-decreasing amount of carbonic maceration takes place until all the grapes are broken up. The alcoholic fermentation may be followed by a post-fermentation maceration and/or maturation in oak to add complexity (with the cost implications associated with these techniques). This approach can lead to a better integration of the aromas from intracellular fermentation with aromas from the grape variety. It results in wines with more fruitiness and a softer mouthfeel than crushed fruit fermentations, and is a technique sometimes used when making fruity styles of Pinot Noir, Malbec, Tempranillo, Gamay and Carignan, among other grape varieties.

WHOLE BERRIES/BUNCHES WITH CRUSHED FRUIT

A further variation is to mix whole berries/bunches with crushed grapes in the fermenting vessel at the start of the fermentation. If whole bunches are used, care is needed that the stems are ripe as they will be macerating in the juice/wine during the fermentation.

Although the whole berries/bunches in the vessel are not blanketed in CO_2, they are largely submerged by the crushed grapes and kept away from oxygen, therefore intracellular fermentation takes place. More 'carbonic' characteristics can be achieved by raising the percentage of whole berries/bunches that are present at the start of the fermentation. The whole berries/bunches are progressively crushed during the fermentation as the cap is regularly punched down. Similar to semi-carbonic maceration, a period of post-fermentation maceration and/or oak maturation may follow. It is difficult to define the effect of whole berries/bunches with crushed fruit due to the many ways that winemakers use this technique; however, it is generally thought to give a smoother texture and more vibrant and fresh primary aromas (than crushed fruit fermentations). It is used on a wide range of grape varieties and wines of different qualities and prices.

18.4. Fermentation Temperatures and Vessels for Red Wines

Red wines are usually fermented at warmer temperatures than white wines because higher temperatures help to promote extraction. However, warm temperatures can cause volatile, fruity aromas to evaporate, so, depending on the style of wine, a balance needs to be struck. Winemakers wanting to produce fruity, low tannin wines will typically ferment at relatively cool temperatures (e.g. 20°C / 68°F). Winemakers wanting greater extraction to produce wines with the concentration and tannin structure to age, may ferment at slightly warmer temperatures (e.g. 30°C / 86°F). The temperature can be monitored and controlled throughout the fermentation to increase or reduce the extraction of certain compounds (e.g. cooling the ferment near the end to avoid excessive tannin extraction) and also to generally promote a healthy ferment to dryness (see Alcoholic Fermentation in General Winemaking Options).

Large oak vats are more common than small barrels for red wine fermentation.

Red wines may be fermented in stainless steel, concrete or wooden vessels. These can be open at the top, which is needed for extraction techniques such as punching down, or closed vessels. If oak is used for fermentation, it is generally in the form of a large vat; however, small oak barrels (e.g. 225–500 L) are sometimes used. The barrels are kept on their side, with one of the heads removed to form a very small, open top fermenter.

Managing fermentations in these vessels is extremely labour intensive, and therefore typically limited to premium- and super-premium priced wines. It is thought that fermentation in oak gives a rounder mouthfeel to the wine and leads to better integration of oak compounds during maturation. Concrete and stainless steel help to retain fruit flavours.

For details regarding choice of yeast for fermentation see Alcoholic Fermentation in General Winemaking Options.

18.5. Post-Fermentation Maceration

Some winemakers may choose to leave the wine macerating on the grape skins for a period of time (from a few days to a few weeks) after fermentation. This practice is thought to further extract tannins and encourage the polymerisation of tannins, with the aim of improving tannin structure and texture and the wine's ageing potential. These effects mean that it is generally conducted on premium and super-premium, very good and outstanding wines that are intended for ageing. Post-fermentation maceration also takes up tank space and time, so it is often not possible or desirable from a logistical point of view in the production of high-volume, inexpensive wines.

18.6. Pressing the Wine

Pressing separates the wine from the skins and therefore takes place when no more extraction is desired. For options about the types of press used for red wine, as for white, see Pressing in General Winemaking Options. Red wine is usually better protected against the effects of oxidation than white wine, so techniques such as flushing the machines with inert gas are less widely practiced. The free run wine will be drained from the fermentation vessel, and the mass of grape skins then removed for pressing. The free run wine contributes fruity flavours and is lower in tannins than the press wine. Press wine may be mixed with free run wine as a blending component to add extra colour, flavour and tannins. The quality of the fruit and management of the press are important considerations with high quality grapes. The gentle first pressings may enhance the tannin structure of a wine. The press wine from lesser quality grapes and rougher pressing can increase bitterness. Press wine that is not wanted may be sold to another winery or for distillation.

The timing of pressing is relatively variable in red wines (compared to white wines) and depends on the style of wine being produced. For wines that have been made by carbonic maceration, pressing may occur when the fermenting must reaches 2% abv to produce a wine with medium levels of colour and fruity flavours but low tannins. At the opposite end, some red wines will be pressed after a period of post-fermentation maceration to maximise the tannin structure of the wines. The winemaker also has the option to press straight after alcoholic fermentation is complete (the wine is dry), or press just before the end of alcoholic fermentation, usually with the intention that the wine will finish fermenting in barrels. This latter practice is thought to lead to a better integration of oak flavours and rounder mouthfeel.

18.7. Malolactic Conversion for Red Wines

Malolactic conversion is routinely carried out for red wines. However, the winemaker can choose the vessel in which malolactic conversion occurs; it is felt that malolactic conversion in oak barrels can lead to a better integration of oak characteristics during maturation. The winemaker can also decide whether to encourage malolactic conversion to occur during alcoholic fermentation, or whether it will take place after fermentation has ended (for more details, see Malolactic Conversion in General Winemaking Options).

Malolactic conversion will decrease the acidity and increase the pH of the wine. It is possible to adjust the acidity of the wine as necessary (this adjustment can also be made at the must stage). It is also possible for winemakers to reduce the alcohol of the wine at this stage (for more details, see Post-Fermentation Adjustments).

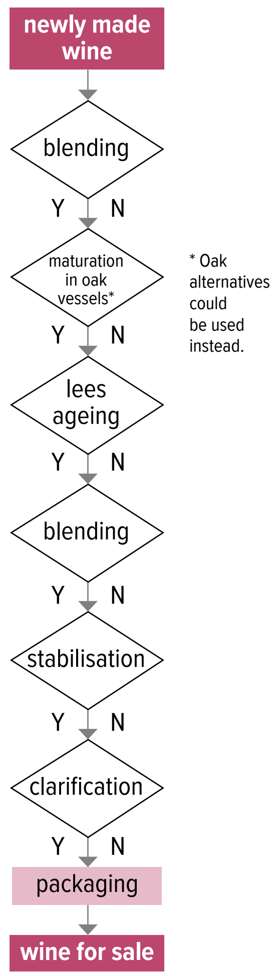
18.8. Maturation in Wooden Vessels for Red Wines

As with white wines, maturation in oak vessels can have a significant impact on the style of a red wine. However, maturation in oak is generally much more common for red wines than white wines, particularly for wines that are mid-priced or more expensive. For more details on maturation in oak vessels, see The Role of Wood in Maturation.

Inexpensive red wines are likely to be released soon after fermentation for cost and logistical reasons, and therefore do not generally undergo maturation in barrel. The winemaker may choose to obtain the spicy flavours of wood from oak alternatives such as staves, which can be inserted into a stainless steel tank or concrete vat and can provide oak flavours cheaply and quickly.

The majority of mid-market, premium and super-premium red wines will be matured in oak vessels for a range of time, typically between six months and two years (see The Role of Wood in Maturation). A proportion of new oak may be used if the winemaker feels the flavours of oak (vanilla, cloves, etc.) would enhance the complexity of the wine. Furthermore, the gentle oxidation that occurs, particularly in small oak vessels such as barrels, helps to soften tannins and can lead to the development of tertiary aromas and flavours that can enhance complexity and quality. (These tertiary characteristics will develop over time and therefore, in standard cool cellar conditions, are more likely to be present in a wine that has been aged for a couple of years, rather than a few months.)

It is possible to find examples of mid-market and premium red wines that have not been matured in oak or have only undergone a minimal period of ageing in old oak; usually in cases where the winemaker wants the focus to be on the primary aromas and flavours of wines. Examples include the unoaked styles of Loire Valley Cabernet Franc, Spanish Mencía and Argentine Malbec, among others. However, these are exceptions, and the majority of wines from these regions and grape varieties will be matured in oak.



Specific Options for Red Winemaking (Maturation, Finishing and Packaging)

However, there has been a trend in many wine regions over the last few years to use less new oak, and hence gain more subtle oak flavours alongside the primary fruit.

18.9. Lees Ageing for Red Wines

Lees ageing can help soften tannins in red wines. However, a possible disadvantage is reduced colour intensity. Racking can be used to separate the wine from the lees, and therefore control the amount of lees present in the vessel throughout the maturation process. It is not typical to keep gross lees nor to stir the lees when making red wines.

18.10. Blending, Finishing and Packaging for Red Wines

Explanation of the final stages in the wine production process can be found in Blending and Finishing and Packaging.

19 Specific Options for Rosé Winemaking

Rosé wines come in an array of styles. They range from those with pale colour and subtle fruity characteristics to those that are much more deeply coloured and with more obvious character from the black grapes that they were produced from. Rosé wines also range in sweetness, from dry to medium-sweet.

This chapter will focus first on the key methods of influencing colour and aroma in rosé wines and look at other options within their production such as grape growing practices, harvesting decisions and fermentation and maturation options.

19.1. Key Methods to influence Colour and Aroma in Rosés

There are three key ways of making rosé wines.

DIRECT PRESSING

Direct pressing makes some of the lightest-coloured rosés. The grapes of a black grape variety are either whole bunch pressed or destemmed (possibly crushed) and immediately pressed to minimise any maceration. Pneumatic presses are typically used and will often be flushed with inert gas to avoid oxidation of the aromas and flavours and browning of the

Pale rosés such as these are generally made by direct pressing or very short maceration.

delicately-coloured juice. The juice is then fermented like a white wine. This technique can produce rosés that are the lightest in colour; however, this will depend on the pressure used when pressing, the duration of the pressing time (a longer pressing time can increase the time of maceration) and how much press juice is used. Wines made by this method are often called '*vin gris*' and they include many of the lightest-coloured Provence wines. Depending on local legislation in force, white grapes can also be co-pressed and co-fermented with black grapes in this process to lend extra acidity and help achieve a paler colour. For example, Rolle (Vermentino) is allowed within the production of the rosé wines of Côtes de Provence.

SHORT MACERATION

Rosés can also be made with a short period of pre-fermentation maceration before pressing. During this time, the must may be protected with inert gas to avoid oxidation and the threat from spoilage organisms. The longer the maceration, the more colour, flavour and, to a lesser extent, tannin will be extracted. The maceration may last a couple of hours to a few days. At the end of maceration, the juice will be drained and the grape skins may be gently pressed. It can then be fermented like a white wine. This technique often, but not always, produces rosé wines that are deeper in colour and more pronounced in flavour than those from direct pressing. Rosé wines with short maceration may include more traditional styles of Spanish rosés (not made in 'Provence' style) and the rosés of Tavel.

Rosé wine made by short maceration is sometimes the by-product of must concentration in red wine production; a technique often referred to by the French term *saignée*, meaning 'bleeding' (see Must Concentration in Crushed Fruit Fermentations). Bleeding off some of the juice (which may then be used for rosé production) concentrates the remaining must and this may be used to enhance the red wine being made. This means that the production of such rosés is relatively cost effective. The potential disadvantage of this method, from the perspective of rosé wine production, is that the black grapes will have been grown and harvested as if they were going to make red wine, and therefore the juice that goes on to make the rosé wine may be less suitable for this latter style of wine (e.g. lower in acidity) than if it were to come from grapes that have been grown specifically for rosé production. However, quality-conscious producers can make both good- to outstanding-quality rosé and red wines using this technique.

BLENDING

Blending to make rosé involves mixing a small proportion of red wine with a much larger proportion of white wine. This imparts a pink colour while retaining the aromas and flavours of the white grape variety. In this way, for example, Sauvignon Blanc Rosé takes advantage of the current popularity of white Sauvignon Blanc.

In locations where red and white wines used for blending are already in production, for sale separately as red and white wines, the blending method of rosé production is simple and cheap. In terms of still wine production, it is often used for inexpensive wines. However, blending red and white wines to make rosé is not allowed in many geographical indications within the EU. Among exceptions are Champagne and Franciacorta. The restrictions remain in place as some EU rosé producers argue that this method lowers the quality of rosé production.

Colour is a vitally important characteristic of rosé wines. They are often packaged in clear glass so that their colour can be clearly seen, and consumers will often purchase or not purchase these wines based entirely on their colour (pale colours are often associated with dry styles, whereas more deeply coloured rosés are often associated – sometimes wrongly – with off-dry, medium-dry and medium-sweet styles). Colour decreases during the fermentation process and this means that, when making wines by direct pressing or short maceration, a certain amount of predictive skill and experience is required to achieve the desired colour in the final wine. In the blending method, the white and red wines are already fermented and therefore the shade of the final rosé wine is much easier to control.

19.2. Other Options in Making Rosé Wines

VITICULTURE FOR ROSÉ WINES

It is usually desirable for rosé wines to have medium to high levels of acidity, low to medium levels of alcohol and fresh fruit flavours. Grapes for good- to outstanding-quality rosé wines therefore tend to be grown:

- either in cool or moderate regions or cool to moderate sites within warmer regions. The cooling influence may come from latitude, altitude, aspect (facing away from the equator) and/or proximity to large bodies of water/the coast. It is also common for yields for rosé wines to be higher than for red wines, slowing down ripening and helping to produce grapes with less concentration.
- alternatively, in warmer climates, grapes will be picked early to retain fresh fruit and acidity.

The current market trend is for rosés that are pale in colour with minimal tannins, and therefore black grape varieties that have low or medium levels of colour and tannins tend to be easier to make into this style of rosé.

Night harvesting allows grapes to be picked when cool, limiting oxidation and the threat from spoilage

organisms.

The harvest time for grapes destined for rosé wines tends to be earlier than that of black grapes used to make red wines (unless the rosé wine is being made as a by-product of red winemaking). This helps to retain acidity (rosés are generally made to be refreshing) and obtain delicate, fresh red fruit characteristics. If wines are made by short maceration, it is important that tannins are ripe to avoid any extraction of green flavours. This is less important for wines made by direct pressing.

Harvesting may be carried out by machine or hand. Hand harvesting allows whole bunch pressing to gain a juice that is low in colour. Machine harvesting can be beneficial in warm climates where harvesting at night means that grapes can remain cool until they arrive at the winery. Machine harvesting is also quick if large volumes need to be picked at a certain level of ripeness, and can also be cheaper in such circumstances.

FERMENTATION, MALOLACTIC CONVERSION AND MATURATION FOR ROSÉ WINES

Pre-fermentation adjustments may be made to the acidity or sugar levels as needed (for more details see Must Adjustments).

Rosé wines are usually fermented at cool temperatures (12–16°C / 54–61°F) to promote the production and retention of aroma compounds. Stainless steel tanks are often used because they are neutral and allow control of temperature. Oak vessels (new and old) are occasionally used to provide more texture; although, these are usually a more expensive option than stainless steel tanks. If using oak vessels (as with oak maturation), the wine must have enough fruit concentration to not be overwhelmed by the influence of the oak. Cultured yeast strains are used in the majority of cases, and certain strains may be selected to enhance fruity flavours.

Rosés that have residual sugar are typically made by stopping the fermentation before it reaches dryness or by blending a sweetening component with the dry rosé wine (for more details on these processes, see Specific Options for Producing Wines with Residual Sugar).

Malolactic conversion is usually avoided in the production of rosé wines; buttery flavours are not wanted as they would mask the fresh fruit aromas that are appealing in these wines. Also, many rosés are designed to be refreshing to drink and therefore winemakers are often looking to retain acidity.

The wine may mature for a short period on the lees and/or in oak vessels (new or old) if the winemaker wants to add texture and body to the wine. New oak adds oak flavours, such as vanilla and clove, and is used by a few producers who are looking to create a different style of rosé (often more suited to pairing with food). Wines matured on lees or for a period of time in oak are likely to be at least mid-priced because of the time spent in storage in the winery and the cost of any barrels.

Blending red and white wine is a method of gaining colour to produce rosé wines, however, many rosés (including those made by direct pressing and short maceration) will be blended just before finishing and packaging. This may be for a number of reasons, for example, to adjust the colour and flavour profile or to ensure consistency of colour across batches.

The appearance of rosé wines is an important part of their appeal and therefore the majority of rosé wines will be fined and filtered to increase their clarity. Sterile filtration is also important for wines that have some residual sugar to avoid the presence of unwanted microbes that could otherwise feed off this sugar in the bottle.

20 Examples of Winemaking Choices for Different Styles of Wine

The examples over the next pages have been provided to illustrate what choices in the winery may be made for different types of wine and importantly the reason why these choices may be made and their influence on the style, quality and price of the wine.

These are not intended to be comprehensive. There are obviously other categories of wines that are not covered here (e.g. high volume rosé wines, premium sweet wines to name a couple) and whilst many of the main choices, reasons and influences have been highlighted, there may be others that it was not possible to add without the tables becoming even longer. However, these tables do illustrate how the influence of a winemaking option on the style, quality and price of a wine can be explained.

20.1. Producing Inexpensive, High-Volume Dry Wine from an Aromatic White Grape Variety

The key aim is to make a wine of acceptable or good quality (adequate concentration of primary aromas and flavours; balance between acidity, alcohol and flavours) whilst minimising costs. Efficient use of equipment and tank space also has an implication on costs and therefore options may be favoured that allow the winery to produce the maximum amount of wine for the winery capacity.

Process	Choice	Reason	Influence on style, quality and price
Harvest	Machine harvest	Quicker than hand harvest. Usually significantly cheaper than hand harvest. Allows cooler night harvesting.	Cheaper than hand harvesting for large vineyards, helping to keep price of wine low.
Transportation to winery	Transport during the night or early morning if viable. Otherwise transport during day.	Chance to transport cool grapes. Grapes transported during the afternoon likely to be warm.	Cool grapes less affected by oxidation and microbial spoilage, better for quality, retains aromatic fruity style. Warm grapes more at risk of oxidation and microbial spoilage.
	Addition of SO_2	Protection from spoilage organisms and oxidation.	Retains quality.

Process	Choice	Reason	Influence on style, quality and price
Grape Reception	Limited sorting (MOG only)	Sorting costs in terms of time, labour, equipment and lowering yield.	Keep costs and therefore price of wine low.
	No skin contact	Slows processing time and may add tannins that are not desirable.	Keeps costs and therefore price of wine low. Style of wine suitable for target consumer.
Pressing	Pneumatic press	Can take large press loads. Possible to flush with inert gas.	Keeps costs and therefore price of wine low. Protection from oxidation and spoilage organisms, better for quality, retains aromatic fruity style.
Adjustments	Made as necessary – acidification, deacidification or chaptalisation	Depends on the ripeness of the grapes.	Can help enhance the balance of the wine, which improves quality. Moderate cost.
Must clarification	Flotation, centrifugation, clarifying agents	All methods that speed up clarification, relative to sedimentation.	Speeds up processing, therefore, plays a role in reducing costs.
	Low level of solids	Complexity from high level of solids not desirable. Fermentation with high level of solids needs regular monitoring.	Retain aromatic fruity style. Keeps labour costs and therefore, price of wine low. Less risk of off-flavours that could reduce quality.
Hyperoxidation	No hyperoxidation	Would reduce aromatic compounds.	Retain aromatic fruity style.
Yeast for alcoholic fermentation	Cultured yeast	Reliable, potential to increase aroma release and creation.	Less risk of stuck ferments and of off-flavours that could reduce quality. Create and retain aromatic fruity style.

Process	Choice	Reason	Influence on style, quality and price
Vessel and temperature during fermentation	Cool temperatures (12–16°C / 54–61°F) in stainless steel tank	Enhance and retain aromatic compounds. Stainless steel tank used for ability to control temperature and ease of cleaning.	Create and retain aromatic fruity style. After initial investment in computerized, temperature- controlled stainless steel tanks, costs can be recovered through high volume working and fast throughput.
Malolactic conversion	Avoid	Retain aromatic compounds, avoid buttery flavours	Retain aromatic fruity style.
Blending	In addition, wines may be blended with other wines to maximise volume or to achieve continuity of style.	Maximize volume of wine produced at acceptable quality level.	Acceptable quality. Maximize the amount of wine to sell.
Maturation	Lees ageing generally avoided	Takes time and requires monitoring.	By releasing the wine as quickly as possible, costs and therefore price of wine are kept low. However, lees aging would add texture, and therefore this way of enhancing quality is missed.
	Storage in stainless steel or concrete.	Characteristics of new oak not desired for aromatic style of wine.	Retain aromatic fruity style. By releasing the wine as quickly as possible costs and therefore price of wine are kept low.
Finishing	Tartrate stabilisation – contact process, metatartaric acid or CMC	Consumers will not accept tartrate crystals. CMC or metatartaric acid are quicker and less expensive in terms of energy than cold stabilisation.	Maintain quality expected by consumers. Costs and therefore the price of wine are kept low by releasing the wine as quickly as possible.

Process	Choice	Reason	Influence on style, quality and price
	Fining	Ensure wine stays clear and bright.	Maintain style and quality.
	Sterile filtration	Avoid risk of any faults developing in bottle.	Maintain style and quality.
Packaging	Glass bottle, PET, bag-in- box, can	This wine is for immediate consumption and therefore all formats of packaging are suitable.	Providing wine is drunk within a year of release from winery, no negative impact on quality.
	Screwcap	Screwcap likely to be a popular choice in many markets due to low OTR, much lower risk of cork taint and cheaper price (compared to high quality cork).	Suitable for retaining aromatic fruity style. Keeps costs and therefore price of wine low.

20.2. Producing Premium Small-Volume Dry Wine from a Neutral White Grape Variety

The key aim is to make a wine of outstanding quality with concentrated primary aromas and flavours, usually with complexity from secondary flavours and balance between acidity, alcohol and flavours. Production costs are not the most important factor. The wine will be sold as an outstanding example of its type made from high quality fruit with the winemaker aiming to showcase the fruit in the best way.

Process	Choice	Reason	Influence on style, quality and price
Harvest	Hand harvest	Allows for sorting in the vineyard to pick only healthy, fully ripe bunches and allows for initial sorting to be carried out in the vineyard	Grapes picked at optimum ripeness (generally avoiding underripe or extra-ripe flavours), better for quality. Typically, significantly more expensive than machine harvesting.

Process	Choice	Reason	Influence on style, quality and price
	Grapes picked in the coolest hours of morning and evening during hot weather. The grapes may also be stored in a cold storage on arrival at the winery.	Cool grapes are less affected by oxidation and spoilage organisms.	Retains primary fruit quality, enhancing overall quality. Chilling in cold storage adds cost while protecting quality.
Transportation to Winery	Transport in small crates	Grapes collected and transported in small crates to limit damage and reduce crushing to minimum.	Negative effects on quality are avoided by minimizing crushing and reduces the threat from spoilage organisms or fermentation starting before reaching the winery.
	Addition of SO_2	Protection from spoilage organisms and oxidation.	Retains quality.
Grape Reception	High levels of sorting. Various options – sorted by workers on sorting table, on a moving/ vibrating belt or optical sorting.	Elimination of MOG, under or extra-ripe grapes or bunches and of diseased or mouldy fruit.	Each level of sorting raises potential quality by removing substandard grapes and adds cost (time, labour, equipment). Removing grapes also reduces volume of wine produced, and this has an implication on the price the wine needs to sell at for the winemaker to make a profit.
Press	Pneumatic or basket press	Both are gentle forms of press.	Low extraction of unwanted phenolics. Basket presses take smaller loads and, depending on the volume of grapes, can be more labour intensive and therefore more expensive.

Process	Choice	Reason	Influence on style, quality and price
	Option: whole bunch press	Less oxidation as no prior stage of crushing, especially if grape bunches are covered with an inert gas. Low extraction of tannins	Creates a smoother mouth feel. Whole bunch pressing is slow and more expensive than pressing crushed grapes.
Must clarification	Sedimentation	Sedimentation is typically chosen as the method of clarification as it is traditional and involves the least manipulation. Additionally, there is often less pressure to speed up the winemaking process, compared to high-volume production.	Clarifying must can lead to less clarification post-fermentation with the aim of retaining delicate aromas and flavours.
	Option: retain a relatively high proportion of solids	A proportion of solids may be retained to increase complexity of aromas.	Increase in complexity of aromas, with possibly low levels of reductive sulfur compounds. Less fruity aromas and flavours.
Hyperoxidation	Option: hyperoxidation may be carried out in some cases.	Oxidises at this point the compounds which are most prone to oxidation. Remove bitter compounds.	Smoother final wine and one less prone to later oxidation. This adds cost as this is a further procedure to be carried out.
Adjustments	Made as necessary	As great care has been taken with the picking date (and therefore the balance of fruit ripeness and acidity level), adjustments will be minimal. In some years, wines may need to be chaptalized or the acidity adjusted.	Can help enhance the balance of the wine, which improves quality.

Process	Choice	Reason	Influence on style, quality and price
Fermentation Vessel	Option: rack to barrels Fermentation in barrel is an option for high quality white wines, e.g. Chardonnay or Bordeaux blend	If new barrels used, this adds oak flavours. If old barrels are used, there will be gentle exposure to oxygen. There may be variations between the barrels and this gives the winemaker more blending options.	Deeper colour, fuller body, above all better integration of the flavours of oak and primary fruit.
	Option: ferment in neutral container. High quality white wines such as Alsace Pinot Gris Grand Cru are typically fermented in large old wood vessels, concrete or stainless steel.	No added oak flavours desired.	Preserves the primary fruit.
	Option: ferment in concrete eggs. Concrete eggs give a further option, often to produce a portion of the final wine for blending	The shape of the egg is said to set up convection currents mixing the fermenting must and the lees	Adds a portion of the wine which can then be blended into the final wine for additional complexity. Adds cost as the eggs are expensive to buy, contain relatively little wine and are additional vessels to monitor.
Alcoholic fermentation and yeast	Option: ambient yeast	Ambient yeast may have a range of species present and may contribute complexity. No additional product is required.	Promotion of distinctive aroma/flavour characteristics in the wine

Process	Choice	Reason	Influence on style, quality and price
	Option: cultured yeast	Cultured yeasts chosen for neutrality or for promoting aromatic traits; and for reliable ferment to dry.	Possible promotion of certain selected aroma/ flavour characteristics, or production of relatively neutral wine to which flavours and texture from oak and lees can be added.
Temperature during fermentation	Moderate temperature (17–25°C / 63–77°F)	Up to 20°C / 68°F for Pinot Gris Grand Cru to retain fruitiness but avoid low-temperature esters. Up to 25°C / 77°F for barrel-fermented Chardonnay to avoid low-temperature esters.	Pinot Gris: maximum fruit expression. Chardonnay: fruit expression and added complexity.
Malolactic conversion	Option: avoid malolactic conversion	To retain primary fruit flavour and acidity (for example in Alsace Pinot Gris).	Fruitier, no buttery aromas. Higher acidity than if malolactic conversion was encouraged.
	Option: encourage malolactic conversion	If choice is full malolactic conversion, then this slightly lowers acidity and can add buttery flavours (for example, white Burgundy).	Slightly lower and more rounded acidity, additional complexity of buttery notes, less fruity.
		Some will choose for a part of the wine to go through malolactic conversion creating options for blending for the final wine.	Part malolactic conversion: create further complexity by creating blending options for final wine.

Process	Choice	Reason	Influence on style, quality and price
Blending	Choosing the lots that reach the quality standard and the style required.	Attain the quality required: flavour intensity, balance between flavour and acidity.	Final wine to show the flavour intensity and balance required. Where lots are not used in the top wine, this leads to a potential loss of income.
	Blending of multi-varietal wines or of lots of single varieties	Create the final blend for optimum quality. Choosing: • the precise proportions of the varietal components if a multi-varietal blend; • the best blend if blending the components of a single variety. The choice may be from fermentation in different types of vessel, from full or partial malolactic conversion lots or from slightly different expressions in individual barrels.	Maximize complexity and balance. Where lots are not used in the top wine, this leads to a potential loss of income.
Maturation	Option: small oak barrels	If an oaked style is desired, then wine can be aged in small barrels to add oak flavours and to age the wine in a mildly oxidative process. Wines will also begin to clarify naturally due to time of maturation.	Deeper colour, fuller body, addition of vanilla/ sweet spice oak notes, start of the development of tertiary characteristics. Additional cost of barrels and of monitoring the wine and racking it as required.

Process	Choice	Reason	Influence on style, quality and price
	Option: large barrels or stainless steel	Time in neutral containers allows flavours to integrate and for the wine to lose the aromas of fermentation esters associated with very young wines. Wines will begin to clarify naturally due to time of maturation.	Best expression of primary fruit flavours. Additional costs are the requirements for more large containers for the maturing wine, the space to house them at the appropriate temperature and the need to monitor them and rack them as required.
	Lees ageing	Adds texture while retaining freshness	More textured palate, additional costs due to keeping the wine and monitoring its development on the lees.
	Option: lees stirring	Lees stirring can add body to the wine and lessens the chance of reduction.	Adds body, aroma compounds and, lessens the chance of reductive sulfur compounds forming. Additional costs due to the work of stirring the lees and monitoring the wine's development.
Final blend	Final blend of lots or barrels	Final blending to create the desired style of the wine	Overall balance of fruit, oak, acidity and desired level of complexity. The cost is if some barrels of wine are not included in the final blend and are sold for less.

Process	Choice	Reason	Influence on style, quality and price
Finishing	Tartrate stabilisation	Consumers of premium wines may not accept tartrate crystals. If this is regarded as an issue, wines can be stabilised. Cold stabilization is the most likely option as it is traditional and involves the least manipulation.	Maintain quality and style and avoid what some consumers may see as a fault.
	Option: sedimentation	Some makers of premium wines believe that quality is preserved by the fewest possible interventions. They may wish to avoid fining and filtering the wine. Sedimentation to clarify the wine is the main option in this case.	Maintain quality and style. Additional cost as wine has to be stored until it is clear.
	Option: fining	Ensure wine stays clear and bright.	Maintain style and quality.
	Option: sterile filtration	Avoid risk of any faults developing in bottle.	Maintain style and quality.
Packaging	Glass bottle	Only glass is suitable for wines which are intended to age as it is impermeable to oxygen.	Maintain style and quality and offer possibility of further ageing in the bottle.
	High quality cork or other high quality closures	Most premium wine bottled under high quality cork. This is partly because this is what consumers expect of high quality wines and partly because they offer the potential to age the wine further in bottle. Some premium producers will choose either a screwcap or a high quality technical cork with low oxygen transfer rate, or glass stoppers.	Maintain style and quality and offer possibility of further ageing in the bottle. Both high quality natural cork and glass stoppers are costly options.

20.3. Producing Inexpensive, High-Volume Dry Red Wine

The key aim is to make a wine of acceptable or good quality (adequate concentration of primary aromas and flavours; balance between acidity, alcohol and flavours) while minimising costs. Efficient use of equipment and tank space also has an implication on costs and therefore options may be favoured that allow the winery to produce the maximum amount of wine for the winery capacity.

Process	Choice	Reason	Influence on style, quality and price
Harvest	Machine harvest	Quicker than hand harvest. Usually significantly cheaper than hand harvest. Allows night harvesting. Fruit is already removed from the stems and so does not need destemming.	Cheaper than hand harvesting for large vineyards, helping to keep price of wine low.
Transportation to Winery	Transport during the night or early morning if viable. Otherwise transport during day.	Chance to transport cool grapes. Grapes transported during the afternoon likely to be warm.	Cool grapes less affected by oxidation and microbial spoilage, better for quality, retains primary fruit. Warm grapes more at risk of oxidation and spoilage organisms.
	Addition of SO_2	Protection from spoilage organisms and oxidation.	Retains quality.
Grape Reception	Limited sorting (MOG only)	Sorting costs in terms of time, labour, equipment and lowering yield.	Keep costs and therefore price of wine low.
Adjustments	Made as necessary – acidification or deacidification, chaptalisation, adding of tannins	Depends on the ripeness of the grapes.	Can help enhance the balance of the wine, which improves quality. Moderate cost.

Process	Choice	Reason	Influence on style, quality and price
Option: crushed fruit fermentation	Grapes are crushed to release the juice and begin the process of fermentation. Cold maceration unlikely.	Facilitate the beginning of fermentation and of the extraction of colour, aroma compounds and tannins from the skins. Cold maceration not practiced as it would slow down processing.	Adequate depth of colour, flavour and level of tannins.
Option: carbonic or semi-carbonic maceration	Promoting initial intracellular fermentation	Make fruity wines with a low tannin profile	Distinctive kirsch and banana fruitiness, wines for early release and consumption.
Option: extraction using heat	Options of either *flash détente* or thermovinification	Rapid extraction of colour and low level of tannins. Wine then can be vinified quickly like white wine (no need for extended period of maceration on the skins).	Wines produced are fruity and low in tannins, suitable for early sale and consumption. Thermovinification has additional costs (heat source) but these can be offset by the time and tank space saved. *Flash détente* requires substantial initial investment which can be recovered by large volume production. These costs can be offset by the time and tank space saved.
Yeast for alcoholic fermentation	Cultured yeast	Reliable, potential to increase aroma and flavour release and creation.	Less risk of off-flavours that could reduce quality. Create and retain fruity style.
Vessel and temperature during fermentation	Relatively cool temperatures (for red wine, 17–25°C / 63–77°F) in stainless steel tank	Sufficiently high temperature to extract flavour and tannins but cool enough to retain fruity aromas. Stainless steel tank used for ability to control temperature and ease of cleaning.	Create and retain fruity style. After initial investment in computerized, temperature-controlled stainless steel tanks, costs can be recovered through high volume working and fast throughput.

Process	Choice	Reason	Influence on style, quality and price
Cap management	Cap management (in standard tank): mechanised pump over and/or punch down.	Extraction of desired amount of colour, aroma compounds and tannins. Rack and return would require the availability of additional empty vessels.	Fruity wine with desired colour intensity and a medium level of tannins.
	Option: rotary fermenter	The whole tank rotates and internal blades break up the cap and ensure efficient extraction.	Best suited to high coloured, tannin and flavour intense varieties (e.g. Cabernet Sauvignon or Syrah). High initial investment, costs can be recovered through high volume working and fast throughput.
Malolactic conversion	Malolactic conversion will happen routinely but can be carried out during alcoholic fermentation by adding lactic acid bacteria and ensuring the right conditions.	Malolactic conversion during alcoholic fermentation means that the wine can be processed more quickly, freeing up tank space and enabling the wine to be sold sooner.	Smoother, softer style. Greater microbial stability.
Post-fermentation maceration	Usually not carried out. At most, post-fermentation will be short (3–5 days)	Takes time and ties up valuable tank space. Where done, additional extraction from the skins	Fruity wine with desired colour intensity and a medium level of tannins. Additional cost of monitoring the wine and use of fermentation tank space that may be required for another wine.

Process	Choice	Reason	Influence on style, quality and price
Pressing	Pneumatic press either during alcoholic fermentation, at the end of alcoholic fermentation or a few days later.	Pneumatic press can take large press loads. Pressing during the fermentation reduce tannin extraction towards the end of fermentation.	Keeps costs and therefore price of wine low. Pressing during fermentation helps create a wine with relatively little tannin.
Blending	Free run from the press blended with most or all the pressed wine. In addition, wines may be blended with other wines to maximise volume or to achieve continuity of style.	Maximize volume of wine produced at acceptable quality level.	Acceptable quality. Maximize the amount of wine to sell.
Maturation	Wine may be stored according to market demand	If wine is not required immediately it may be stored for 3-4 months.	Fruity style preserved. By releasing the wine as quickly as possible, costs and therefore the price of wine are kept low.
	Option: oak alternatives	Inexpensive addition of oak flavours	Adds additional flavours. Significantly cheaper than using oak barrels.
Finishing	Tartrate stabilisation – contact process or metatartaric acid.	Consumers will not accept tartrate crystals. Metatartaric acid is quicker and less expensive in terms of energy than cold stabilisation.	By releasing the wine as quickly as possible costs and therefore the price of wine are kept low.
	Fining	Ensure wine stays clear and bright.	Maintain style and quality.
	Sterile filtration	Avoid risk of any faults developing in bottle.	Maintain style and quality.

Process	Choice	Reason	Influence on style, quality and price
Packaging	Glass bottle, PET, bag-in-box, can	This wine is for immediate consumption and therefore all formats of packaging are suitable.	Providing wine is drunk within a year of release from winery, no negative impact on quality.
	Screwcap, agglomerate cork or moulded closure	All these options are inexpensive and have a much lower risk of cork taint (compared to natural cork)	Suitable for retaining fruity style for wines for early consumption. Keeps costs and therefore price of wine low.

20.4. Producing Premium, Small-Volume Dry Red Wine for Bottle Ageing

The key aim is to make a wine of outstanding quality with concentrated primary aromas and flavours, usually with complexity from secondary and sometimes tertiary flavours, and balance between acidity, alcohol, flavours and tannins. Production costs are not the most important factor. The wine will be sold as an outstanding example of its type made from high quality fruit with the winemaker aiming to showcase the fruit in the best way with additional complexity from oak ageing.

Process	Choice	Reason	Influence on style, quality and price
Harvest	Hand harvest	Allows for sorting in the vineyard to pick only healthy, fully ripe bunches and allows for initial sorting to be carried out in the vineyard.	Grapes picked at optimum ripeness (generally avoid underripe and extra-ripe grapes), better for quality. Typically, significantly more expensive than machine harvesting.
Transportation to Winery	Transport in small crates	Grapes collected and transported in small crates to limit damage and reduce crushing to minimum.	Negative effects on quality are avoided by minimizing crushing and the threat from spoilage organisms or fermentation starting before reaching the winery.

Process	Choice	Reason	Influence on style, quality and price
Grape Reception	High levels of sorting. Various options – sorted by workers on sorting table, on a moving/vibrating belt or optical sorting.	Elimination of under or extra-ripe grapes or bunches and of diseased or mouldy fruit.	Each level of sorting raises potential quality by removing substandard grapes and adds cost (time, labour, equipment). Removing grapes also reduces volume of wine produced, and this has an implication on the price the wine needs to sell at for the winemaker to make a profit.
Adjustments	Made as necessary	As great care has been taken with the picking date (and therefore the balance of fruit ripeness and acidity level), adjustments will be minimal. In some years, wines may need to be chaptalized or the acidity adjusted.	Can help enhance the balance of the wine, which improves quality.
Option: crushed fruit fermentation (standard option)	Grapes are crushed to release the juice and begin the process of fermentation. Cold maceration optional.	Facilitate the beginning of fermentation and of the extraction of colour, aroma compounds and tannins from the skins. Where cold maceration is carried out, the purpose is to extract colour with minimal tannin extraction	Beginning of process of extraction for desired level of colour, flavour and tannins. Cold maceration leads to deeper coloured wines, especially for low anthocyanin Pinot Noir. Additional costs of energy for chilling and taking up tank space.
Option: retaining whole bunches or whole berries	Fermentation is started including a portion of whole bunches or whole berries	Whole bunches can add spicy/herbal flavours and some tannins. Whole bunches and berries can add a vibrant, fresh fruit character.	Add to the complexity of the final wine. Minimal cost.

Process	Choice	Reason	Influence on style, quality and price
Vessels for fermentation	Stainless steel, concrete or oak	Stainless steel and concrete do not add oak flavours. Some winemakers will choose oak for a rounded mouthfeel and better integration of oak compounds during maturation	Rounded mouthfeel and good integration of oak compounds. Large, high quality oak fermenters are expensive.
Yeast for alcoholic fermentation	Option: ambient yeast	Ambient yeast may have a range of species present and are considered part of *terroir*	Promotion of distinctive aroma/ flavour characteristics in the wine
	Option: cultured yeast	Cultured yeast chosen for neutrality or for promoting fruity traits, and for reliable ferment to dry	Possible promotion of certain selected aroma/ flavour characteristics.
Temperature during fermentation	Relatively high fermentation temperatures (e.g. 30°C / 86°F)	High temperatures promote extraction.	Deeper colour, more flavour, higher level of tannins.
Cap management	Choices from punch down, pump over and rack and return	Punch down by hand is appropriate for very small batches. Pump overs are very gentle. Rack and return is more extractive. The winemaker must choose the mix, the frequency and the timings of these options.	Desired levels of extraction of colour, aroma compounds and tannins. The cost varies depending on the number of hours of work, initial investment in specialised machinery (e.g. mechanised pump overs) and the requirement for additional tank space for rack and return.

Process	Choice	Reason	Influence on style, quality and price
Post-fermentation maceration	Option: additional time on skins	Longer maceration continues the extraction of tannins and encourages the polymerisation of tannins.	Improved tannin structure, which enhances the wine's ageing potential. Additional costs are the time to monitor the wine and the additional tank space.
Malolactic conversion	Allow malolactic conversion to happen naturally or initiate it during or after alcoholic fermentation. Racking the wine to barrels so that it happens in barrels is also an option.	Allowing malolactic conversion to happen naturally may be part of low-intervention winemaking.	If malolactic conversion is in barrel: better integration of flavours. Additional cost is associated with every individual barrel needing to be monitored (see maturation in oak below).
Pressing	Pneumatic press or basket press at the end of post-fermentation maceration.	Both types of press are gentle, and so avoid extracting bitter seed tannins. Attention will be paid to the separation of free run juice and the pressed wines to give options for blending.	Options to blend for the preferred style of wine especially the desired level of tannin for long term bottle ageing.
Blending	Initial blending before maturation (e.g. of free run and press wine).	Wine to be blended to anticipate the desired style of the final wine.	Balance between fruit intensity, tannin and acidity.
Maturation	Most small volume premium red wine is aged in small oak barrels.	Ageing in small barrels promotes slow, gradual exposure to oxygen and, especially if the barrels are new, exposure to extractable oak compounds and hence additional flavours.	Greater complexity in the wine due to slow controlled exposure to oxygen plus additional flavours such as vanilla and cloves. Intensity and diversity of oak flavours will depend on proportion of new oak, type of barrels, length of time in oak etc.

Process	Choice	Reason	Influence on style, quality and price
Final blend	Final blend of barrels	Final blending to create the desired style of the wine	Overall balance of fruit, oak, tannins and acidity and desired level of complexity. The cost is if some barrels of wine are not included in the final blend and are sold for less.
Finishing	Tartrate stabilisation	Consumers of premium wines may not accept tartrate crystals. If this is regarded as an issue, wines can be stabilised. Cold stabilization is the most likely option as it is traditional and involves the least manipulation.	Maintain quality and style and avoid what some consumers may see as a fault.
	Option: sedimentation if the wine is not sufficiently clear from time in barrel	Some makers of premium wines believe that quality is preserved by the fewest possible interventions. They may wish to avoid fining and filtering the wine. Sedimentation to clarify the wine is the main option in this case.	Maintain quality and style. Additional cost as wine has to be stored until it is clear.
	Option: fining, for example the traditional choice of egg whites	Ensure wine stays clear and bright. Egg white chosen as it is gentle to wine, removes harsh tannins and clarifies.	Refine the tannins and maintain style and quality.
	Option: sterile filtration	Avoid risk of any faults developing in bottle.	Maintain style and quality.
Packaging	Glass bottle	Only glass is suitable for wines which are intended to age as it is impermeable to oxygen.	Maintain style and quality and offer possibility of further ageing in the bottle.

Process	Choice	Reason	Influence on style, quality and price
	High quality cork or other high quality closures	Most premium wine is bottled under high quality cork. This is partly because this is what consumers expect of high quality wines and partly because they offer the potential to age the wine further in bottle. Some premium producers will choose either a screwcap or a high quality technical cork with low oxygen transfer rates, or glass stoppers.	Maintain style and quality and offer possibility of further ageing in the bottle. Both high quality natural cork and glass stoppers are expensive options.

D1 Wine Production: Recommended Further Reading List

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The Diploma reading provided by the WSET gives students the study materials they need for successful study.

If students wish to extend their studies, the following are recommended but are **not required**. You do not need to buy any additional books. In the case of conflict between the WSET study guide and other sources, students should follow the WSET study guide for the purposes of the examination.

Bird D. and Quille N., 2021, *Understanding Wine Technology: The Science of Wine Explained*, 4th edition, Newark: DBQA Publishing

Easton, S., 2017, *Vines and Vinification*, London: WSET

Goode, J., 2021, *Wine Science, the Application of Science in Wine from Vine to Glass*, 3rd edition, London: Mitchell Beazley

Robinson, J. and Harding, J, 2015, *The Oxford Companion to Wine*, 4th edition, Oxford: Oxford University Press, referred to as OCW. (5th edition due to be published in September 2023.)

Robinson, J., Harding, J. and Vouillamoz, J, 2012, *Wine Grapes: A Complete Guide to 1,368 Vine Varieties, Including Their Origins and Flavours*, London: Penguin Books

Skelton, S. 2019, *Viticulture*, 2nd edition, London: S. P. Skelton Ltd

Waldin, M., 2016, *Biodynamic Wine*, Oxford: Infinite Ideas

A world of knowledge

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