TECHNICAL REVIEW

AHDB

Optimising flavour in basil

Figure 1. Younger basil crops have a more desirable flavour

Action points

- **Maintain consistent daytime temperatures of around 25°C where possible, to promote production of flavour compounds**
- **Exploit UV-B lighting and glass filters to promote production of terpenes, the main flavour compounds; these are produced by the plants as UV protectants**
- **Use appropriate varieties according to your growing conditions and season**
- **Keep crops well hydrated as basil responds poorly to water stress**
- **Harvest crops when young, as older leaves have a less favourable chemical profile (Figure 1)**
- **Maintain consistent temperatures of 10–12°C (depending on the variety) throughout postharvest storage; lower temperatures can cause discoloration while higher temperatures promote respiration and development of off-flavours**
- **Use oxygen scavengers in storage and transit to avoid development of off-flavours**

This technical review focuses on basil which is grown for the fresh cut and potted markets. Nearly all UK commercially grown basil is *Ocimum basilicum,* however other species are grown for niche or worldwide markets. Basil types are typically classified into several groups based on the composition of flavour compounds. The most significant being European or sweet basil; other main classes include reunion and African or holy basil.

Introduction

Over 200 different volatile compounds, predominantly phenylpropanoids and monoterpenes, have been identified in basil essential oil. Different types of basil can be classified by their ‘chemotype’, or predominant chemical constituents. European basil is predominantly linalool, eugenol and 1,8-cineole, but also important to the flavour are estragole, chavicol and limonene.

A high linalool/eugenol profile is typical of European type varieties and is considered the highest quality. It is established as the primary chemotype grown in the UK. Others types containing cinnamate or estragole as the major constituent are considered niche varieties in the UK, but they may be popular for international cuisine. The six

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main chemicals listed in Table 1 can comprise up to 85% of the essential oil, and represent the main contributors to flavour in healthy plants regardless of sugars and other flavour compounds which may also be present.

Metabolic pathways of some of the main compounds in basil show how the compounds are related. Chemicals within the same pathway are closely linked, but those in different pathways can be altered independently of each other, allowing a change in the overall flavour composition. The two classes of flavour compound are produced through separate metabolic pathways (Figure 2) and so conditions such as stress will affect each differently. Genetic differences between cultivars may mean that parts of the pathways are restricted, altering the overall composition of the oils, and giving rise to the different chemotypes, as well as differences in the performance of varieties.

Volatile oil content can directly affect flavour with low oil leaves being seen as watery and insipid. Consumers show a preference for samples they describe as 'intense'. Linalool rich basil is widely considered the best in terms of flavour, while eucalyptol is also a marker of a good quality basil. Eugenol and estragole are considered undesirable to flavour in European type basil if in high quantities, but essential to the characteristic basil aroma at lower concentration. While specific varieties may be considered of a higher flavour quality than others, the full complexity of flavour is not understood. Unfortunately little is known about the detection thresholds of the individual chemical components in basil.

Other factors influencing taste are the presence of polyphenols which impart a bitter taste and aldehydes such as hexanal which impart the typical ‘green or ‘grassy’ aromas associated with leaves. Compounds such as the phenylpropanoids cinnamate occur naturally at low concentrations, but adversely affect the liking of the crop.

In basil, the sugar content by Brix is approximately 5% in healthy leaves but may drop to 1.5% in unhealthy crops [1]. However it is not known how much of an effect this has on taste perception.

Environmental effects and agronomic impact

The majority of the flavour compounds produced in basil occur naturally as UV protectants, released into the atmosphere in response to the Mediterranean climate where it is traditionally grown. They are also produced in higher quantities when the crop is placed under environmental stress.

Mild environmental stress, especially light stress, can modify the flavour of basil while ensuring that the productivity of the herb is not adversely affected.

Table 1. The main constituents of basil essential oils, showing which metabolic class they belong to, the aroma they impart, and varieties in which they are typically found in significant quantities

Name	Chemical class	Aroma	Varieties found in
Linalool	monoterpene	Fresh, floral, spicy	Genovese, Mammoth, Napoletino, Opal, Sweet, Lemon and other European types
Eugenol	phenylpropanoid	Fresh, clove, spicy, woody	Genovese, Thai, African
1,8-cineole (eucalyptol)	monoterpene	Spicy, herbaceous, camphor	Genovese, Sweet, Opal
Estragole (methyl chavicol)	phenylpropanoid	Anise, sweet, green, fennel	Lemon, Mammoth, Napoletano
Chavicol	phenylpropanoid	Phenolic, medicinal, herbal	Thai, Holy
Limonene	monoterpene	Citrus	Lemon

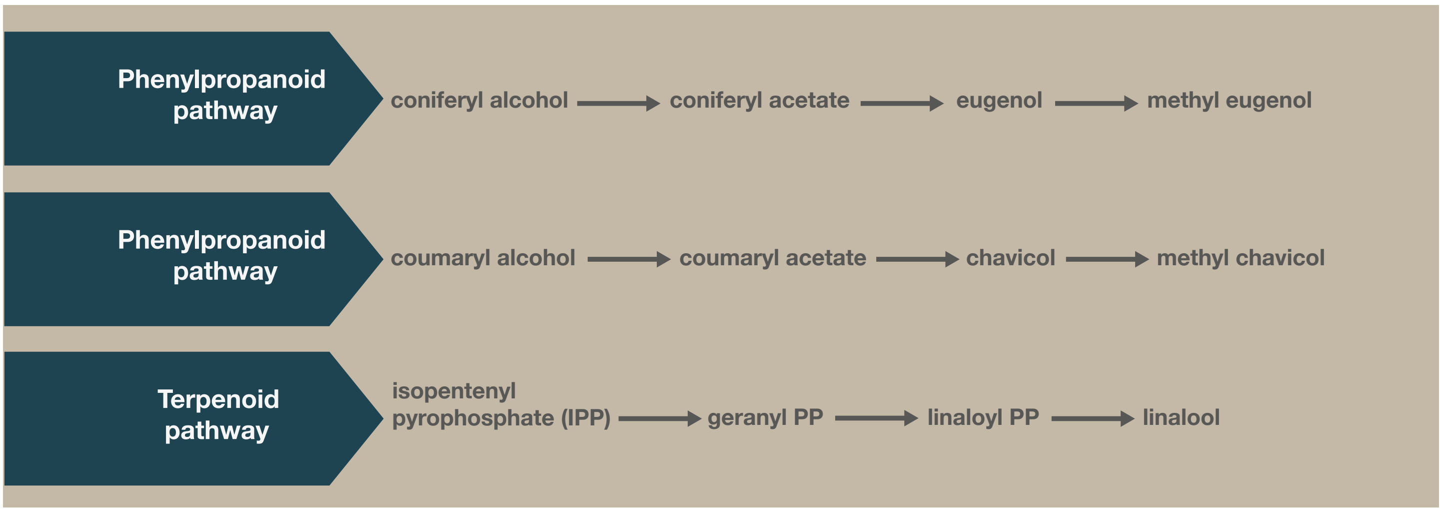

Figure 2. Metabolic pathways leading to different flavour compounds in basil

Cultivar

Genovese types are the most commonly grown for fresh production, but the specific profile of volatiles changes down to the specific cultivar [2]. The total abundance of essential oils appears to be fairly consistent in spite of variety choice, so the intensity is a relatively stable factor at the variety level. However the composition of the essential oil, and therefore the flavour quality varies greatly.

Fertiliser and nutrition

Abiotic plant stresses, such as under fertilisation, can affect the plant's ability to produce flavour compounds. In basil, a consistent nitrogen fertilisation is seen as the most effective way to maintain a high quality crop, but there is conflicting information on whether lower nitrogen application can increase the total essential oil concentration [3–5], but restricting nitrogen does limit yield. Potassium is the next main limitation on adequate plant growth and so plants should be fertilised appropriately [6], though little scientific data exists with relation to flavour.

Growers should ensure that nitrogen, phosphorus and potassium fertilisation is adequate, paying particular attention to nitrogen levels to maximise photosynthetic potential and the content of essential oil. Treatments which can increase reliable uptake of minerals, such as phosphorous and boron, may represent a way to increase quality, while maintaining iron content of the soil is important to the production of the terpene class of flavour compounds, though more research is needed in this area.

Biostimulants and growth regulators

Research applications of foliar sprays of salicylic acid at rates of 0.5mM for 15 days before harvest (with 0.5mM applied every three days; there were five spray applications in total) increased oil content by up to 30% but it did not affect composition [7]. This is thought to be the result of increased potassium and iron uptake from soil as a stress response to perceived infection risk. Jasmonic acid has been found to increase quality and quantity of essential oil in basil [8] while methyl jasmonate can lead to high production of linalool and β-ocimene, so increasing quality. Application of these growth hormones might represent a way to alter the essential oil profile of basil. One study [9] showed that commercial biostimulants could alter the essential oil composition, with aminoforte (an amino acid mixture) and nitroxin products resulting in the highest total essential oil yield, and their ideal treatment was kadostim×nitroxin and fosnutren×nitroxin as this gave the best oil composition.

Although research is limited in this field, artificially inducing a stress response by treatment with salicylic acid or other growth regulators seems to have the potential to improve basil essential oil content and quality. The response of a plant is cultivar-specific, and the treatments may affect other important factors such as physiology and yield.

Irrigation

Basil is not tolerant to water deficit, it responds to water stress with an increased concentration of essential oil, and often with a preferable composition regarding flavour. However when growing basil for fresh herbage, the yield is significantly affected. Basil has to be adequately watered on account of the potential yield losses, despite some evidence that flavour can be improved under mild drought stress.

Light quality

Many secondary metabolites, especially in basil, are produced as a defence mechanism to limit oxidative damage caused by UV in sunlight. As a result, light quality and availability is a major limiting factor in development of flavour compounds in basil in the UK.

Monoterpenes and phenylpropanoids in basil are produced specifically as UV protectants. Consequently, altering the duration, intensity and quality of light that the plant receives can change and improve the flavour, by causing more of these chemicals to be produced.

UV-B is essential to the normal filling of glandular trichomes/oil sacs which contain the essential oils indicative of basil flavour, and consequently are important to the development of normal flavour [10]. Glass cuts out considerable levels of UV-B, so glasshouse production could adversely affect the flavour of glasshouse grown basil when compared to basil grown in the field under exposure to natural light levels. Diffuse glass which allows a greater proportion of UV-B light through may be a consideration to basil growers.

Total essential oil content rises when UV-B irradiation is available and so will result in a more intense flavour. In addition, there is a greater influence on the level of terpenes, such as linalool and 1,8-cineole than phenylpropanoids, meaning the composition as well as the content is preferably altered, with up to five times the content of some terpenes including linalool [11]. 15 minutes of UV-B exposure per day could increase leaf thickness (and robustness) and cause more auxiliary shoots, as well as oil composition change, with greater effects if exposure is longer. However application of UV-A or UV-B in excess, or when a plant is very young, can cause reduced linalool and result in cell damage, reducing subsequent growth and therefore yield [12]. It has been reported that the plants respond best if the UV is applied in the mornings, though the reasons behind this are still not known [13].

In basil, shade (encapsulated by a higher ratio of far red to red light) conditions lead to stem elongation, and higher levels of methyl eugenol which is undesirable. Reduction in both linalool and eugenol is also seen in the shading response which is detrimental to the quality of the herb. Younger leaves are more affected by this change than older leaves.

A study by Loughrin and Kasperbauer [14] found that a simple method of altering available light was by using coloured plastic mulch, reflecting different wavelengths of light in differing proportions, without the need for installation of glasshouse films or LED lighting. They conclude that an increase in red light by using red coloured mulch can lead to larger leaves, while yellow and green wavelengths can result in a change in chemical profile of the essential oil, increasing terpenes such as the preferable linalool. Figure 3 from Carvalho et al [15] shows the different response of basil plants under treatments of specific light wavelengths by their main chemical group. There is a higher essential oil yield with treatments including red light. Far red light leads to a higher proportion of phenylpropanoids while the highest proportion of monoterpenes and sesquiterpenes result from application of green and yellow wavelengths.

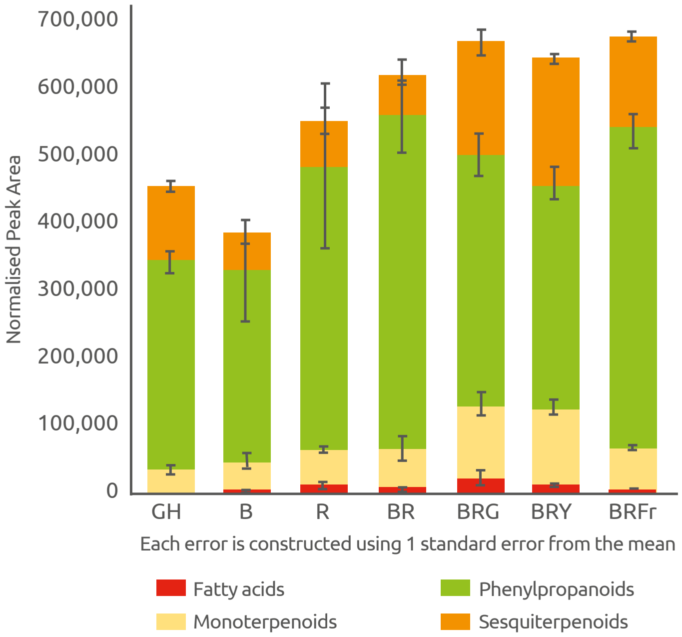

Figure 3. [15]. Impact of different light wavelengths on terpene content in basil. Plants exposed to blue, red and green/yellow light were significantly different to the composition seen with application of other light wavelengths, where a higher proportion of phenylpropanoids are present. Of these profiles, BRG or BRY would be preferable from a flavour perspective

Basil prefers direct sun conditions, therefore applying these conditions either directly or through manipulating the light quality in terms of red:far red ratio and UV-A:UV-B ratio is recommended. Consequently for growers who are using a high intensity system, increasing light quality through UV-B via lamps and specific wavelength lighting can make a significant difference to trichome development and filling.

Altering the available light, whether by supplementary lighting or using reflective coloured mulch, can influence the physiology and secondary metabolism of basil, increasing the total oil content, and therefore perceived intensity. Supplementary light can also affect the quality of the essential oil by increasing the proportion of monoterpenes such as linalool and eucalyptol. Increasing red, blue, and green light wavelengths in the glasshouse is likely to have the greatest positive effect.

Day length

Leaves grown under short day conditions have been found to remain physiologically young. In basil this is preferential, due to an increase of linalool and decrease in estragole, however short day conditions will also reduce photosynthetic capacity and yield.

Time of harvest is seen as a factor in maintaining flavour, with crop grown early or late in the season being less favourable. The typical UK basil season is shown in Figure 4 [16] although modern glasshouse production extends this significantly. This is a factor of available light outside of summer months.

Long days increase yields through greater photosynthetic potential, however it is known to decrease the oil content and quality, with plants producing more methyl chavicol and other phenylpropanoids [17]. However, scientific data is limited with relation to the effects of day length on basil; a balance must be struck between short days improving flavour, and decreasing yield.

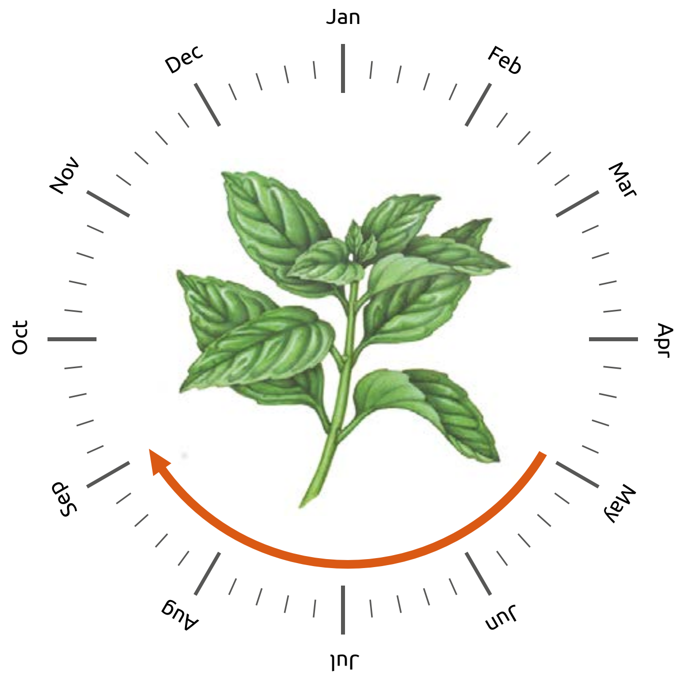

Figure 4. UK main cut basil season shown in red. Basil is mostly grown from May up until October though, with supplementary lighting, can be grown under glass for an extended season

Temperature

Temperature affects volatile production. Growth at 25°C is preferable to 15°C, both in terms of growth physiology and in content and quality of essential oil, with up to three-times the oil content produced at the higher temperature according to one study [18]. At temperatures over 30°C, growth and volatile production was impaired, so a temperature range of 21–30°C throughout growing days seems optimal but other reports suggest that temperatures over 26°C trigger the onset of adverse changes to essential oil composition. Sufficiently high temperatures, especially in the final two weeks of production, are seen as critical to the content of linalool at harvest.

Growers should control the temperature and light levels as far as is practical under their growing system. Under glasshouse production these temperatures may be easy to exceed in summer, while an economic case must be made for heating glass in winter.

There is no conclusive information on which approach is likely to have the greatest benefit to flavour; further research is needed.

Plant physiology

Basil essential oil is produced in specific glands called trichomes, which fill with oil over time in response to environmental factors, before breaking open and releasing the volatile oils. Two main types of trichome are important to the essential oil production in basil – capitate and peltate trichomes. Terpenoids are typically produced in capitate glands, while more phenylpropanoids are produced in peltate glands (Figure 5). The glands fill with oils which are released when conditions such as physical contact or high temperature damage them, releasing the aroma.

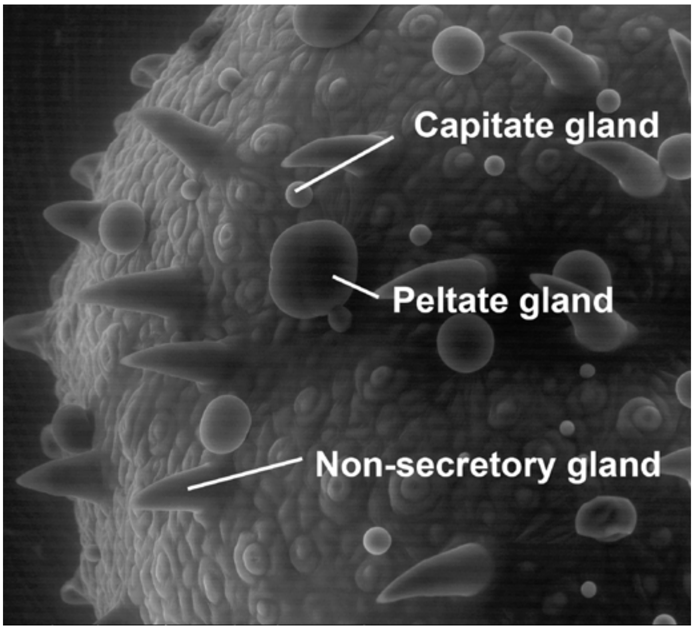

Figure 5. [20] Electron micrograph of a basil leaf showing capitate and peltate glandular trichomes

The physiological age of leaves (size and maturity) appears to greatly affect the oil composition, with more developed leaves containing fewer capitate trichomes and proportionally more peltate trichomes. This leads to fewer terpenoid compounds such as linalool in more developed leaves, and proportionally more phenylpropanoids, such as estragole and eugenol. It is therefore well established that plants are harvested as young as is viable to improve flavour, with plants less than 12cm in height preferable for high quality pesto products [19]. Older plants close to flowering are typically used for oil production, as there is a greater content of oil, though the quality is lower.

Young leaves can have up to six times more capitate glands (the production site of terpenes) compared to mature leaves, hence more linalool and other terpenes, and higher overall quality [11].

Defence mechanisms are typically altered or upregulated during flower initiation, so harvest time is an important factor in controlling a plant's flavour. In basil, the change is undesirable leading to a stronger but less palatable composition with predominantly phenylpropanoids.

Post-harvest

Consistent temperatures of 10–12°C should be maintained throughout the supply chain, depending on the variety. Chilling injury occurs when product is stored at temperatures lower than 10°C, resulting in lower levels of characteristic volatiles and so flavour is directly impaired.

Protein and lipid degradation both correlate to rates of ethylene production in climacteric plants. 1-MCP has been used with success to reduce ethylene-based senescence in basil, and shows potential in other herbaceous plants [21]. Avoiding degradation of the crop through use of suitable cold chain will reduce the development of off-flavours that may occur through enzymatic, microbial and light-based oxidation. Evaporative cooling as a result of the washing/drying process can lead to chilling damage even above 12°C, and so should be closely monitored.

Conclusion

- More research is required in many areas, particularly looking at preference of consumer groups in the UK
- Use appropriate varieties to suit your growing conditions and market. Varietal differences are likely to result in the highest variation due to the specific variation in the metabolic pathways of terpenes and phenylpropanoids
- Avoid shade conditions, and if possible alter the available light, using supplementary UV-B, red-blue LED lighting or coloured reflective mulch
- Maintain high temperatures in the growth environment to encourage production of secondary metabolites
- Induce stress responses with application of UV light, or sprays of salicylic acid, but not by limiting essential nutrients or water as this will reduce yields
- Grow with plant nutrition in mind, and avoid biotic and abiotic stress to maximise the essential oil content and quality
- Minimise heat shock post-harvest and harvest when conditions are cool. Handle with care throughout the supply chain to minimise degradation

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