TECHNICAL REVIEW

AHDB

Optimising flavour in rosemary

Figure 1. The main flavour components are strongly regulated by light conditions during growth

Action points

- **Maintain daytime temperature below 29°C during growth, as volatiles are rapidly lost at higher temperatures**
- **Deficit irrigation has been shown to improve the flavour profile in rosemary**
- **Use appropriate varieties for your environment. Further research is needed as there is wide variation in varietal chemical profiles**
- **Mild salt stress can improve flavour, but extremes will damage yield**
- **Maximise light availability and quality. Supplementary lighting with high UV-B, low red:far red ratio, and high light intensity will help develop a strong typical flavour (Figure 1)**
- **Store cut herbs in cool conditions in the absence of light to avoid loss of volatiles**

This technical review relates only to fresh cut and potted rosemary. Several species exist, however only *Rosmarinus officinalis* is used on a commercial scale. It naturally grows in well drained and alkaline soils, and can be exposed to drought and extreme heat without significant damage. Flavour in rosemary is primarily the result of terpenes produced by the plant as a protectant from UV damage.

Flavour components

There are some different classifications of rosemary based on the chemical composition of the oil. These are broadly specific to global regions [1-3], and consist of 1,8-cineole types, camphor, myrcene and verbenone types.

There are around 100 compounds identified in rosemary essential oils, many of which impart some flavour, but the 11 main constituents are given in Table 1.

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Table 1. List of the most abundant essential oil constituents relevant to flavour of rosemary, their chemical classification as monoterpenes or sesquiterpenes, and some flavour notes for isolated compounds

Name	Chemical class	Aroma
1,8-cineole	Monoterpene	Cardamom, camphor, cool, spicy
Verbenone	Monoterpene	Herby, camphor, pine
Alpha pinene	Monoterpene	Oily, woody, spicy
Alpha terpineol	Monoterpene alcohol	Pine, woody, harsh
Beta pinene	Monoterpene	Woody, earthy, pungent
Camphor	Monoterpene	Strong cucumber, camphorous
Borneol	Monoterpene alcohol	Camphor, herbal, pungent
Beta caryophyllene	Sesquiterpene	Herbal, spicy, terpene like
Limonene	Monoterpene	Lemongrass, herbal
Camphene	Monoterpene	Camphor, terpene, herby
Linalool	Monoterpene alcohol	Lavender

Verbenone-containing cultivars are considered to have the best taste, with verbenone thought to be one of the characterising flavours in rosemary. However it is not found in all varieties and its presence is not essential to a recognisable rosemary flavour. The full flavour profile is poorly understood at present, with detailed information of the sensory characteristics of oils not yet researched and sensory thresholds of individual compounds not known.

Drying rosemary modifies its flavour significantly, as many of the highly volatile monoterpenes are lost or modified in the drying process. It is more generally described as woody or hay like, and not characterised so strongly by the volatile essential oils [4].

The metabolic pathway of chemicals (Figure 2) helps us to understand how different chemicals are linked and how the relative quantities can affect each other. For example, a variety which contains verbenone will always contain α-pinene, while high camphene may mean that carbon resources are being drawn away from α-terpineol synthesis, so reducing the potential content of that compound. In rosemary, all of the main flavour compounds are in the monoterpene class and are strongly regulated by light conditions.

Essential oil content as well as composition can directly affect flavour, with low oil leaves being seen as watery and insipid which may unmask other less desirable flavours.

Carnosol, carnosic acid and rosmarinic acid are polyphenolic compounds which have minimal effect on flavour, although they do impart a mild bitter taste. They are powerful antioxidants which will help to prevent the generation of off-flavours.

Environmental effects and agronomic impacts

Many secondary metabolites in rosemary are potent antioxidants produced as a defence mechanism to limit oxidative damage caused by sunlight and high temperatures. As a result, light quality and availability is the main limiting factor in development of flavour compounds. The production of terpenes and the resulting flavour is primarily related to cultivar choice and light quality and intensity.

Cultivar

Rosemary plants are sometimes classed by their major oil constituents, with broad groupings such as α-pinene types and myrecene types which could have oil with over 30 per cent of that compound, or which have a more even mix of eucalyptol, camphor, and pinenes. Some are

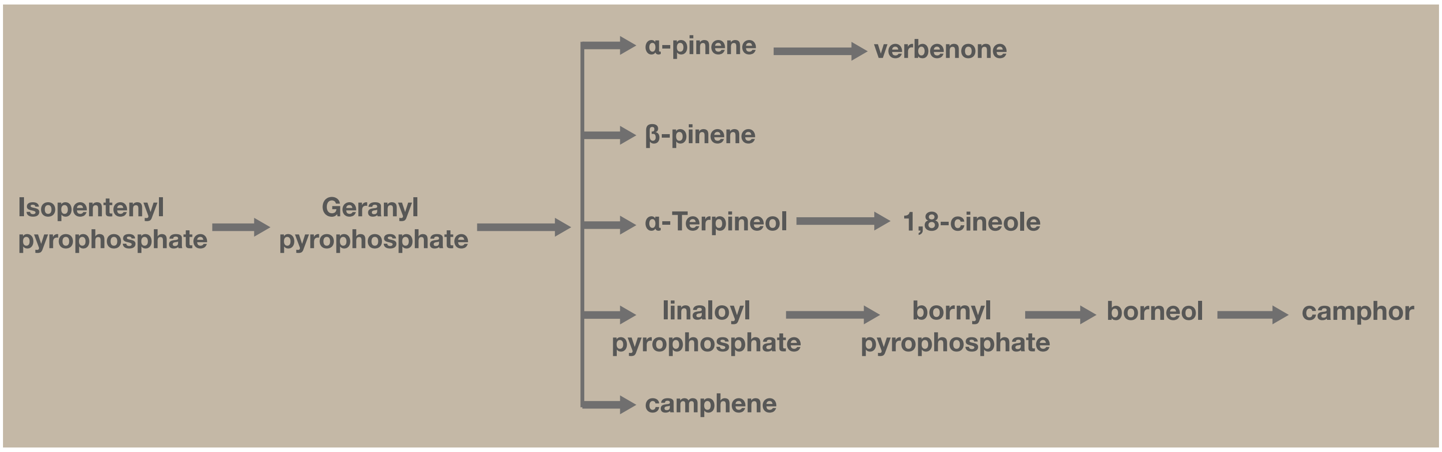

Figure 2. Simplified schematic of the metabolic pathways involved in the production of some of the main flavour compounds in rosemary

classified as verbenone types, often containing up to 15 per cent verbenone in the oil, but the same compound may be entirely absent in other varieties. The variation of oil composition within some UK grown varieties is shown in Figure 3.

Rosemary varieties are variable with relatively little previous work focused on breeding for flavour. One of the simplest factors to change when aiming to improve flavour quality is altering the variety used. Different varieties have a wide range of chemical profiles, some of which will be more stable than others under changing environmental conditions.

Although no quantitative data is available, verbenone is often implicated in varieties that are ranked as good tasting; however the compound is highly variable across cultivars. Many cultivars do not express this component at a significant level. Choosing varieties known to contain verbenone at concentrations of 10 to 15 per cent may represent a way of improving flavour without resorting to changes in growing techniques or compromising yield, although more research into flavour preference in rosemary is required.

Fertiliser and nutrition

Abiotic plant stresses such as under-fertilisation can affect the plant's ability to produce flavour compounds. In rosemary, it is understood that nutrient deficiency will raise the concentration of secondary metabolites through a stress response, this is consistently the case, with over fertilisation affecting biomass and oil yield. Rosemary prefers well-draining calcareous soils types which may be unsuitable for some other crops. It does respond well to nitrogen fertilisation which generally favours vegetative growth and production of secondary metabolites.

As iron is used in terpene synthesis, this can become a limiting factor; however rosemary also prefers to grow in high pH, which makes iron less accessible to the roots [7]. High pH leads to more oxygenated terpenoid compounds particularly 1,8-cineole and α-pinene, but a lower overall yield of terpenes in essential oil compared to a lower pH soil [8]. Fertilisation with higher levels of iron can counteract this.

A fertiliser regime with comparatively higher iron content is recommended, particularly where rosemary is grown on high pH soils.

Figure 3. Oil composition of rosemary plants by variety, showing percentage abundance of some of the most common oil constituents [5]

Biostimulants and growth regulators

Naphthalene acetic acid (NAA) and cytokinins can lead to smaller plants with higher essential oil yield, which at a higher planting density could be used to create a more flavoursome product. Benziladenine (BA) has been implicated in the formation of glandular hairs [6] and shows a potential use in increasing the overall content of essential oils, a technique which could be used in a range of herb crops.

Biostimulants represent an area of future interest although more trials are needed to make specific recommendations. Application of growth regulators specifically to modify plant stress response and trichome gland development shows potential, although there is not currently enough information to make recommendations in rosemary.

Irrigation

Overwatering limits growth and can be detrimental to growth in rosemary. Rosemary is moderately salt tolerant and can be grown in the presence of low salt levels without adverse effects.

Various different salts have been tested and could potentially be applied to irrigation in low levels. Common table salt, sodium chloride, at 100mM increased the relative abundance of 1,8-cineole and camphor, but decreased borneol, α-terpineol, nopol and camphene, and this is potentially advantageous to flavour [9]. These effects are likely to vary depending on specifics such as variety used and the environment under which the crop is grown. Additionally, this study suggests that different salts elicit different responses, so further testing is needed before making changes. Salt stress is a potential means of improving the flavour of rosemary.

Deficit irrigation can be used in rosemary when addressing flavour; increasing α-pinene, 1,8-cineole and borneol, but lowering linalool and camphor [10]. Oil concentration increases with water deficit but yield can be reduced substantially. Overwatering is also likely to induce stress, but without a beneficial change to oil composition.

Light quality

Light quality is known to influence volatiles produced by herbs across the Lamiaceae plant family and is one factor which causes significant changes to the terpenoid metabolic pathway consistently. Different light wavelengths, which are interpreted by the plant as shade, climate and altitude will alter the physiology in both the physical and chemical characteristics of the plant. Rosemary is especially susceptible to light-related changes [11]. The plant's response to light signals which represent high altitude and UV exposure lead to higher production of volatile terpenes. Such signals may be due to direct exposure to UV, higher light intensity or lower red:far red light ratio [12]. Far red light relative to red light increases oil production.

Where possible, supplementary lighting, particularly far red and UV-B, can be used to modify flavour in rosemary [13]. Far red to red light ratio can be modified with supplementary lighting, even if it is only for a short period of time during the day. UV can be applied by fixed lamps or lights attached to booms in glasshouse production.

Day length

During winter, supplementary lighting to maintain at least a 12-hour day is advisable, to allow the plant to grow well and with 'normal' physiology. This is achieved naturally between March and November, although supplementary lighting in glasshouses make production possible throughout the year (Figure 4). Oil content has been observed to decrease with shorter days, probably due to less available photosynthate. Myrcene and α-pinene decrease most sharply with this change.

Reducing the effects of short days on rosemary can be useful to maintaining a high flavour quality. This is of most significance for glasshouse growers during winter months where supplementary lighting will be required for both suitable development of flavour and normal crop growth.

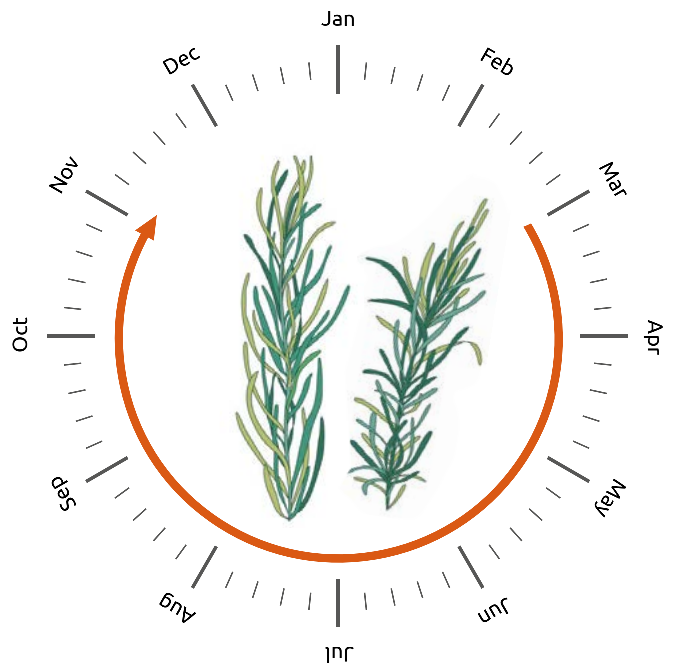

Figure 4. The UK cut rosemary season shown in red [14]. Potted herbs grown under glass are able to be grown throughout the year

Temperature

Temperature also affects volatile production. The maximum ideal temperature is thought to be 29°C [15] but in practice this is likely to be higher than is practically achievable, unless grown under glass. Beyond this threshold, the concentration of volatile compounds can fall due to a combination of stomatal closure, a reduction in enzyme activity and evaporative loss of volatile compounds.

Higher temperatures are expensive to achieve in winter glasshouse productions, while in-field production temperature is hard to manipulate.

For flavour maximisation, temperatures in the range of 22–29°C are recommended, as higher temperatures would result in loss of volatiles to evaporation.

Harvest time

Seasonality and the changes in light availability throughout the year, coupled with the plant's natural growth cycle, have a significant effect on composition of the essential oil and on flavour. There is a change in chemical composition related to season, with long days and falling temperatures at the end of summer leading to a higher accumulation of verbenone in verbenone rich varieties. More diterpenes are observed in winter than in summer, coinciding with the end of the flowering period and seed set [16].

Rosemary for the cut market is cut several times per crop and it is understood that there will be a difference in flavour quality in different cuts of the crop. Crop from first and second cuts have a greater oil content than subsequent cuts, however initiation of flowering increases oil content and may counteract this [7]. More research is needed to confirm quality differences.

Plant physiology

Essential oils in herbs of the Lamiaceae are located throughout the plant, although predominantly in the leaves. In rosemary, α-pinene is predominantly found in the leaves, while borneol and camphene are mostly found in stems.

UV-B is thought to be essential to the normal filling of glandular trichomes/oil sacs (Figure 5) which contain the oils responsible for flavour [17]; however, it is not known exactly how much is required. Glasshouses cut out much of the UV, so supplementary UV lights should be investigated as a way to improve flavour.

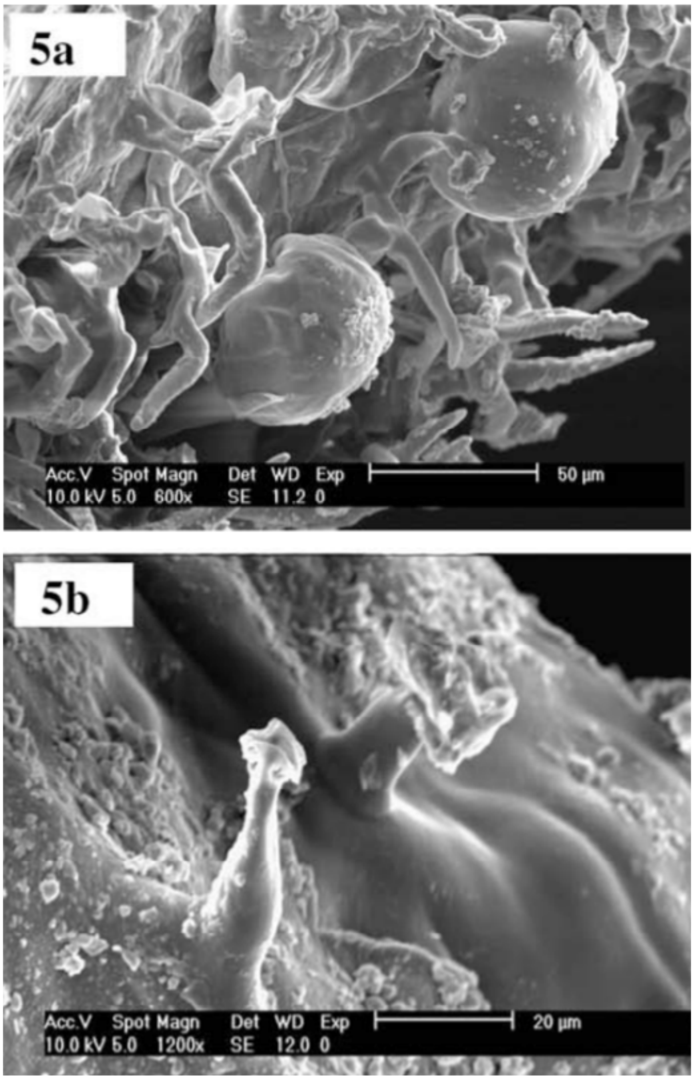

Figure 5. Electronmicrograph of capitate and peltate leaves in rosemary [18]

There is an effect of flower initiation with more sesquiterpenes, monoterpene alcohols and esters being produced, but fewer monoterpenes in the plant after flower initiation. Flower initiation is not a factor in potted herbs as they are sold on before the flower stage. It has been reported that up to five times more essential oil can be collected from plants post-flowering and up to seed set, compared to before. Composition also changes with more camphene and α-pinene at flowering than before flowering [7], while verbenone-type cultivars experience higher verbenone content after flowering [19]. Contrary to most plants, the flavour profile can be improved after flower initiation.

There are minimal differences in flavour between older and younger leaves on the same plant. Potted herbs grown and sold as small whole plants will contain all young leaves, while cut rosemary is kept growing and cut repeatedly throughout the season.

Varieties which initiate flowering more quickly, and for a longer period of time, represent a strategy to maximise the duration of high flavour quality production in cut rosemary. No recommendations can be made regarding the harvest of young or older leaves on a plant. Potted rosemary is sold before flower initiation and so this is not a potential route to improve flavour in these crops.

Post-harvest

As most of the flavour compounds are volatiles, it is important to use the herb soon after picking as up to half of the volatiles are lost 36 hours after picking in substandard conditions [16]. Where possible, for cut herbs, limit times between harvest and marketing and maintain low temperatures to reduce volatile losses that are detrimental to flavour. A cool post-harvest supply chain is important to rosemary to avoid loss of volatile oils.

Rosemary is known for some of the most potent natural antioxidants, namely carnosol and carnosic acid, which are two abundant diterpenes with a slight bitter taste. These limit oxidative degradation. Shelf life of rosemary is therefore better than other lamiaceous herbs, such as mint and basil. Rosemary antioxidants have a history of use as preservatives and are sometimes used as additives in pre-packaged meat products, such as sausages, to prevent oxidative damage. However, flavour can deteriorate with time as the volatiles are lost to the atmosphere. While carnosic acid and carnosol are noted for their antioxidant potential, α and β-pinene, camphor and 1,8-cineole have the greatest action effect on reducing microbial and fungal growth. Consequently, there is limited potential for oxidation to cause loss off-flavours in rosemary.

A short post-harvest chain with conditions of around 0°C for cut herbs and 5°C for live, potted plants is recommended.

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Conclusion

- Use appropriate varieties, potentially with high verbenone content, but suited to different requirements for potted, cut, glasshouse or field production
- Avoid over fertilisation and high irrigation which could damage the growing plant. Ideally use a separate regime to other plants growing on the site
- Plant growth regulators represent a potential to increase flavour and growth habit, especially in cut plants which have a long harvest period. However results will be highly specific to the cultivars and biostimulants used
- Induce mild stress through low level salt stress as appropriate
- High intensity light should be used, where economically viable, to promote essential oil production. In glasshouse production, consider UV-B application

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