Project title:	Determining the basis of variation in herb flavour
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Project leader:	Prof Carol Wagstaff, University of Reading
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Key staff:	Ana Contente Dr Maria-Jose Oruna-Concha
Location of project:	University of Reading
Industry Representative:	Philip Dodd, Herbs Unlimited, York
Date project commenced:	12th March 2018

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Professor Carol Wagstaff

Principal Investigator, Head of School Chemistry, Food and Pharmacy

University of Reading]

Signature ....C. Wagstaff........ Date ..16th April 2021……

Report authorised by:

Professor Carol Wagstaff

Principal Investigator, Head of School Chemistry, Food and Pharmacy

University of Reading]

Signature ....C. Wagstaff........ Date ..16th April 2021……

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GROWER SUMMARY

Headline

Elucidating the volatile and non-volatile profile of culinary herbs and understanding how this profile varies with season and production method will help growers understand how these factors affect the flavour of the product. This will direct growing practices that will improve consumer satisfaction of the herbs, leading to market growth for growers.

Background

Herb flavour can vary in its composition as well as intensity. This variation can happen as a result of different cultivars, agronomic practices, season and climate. There has been an increase in the consumption of fresh culinary herbs due to pressure to reduce salt content in foods whilst retaining a flavourful eating experience, so the flavour is the most important attribute of the herbs. Therefore, understanding how flavour varies in composition and abundance within a herb species as a result of different production systems and climate conditions, and how these differences are perceived by consumers, will help the growers to adjust their practice to enable the industry to deliver a more consistent and acceptable product.

The overall aim of this 4-year PhD study is to elucidate the chemical profile of commercially important culinary herb crops and understand how season, agronomic practice, cultivation system and environment interact with this. The focus of work in this project year was to gain an initial understanding of how variable flavour chemistry is between different seasons and years, and how production systems influence herb flavour. This analysis was done using herb samples collected in 2018 and 2019.

Summary

Three different herbs were selected as being of the greatest commercial relevance and covering both annual, perennial, soft and woody herbs: basil, coriander and rosemary. Sample cultivar was consistent for basil and coriander, but less so for rosemary. The project steering group provided a number of sites giving rise to a breadth of production methods that were sampled from West Sussex, Lincolnshire, Berkshire, Worcestershire, Norfolk and Yorkshire. These sites provided samples covering herbs produced in protected conditions under glasshouse, grown in pots (Pots), soil (Soil) or hydroponic system (Hydroponics). Samples grown on outside fields (Field) were also provided for analysis. Not all the production types were analysed for each of the three herbs, as this depended on which herb crops the sites produced. Analysis was carried out across two years (2018 and 2019) and samples were analysed for the summer and autumn season. Because not all the samples were supplied for every season, Table 1 lists the herbs that were analysed in each season as well as the production method.

Table 1. List of herbs and their production systems that were analysed during 2018 and 2019 seasons.

	Summer 2018	**Autumn 2018**	**Summer 2019**	**Autumn 2019**
Rosemary *Rosmarinus officinalis* var. unknown	Pots Soil Field 1 Field 2 Field 3 Field 4	Pots Soil Field 1 Field 2 Field 3 Field 4	Pots Soil Field 4	Pots Soil Field 1 Field 3 Field 4
Coriander *Coriandrum sativum* var. Cruiser	Pots 1 Pots 2 Field 1 Field 2 Field 3	Pots 1 Pots 2 Field 1 Field 2	Pots 1 Pots 2 Field 1 Field 2	Pots 1 Pots 2 Field 1 Field 2 Field 3
Basil *Ocimum basilicum* var. Sweet Genovese	Pots 1 Pots 2 Hydroponics Soil	Pots 1 Pots 2 Hydroponics	Pots 1 Pots 2 Hydroponics	Pots 1 Pots 2 Hydroponics

Sampling from all production methods has so far been conducted to represent Summer and Autumn production systems. Results so far indicate that pot produced herbs are significantly different from the rest production types, variety of the herb (in the case of rosemary) shows to be relevant when analysing the flavour, confirming what is found in literature.

Clear differences were seen between samples produced in the year of 2018 and 2019, the reason for these differences might be due to the higher average temperate occurred in the year of 2018. This confirms what is found in the literature, were temperature is described as being relevant to the flavour composition and also volatiles losses.

From the results, season of production also influences the flavour profile of the samples, when the samples are produced in unprotected conditions, this might be due to these herbs being exposed to the environment conditions causing stress to the plant, therefore higher content in aroma compounds.

Results so far confirm that variables during production influence the flavour profile, however further analysis need to be done in order to understand better how other variables might be influencing the flavour. Another year of sampling needs to be completed in order to give more insight into the differences seen between years of production.

From the results so far, it has been possible to observe some differences between samples from the different sites:

- Variety influences the flavour. Rosemary samples were not from the same variety which might be the main cause for the differences.
- Pot produced herbs showed significant differences when compared with other types of production, such as being grown in an outside field, or in soil under a protected environment (glasshouse) or using hydroponic systems (basil samples only).
- Herbs produced during the summer season showed differences in the flavour profile compared to the herbs produced in the autumn season.
- Differences in the flavour profile were observed between samples produced in the year of 2018 and 2019.
- The temperatures under which samples were produced and transported affects the flavour composition of herbs produced in unprotected systems.
- More variables of production, such as lighting, water supply and soil type, need to be analysed in order to better understand what is influencing the volatile profile of each herb.

Financial Benefits

This project will provide UK herb growers with information to help them understand better the variations in their product, and in doing so, help to deliver a more consistent product throughout the year.

Action Points

None to date

SCIENCE SECTION

Introduction

The consumption of plants has been recently associated with several health benefits like anti-diabetic, anti-inflammatory, anti-carcinogenic properties and can also lower the risk of cardiovascular diseases; they are also known for their antioxidant properties (Bower et al 2016, Chohan et al 2008, Kuban-Jankowska et al 2018, Opara and Chohan 2014). The replacement of salt by culinary herbs has caused an increase in the frequency of consumption of herbs (Bower et al 2016). The use of culinary herbs provides flavour to the dishes and (despite low intake levels) may contribute to the health of those who consume them, due to their high content in polyphenols, providing some beneficial effect (Opara and Chohan 2014).

Herb Production Systems

There has been an increase in the consumer interest of purchasing fresh herbs in supermarkets due to their desirable flavours. Herb crops grown outdoors come mainly from warm climates or are produced under warmer seasons in the UK. When this climate is not available the crops are exported from warmer countries or produced under protected environments in the UK. Within this type of production there are potted herbs, soil grown and hydroponic production under glass. Crops grown in glasshouses can use a lot of energy resource due to the use of supplementary lighting systems. The most common ones are high-pressure sodium (HPS) and metal halide (MH) due to their low costs. HPS also contributes to the temperature since they provide heat. Light-emitting diode (LED) lights are another option since they are energy efficient and wave lengths and light colour can be personalised, however these lights require higher investment (Seely 2017).

Hydroponic production is a method that does not require soil to grow plants, where the nutrients are provided via salts dissolved in water through an irrigation system. Here the roots can be partially or completely submersed in water. In this system the growers can control the concentration of the fertilizers supplied to the roots of the plant and have a more even distribution of the nutrients. This type of production gives growers a higher control of the phenotype of their crops (Putra and Yuliando 2015).

Fresh herbs, as for any other type of fresh produce, suffers from degradation and spoilage after it has been harvested. That is why for many years, and still in many cases currently, herbs are mostly consumed dried. Fresh herbs are comprised mainly of water (75-80%) which needs to be removed to preserve them for longer. In order to decrease this perishability, the herbs go through a drying process; this affects their properties, including their appearance, losses in aroma volatile compounds and increase in polyphenols concentration. For this reason, fresh herbs are described as having better flavour (Hossain et al 2010).

Flavour comes from the essential oils present in the oil glands (trichomes) on the leaf and stem. Variation in the composition and abundance of the compounds present in the essential oil has a significant impact on flavour characteristics. The analysis of the aroma is more efficient when done on fresh herbs compared to dried herbs since when you dry herbs there is a loss in the volatile content (10-30%) (Díaz-Maroto et al 2004, Ravi et al 2007).

Environmental influences on flavour

Temperature is a very important factor when it comes to the production of herb crops, as it influences their yield and growth rate, but it also plays an important role in the production of secondary metabolites like volatiles. Differences were seen between basil samples produced at different temperatures, where higher temperature (25˚C) lead to higher aroma volatile content (70% higher than lower temperature) and an increase in the eugenol amount (Chang et al 2007). Another study showed that the optimal growth temperature for basil is 25˚C, where it reaches higher height and leaf growth, and also higher aroma volatile content. Higher temperatures also affected the aroma volatile composition of the of the oil (Chang et al 2005).

Variety highly influences the flavour profile of the herbs, however, environmental factors also play a role in the production of the volatile compounds. An example of this are aldehydes and alcohols which have their production increased when herbs are wounded (Turner et al 2021). Crops grown at moderate temperatures (around 20˚C), develop a less intense aroma and flavour compared to crops grown at higher average temperatures. However, very high temperatures might cause the opposite reaction and lead to less flavour compounds (Jasper et al 2020).

A study conducted in Spain, looking at the seasonal variation of rosemary oil, concluded that herbs produced during summer season resulted in higher oil yields compared to the ones produced during the winter season. Furthermore, some of the compounds responsible for the rosemary aroma, like camphor, ß-pinene and myrcene, were at higher levels in summer samples; the opposite was seen for α-pinene with highest levels for winter production (Salido et al 2003).

Most of the studies found were looking at oil yield of the herbs and not at the effect of temperature on the growth or flavour of fresh culinary herbs.

Herb metabolites

Plants, through the process of photosynthesis, produce organic compounds called primary metabolites (Cruickshank 2012). The function of the primary metabolites is associated with the structure and physiology of the plant, and consist of carbohydrates, proteins, nucleic acids and lipids. These metabolites are universal to the plants and do not confer uniqueness to individual varieties (Rosenthal and Berenbaum 2012). Secondary metabolites are smaller compounds, with simpler structures that result from further metabolization of the primary compounds (Cruickshank 2012). They are responsible for signalling mechanisms and plant defence, interacting with the environment around the plant and external organisms as well (Rosenthal and Berenbaum 2012). Within the secondary metabolites of relevance to herbs it is possible to divide them into terpenes, alkanes, phenolics and aldehydes (Rohloff 2006).

Aroma Volatile Compounds

Some secondary metabolites are volatile compounds, and get dispersed through the air, allowing the plant to communicate with the environment and other living organisms around the plant.

Volatiles are complex structures, with a broad variety, that consist of a hydrocarbon structure with oxygen, nitrogen and sulphur. The many different structures that these compounds can have, makes them specific for their function.

Volatiles like isoprenoids are a result of an enzymatic process, for instance to achieve geraniol, the activity of geranyl diphosphate synthetase is required in the synthesis pathway. Geranyl diphosphate is a precursor for different monoterpenes including geraniol (Valcourt 2014), see Figure 1 for example.

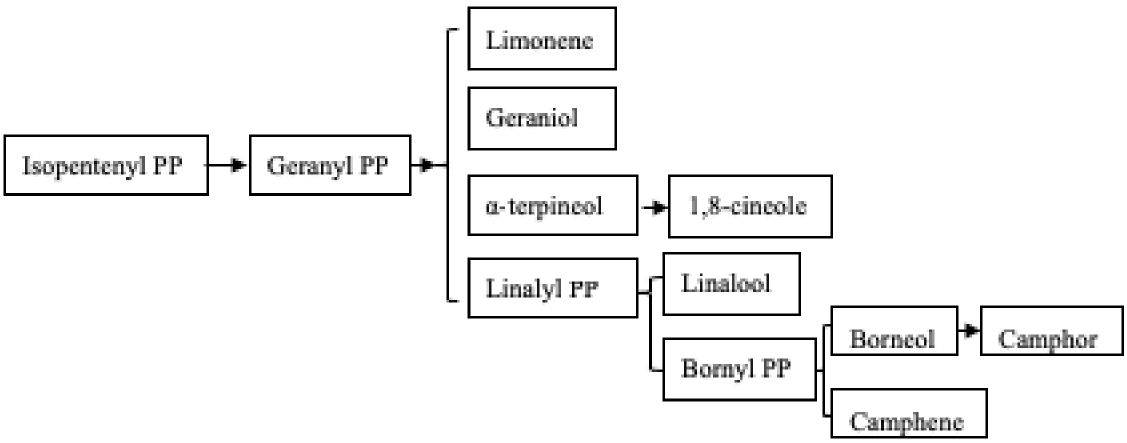


Figure 1. Simplified synthesis pathway of some terpenes. (PP) = diphosphate

Plants like herbs, which produce essential oils in their trichomes or glandular cells, produce some volatile compounds including monoterpenes and sesquiterpenes. These are produced and stored in specific structures of leaves, flowers and seeds and only in certain types of plant families. Because of this, their contribution to the air volatiles is very low, especially when compared to isoprene which are volatiles that are produced by every plant in every green cell (Valcourt 2014).

Volatiles can also be classified as the plant pheromones, since they are signalling molecules that are involved in the defence mechanism of the plant. There are two types of defence mechanisms, direct and indirect. In the first one, certain compounds are produced in order to repel or intoxicate the pests. The second mechanism, the indirect one, is where volatiles are involved, and they work as a calling signal to predators of the organism that is threatening the plant. Aldehydes, like other volatiles, take part in this type of defence mechanism. The production of these volatiles is induced when the plant is wounded or attacked by insects (Chehab et al 2008, Meerburg et al 2008). Aldehydes are produced through two enzymatic reactions, involving lipoxygenase and hydroperoxide lyase. They act in different stages, the substrate being polyunsaturated fatty acids, the first enzyme catalyses their oxygenation originating unstable compounds that are then split into aldehydes and oxo acids. Aldehydes can be transformed into alcohols. Besides being a defence mechanism, aldehydes also contribute to the aroma of the plant (Meerburg et al 2008), usually conferring a green and waxy type of aroma.

<u>Rosemary</u>

Rosemary (*Rosmarinus officinalis*) comes from the family Lamiaceae (the same as mint); it is used fresh, dried and for its essential oil. It is produced worldwide, however the main area of production is the Mediterranean countries. The oil of the rosemary mainly comprises monoterpenes, like camphor, 1,8-cineole and alpha-pinene (Pintore et al 2002). However, the essential oil can also be described as primarily borneol and 1,8-cineole, followed by camphor and limonene, depending on the variety of the herb. When it comes to the oil composition, *Pintore et al.* (2002) distinguish two groups, oils with over 40% 1,8-cineole and equal ratios of 1,8-cineole, α-pinene and camphor. Rosemary extract has been described as having health benefits like being anti-diabetic and anti-carcinogenic (Opara and Chohan 2014).

<u>Coriander</u>

Coriander (*Coriandrum sativum*) is a plant from the Umbelliferae family. India is the world's largest coriander producer and exports to other countries. Coriander flavour is mainly given by primary compounds, unlike most of the herbs which are defined by their secondary metabolites, which means coriander flavour is less affected by environmental changes (Chadwick 2018). Flavour come from the essential oil present in the oil gland on the leaf. International standard of oil/coriander is 70% linalool content. Coriander with strong sweet, floral odour has been attributed to the presence of geranyl acetate in higher amounts (Ravi et al 2007). Coriander can be consumed as leaves or seeds, and both store flavour compounds.

<u>Basil</u>

Basil (*Ocimum basilicum)* is from the Lamiaceae (mint) family and it is highly cultivated in Mediterranean areas, and it is used both fresh and dried. Basil can be classified as different sub-species according to the content of certain volatiles. Chemical composition of the essential oil of basil is very variable with the many constituents being linalool, estragole, eugenol and/or methyl cinnamate. Basil synthethises and stores its essential oil on the leaf and stem surface in peltate trichomes. As described above, drying basil will affect its appearance as well as aroma, since the process leads to changes in the volatile profile. Diaz-Maroto (2004) observed that volatiles losses were 28.6% in oven dried, 27.4% in freeze-dried and 13.6% in air dried. However, an increase of sequisterpenes during the drying process has been described in basil and some other herbs. Samples dried at ambient temperature have a similar composition to fresh samples (Díaz-Maroto et al 2004).

Figure 2 shows some of compounds typically present on rosemary, coriander and basil, with their corresponding chemical structures.

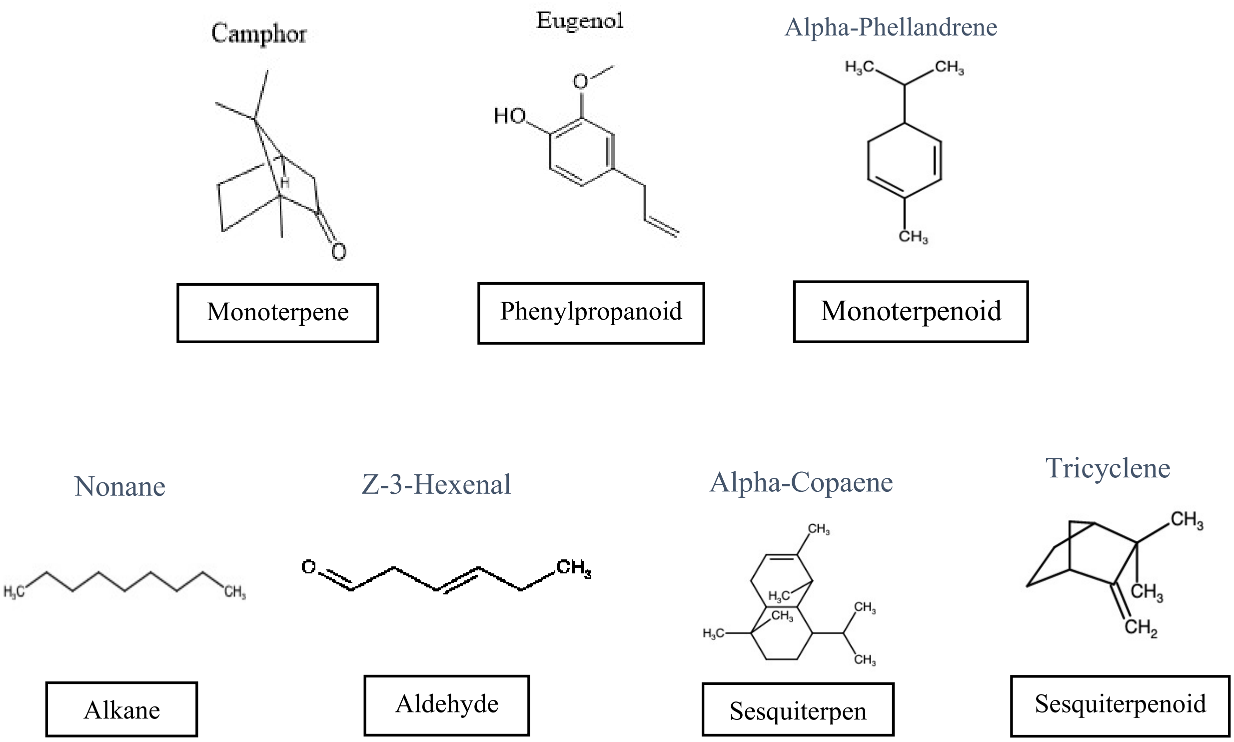


Figure 2. Structures of some of the aroma volatile compounds described in the literature contributing to rosemary, coriander and basil essential oil volatile profiles.

The overall aim of this 4-year PhD study is to elucidate the chemical profile of commercially important culinary herb crops and understand how season, agronomic practice, cultivation system and environment interact with this. The focus of work in this project year was to gain an initial understanding of how variable flavour chemistry is between different seasons and years, and how production systems influence herb flavour. This analysis was done using herb samples collected in 2018 and 2019.

Materials and methods

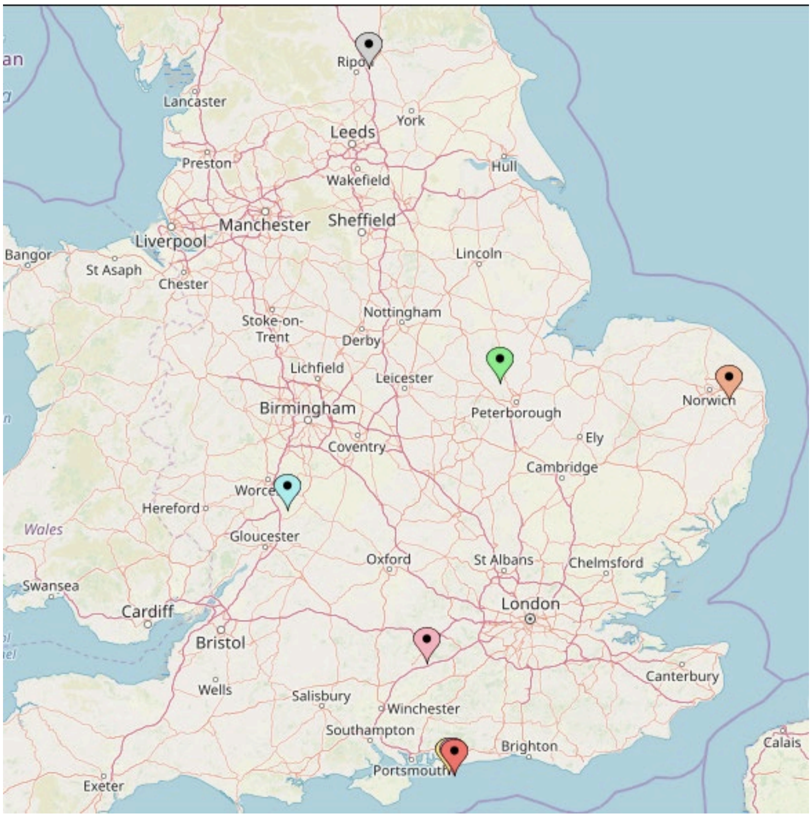
Samples

Rosemary (*Rosmarinus officinalis*), coriander (*Coriandrum sativum* var. Cruiser) and basil (*Ocimum basilicum* var. Sweet Genovese), were provided by different growers across the United Kingdom (UK), and for each herb more than one type of agronomic production was considered. Sample collection was done twice per year and has been carried out for the years of 2018 and 2019.

The type of agronomic practice for the samples consisted of herbs grown in pots under protected conditions (Pot), produced in soil protected under glass (Soil), grown in open field subject to weather conditions (Field) and using the hydroponics system (Hydroponics). Table 1 shows the different samples analysed for each of the herbs for each of the seasons. Furthermore, the location of the growers that provided the samples can be seen in Figure 3. Each sample, from the different types of production and location, was analysed in triplicate (n=3). Information about the cultivation variables was collected using a form and filled by the growers. All the samples were harvested at commercial maturity and sent by a courier in boxes with cooling packs and stored at 5ºC (cut samples) or at room temperature (pot samples). Analysis was carried out within 4 days.

Table 2. List of herbs and their production systems that were analysed during 2018 and 2019

	Summer 2018	Autumn 2018	Summer 2019	Autumn 2019
Rosemary *Rosmarinus officinalis var. unknown*	Pots Soil Field 1 Field 2 Field 3 Field 4	Pots Soil Field 1 Field 2 Field 3 Field 4	Pots Soil Field 4	Pots Soil Field 1 Field 3 Field 4
Coriander *Coriandrum sativum var. Cruiser*	Pots 1 Pots 2 Field 1 Field 2 Field 3	Pots 1 Pots 2 Field 1 Field 2	Pots 1 Pots 2 Field 1 Field 2	Pots 1 Pots 2 Field 1 Field 2 Field 3
Basil *Ocimum basilicum var. sweet genovese*	Pots 1 Pots 2 Hydroponics Soil	Pots 1 Pots 2 Hydroponics	Pots 1 Pots 2 Hydroponics	Pots 1 Pots 2 Hydroponics



Grey- Yorks
Green- Lincolnshire
Blue-Worcs
Orange- Norfolk
Pink- Reading
Red- West Sussex

Figure 3: Map showing the distribution of all the production sites for rosemary, coriander and basil

Sample preparation

2 g of fresh herb (including leaves and stems) were hand cut making sure that different maturities of leaves were included in the sample for analysis. Samples were ground with 2.8 mL of saturated calcium chloride (as it helps to stabilize plant cells, preserving the samples for longer) for 1 minute using a pestle and the mortar.

From this mixture, 5 g of ground herb and solution together with 50 µL of propyl propanoate (internal standard) at 100 ppm were transferred to a vial for solid phase micro-extraction (SPME) and kept at 4˚C on a cooling tray until extraction.

Extraction of aroma volatile compounds by Solid Phase Micro-Extraction (SPME)

The volatile extraction was done using a stationary phase composed of 75 µm divinylbenzene/Carboxen™ on polydimethylsiloxane fibre. Using an automated system, each sample was incubated at 35˚C with an agitation of 500 rpm for 10 minutes. After incubation a needle was inserted into the vial and a stationary phase fibre was exposed to the headspace of the vial so that the volatiles could be extracted. This extraction was done at 35˚C with a 500 rpm agitation for 30 minutes.

Gas Chromatography-Mass Spectrometry (GC-MS) analysis of SPME extracts

The fibre was then inserted into the inlet port of the GC-MS, using an Agilent 110 PAL injection system and an Agilent 7890 gas chromatograph with 5975C mass spectrometer. Using this equipment, the volatiles were removed in a splitless mode for 36 minutes and passed through a DB-5 column.

Compound identification

The relative concentration for each of the compounds found was calculated relative to the known amount of internal standard (propyl propionate).

The volatile compounds were identified using spectral databases (ADAMS, NIST and INRAMSS), linear retention indices (LRIs) were calculated using a set of known alkanes and compared with data in the literature. The compounds found were later grouped into type of chemical compounds for analysis of results.

Statistical analysis

For the purpose of statistical analysis, the type of compounds found across all the samples for each herb were analysed using principal component analysis (PCA) in order to correlate these with the season and year in which the samples were produced.

Results

An example of the GC-MS chromatograms obtained for each of the herbs (rosemary, coriander and basil), can be seen in Figure 4. Rosemary presents a more clustered graph, containing the highest number of peaks, followed by basil and coriander (which contained fewer and less abundant peaks).

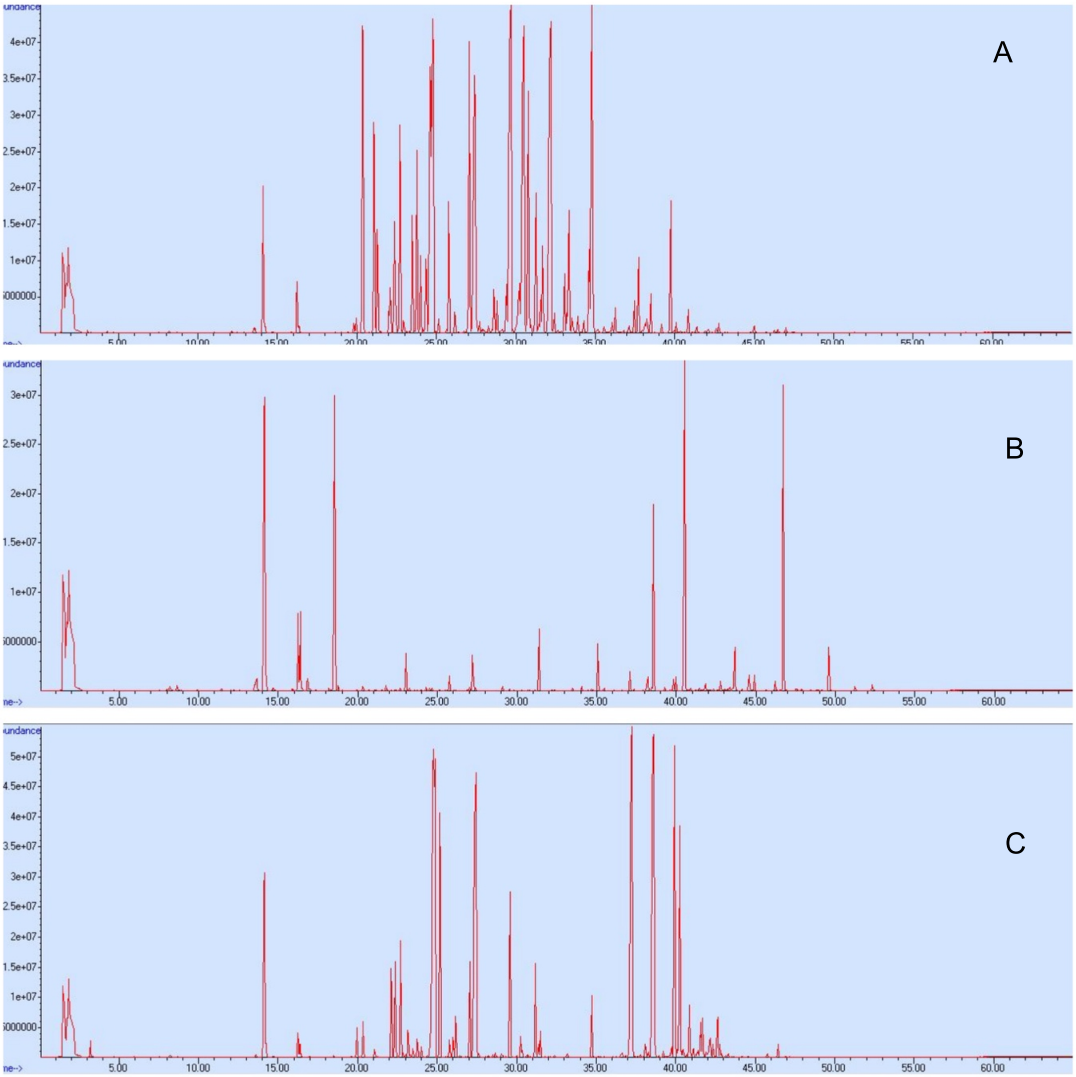


Figure 4. GC-MS chromatograms for the three herbs analysed: A-Rosemary; B-Coriander; C-Basil

Different number of samples per herb were provided (Table 1; Figure 3) which had been grown using different production systems and each sample was analysed in triplicate (n=3). An average of the replicates was calculated as well as standard deviation. The compounds detected were then sorted into groups by type of chemical compound. In the case of rosemary, the type of compounds found consisted of monoterpenes, monoterpenoids, sesquiterpenes, sesquiterpenoids, fatty alcohol, aldehyde, terpene and phenylpropanoids. For coriander, the type of compound detected were alkanes, aldehydes, monoterpenes, monoterpenoids, sesquiterpenes, sesquiterpenoids, terpenes, esters, hydrocarbon, fatty aldehyde and fatty alcohol. As for basil, the type of compounds identified were monoterpenes, monoterpenoids, sesquiterpenes, sesquiterpenoids, phenylpropanoids, fatty aldehydes, fatty alcohols, aldehydes, esters, hydrocarbons, fatty acid and terpenes.

In order to analyse if some of the production variables (season, year and type of production) had any correlation with each other and with the type of compounds found within each of the herbs, principal component analysis (PCA) was done and the results for this analysis can be seen in the graphs presented below (Figure 5, Figure 6 and Figure 7) for rosemary, coriander and basil, respectively. From this analysis, it was possible to see that some types of production have a positive correlation with most of the type of compounds, and that there are some differences between season of production.

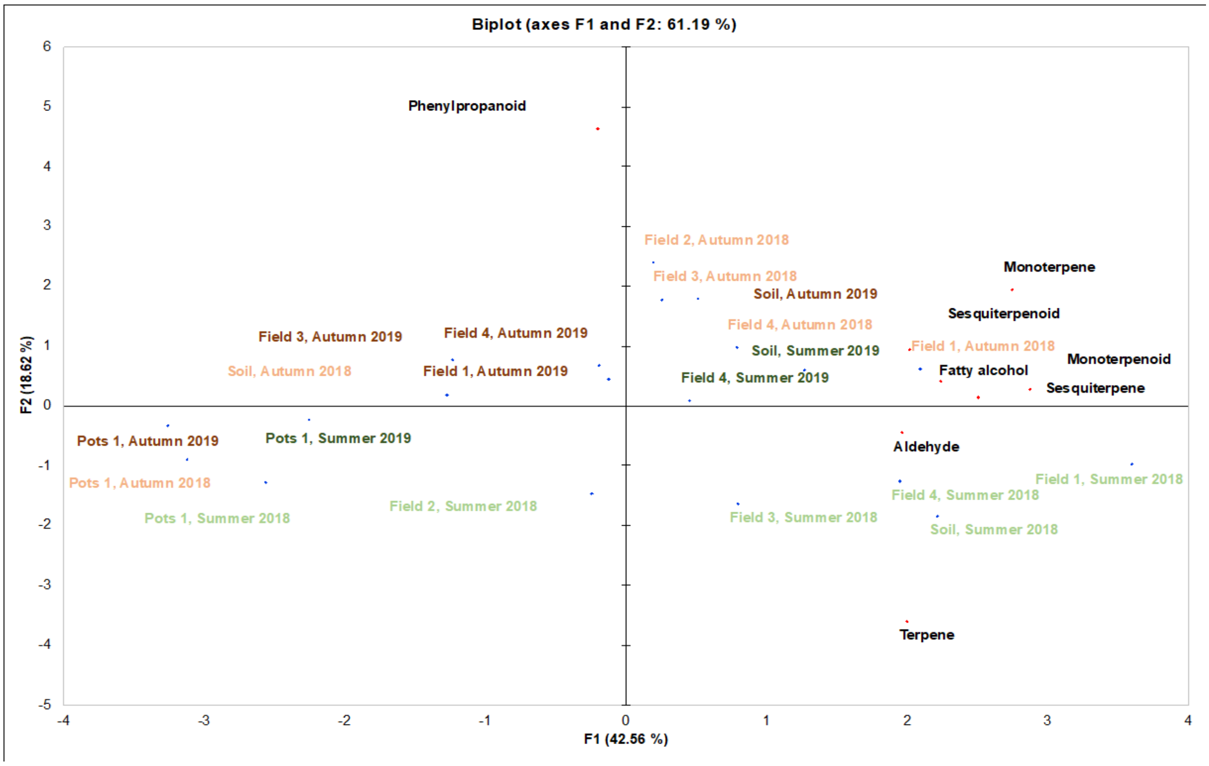


Figure 5. Biplot graph correlating the type of volatile compounds found in rosemary with season of production (green vs orange) and year of production (light colour vs dark colour), for the different production methods.

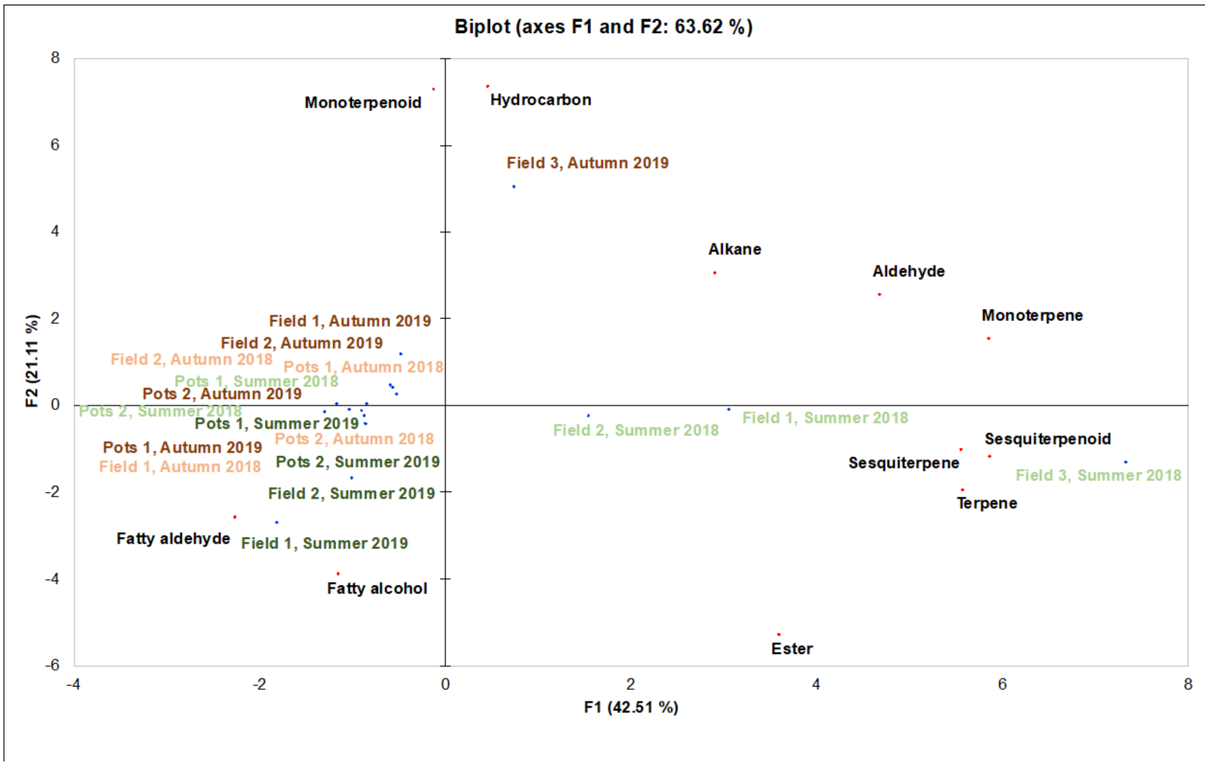


Figure 5. Biplot graph correlating the type of volatile compounds found in coriander with season of production (green vs orange) and year of production (light colour vs dark colour), for the different production methods.

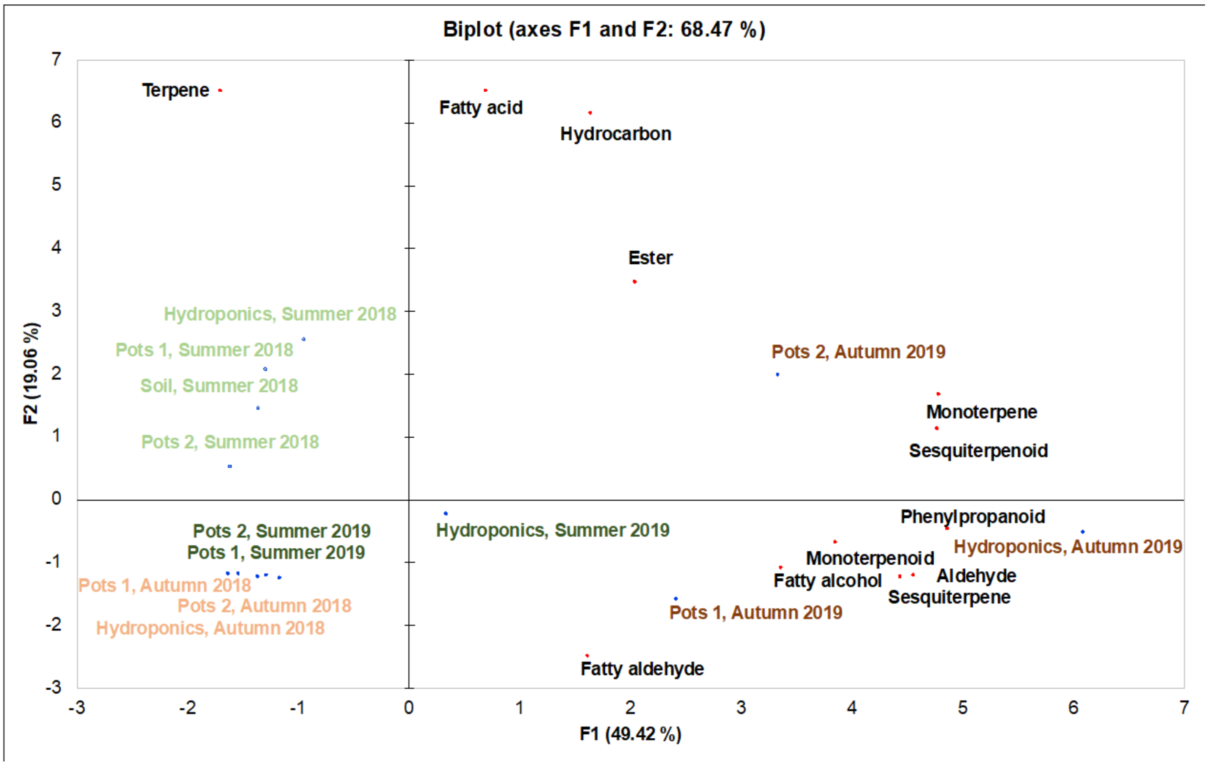


Figure 6: Biplot graph correlating the type of volatile compounds found in basil with season of production (green vs orange) and year of production (light colour vs dark colour), for the different production methods.

The results and conclusions in this report are based on an investigation conducted over a two-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

Discussion

The characteristic aroma volatile profile identified in each of the herbs, allows us to understand and identify the differences in terms of compound composition between samples of the same herb. This also allows possible similarities between samples to be established, and to relate this with some of the characteristics of the growing conditions, like type of production and season.

Principal component analysis allows a graphical vision of the relationship between compounds and also their correlation with the samples. This approach enables insight into which samples are more similar to each other and which compounds are more associated with them.

For a clearer representation of the correlation between the volatiles profile and samples, the volatiles were grouped by type of compounds. The volatiles were grouped into alkanes, aldehydes, hydrocarbon, ester, fatty alcohol, fatty aldehyde, monoterpene, monoterpenoid, phenylpropanoid, sesquiterpene, sesquiterpenoids and terpene.

Rosemary

Rosemary samples are from unknown varieties, which means that some of the differences seen in the results might be caused by this uncontrolled variable (Tawfeeq et al 2016). From the biplot (Fig.5), it is possible to see that there is a clear separation between samples produced in the summer season and the samples produced in the autumn season. It is also possible to see that samples produced in pots are grouped together and away from the samples produced in field either under protected (soil) or unprotected (field) conditions. This might be because the pot samples are from the same producer, which means they are the same variety, but it could also be because pot production has a controlled system where there are no big variations between season or years.

Looking at samples produced during the summer season of 2018, it is possible to see that Field 2 has a lower association with the volatile compounds, which might be due to the average temperature during production being higher than the ideal range (22-29˚C) leading to losses in the volatile content. The other cut samples were produced within the optimal temperature range and transported in iceboxes maintaining cooler temperature, resulting in a higher correlation with the volatiles (>0.80) (Hückstädt et al 2013).

Samples from the autumn 2018 were also produced within the optimal range and transported at cooler temperatures, which as can be seen in Figure 5, lead to a high correlation (>0.80) with the volatile compounds.

The same can be seen for the samples produced during the summer season of 2019.

Samples from autumn 2019 were produced at a lower temperature (<20˚C) and transported at higher temperature than recommended (>6˚C), this meant that there was a lower production of volatiles (Munné-Bosch et al 1999).

Coriander

Coriander samples were all from the same variety. From the biplot (Fig.6), it is possible to see some differences from samples produced in the autumn compared with samples produced in the summer. Samples produced in pots, showed a high level of correlation (>0.80) with each other, due to the controlled conditions in which the samples were grown and the low variation between seasons and years. All the pot samples, independently of the season or the year of production, were grown at the recommended temperature (<25˚C), which would mean a higher production and similar production of volatiles. However, all the samples were transported at higher temperatures than the recommended (0-2˚C) (Chadwick 2018, Telci and Hisil 2008).

Long summer days would result in an increase in volatile content, this was seen in Field samples from Summer 2018, however was not seen for samples from summer 2019 (Zheljazkov et al 2008).

Water stress leads to the reduction of volatile content. This might explain why samples from Summer 2018 have higher correlation (>0.80) with the volatiles, where irrigation had medium range (20-30mm/week), and samples from Summer 2019 were extremes (10mm/week and 70mm/week) leading to reduction in the volatile content (Nadjafi et al 2009, Neffati and Marzouk 2008).

From the results above, it is hypothesised that coriander volatile composition is influenced by the daylight and irrigation during production.

Basil

Basil samples were all from the same variety, and from the biplot (Fig. 7), it is possible to see some separation between samples produced in the year of 2018 compared to samples produced in the year of 2019.

Samples produced in the summer season of 2018 show a low correlation with the type of compounds associated with the basil flavour, this is likely due to the average temperature during production which was very high (>25˚C), leading to losses in the volatile content (Miele et al 2001).

The opposite was seen for the samples produced during the autumn season of 2018, where the average temperature during production was lower than recommended (<20˚C), which resulted in lower volatile production.

Samples from the summer season of 2019, were produced with an average temperature around the recommended (±25˚C), however the post-harvest temperature for pot samples was higher than recommended (>13˚C), which lead to volatile losses in these samples. Hydroponic sample was transported in an icebox which helped to maintain the post-harvest temperature closer to the recommended (10-12˚C), which would explain the higher association with the volatiles of this sample compared to the pot samples (Hassan and Mahfouz 2010, Miele et al 2001).

In the case of samples produced in the autumn season of 2019, all the samples were transported within the recommended temperature range (10-12˚C), which means that there was less volatiles losses. In addition to this, hydroponic sample was grown in average temperature close to recommended(20-25˚C), resulting in higher correlation with volatile associated with the basil profile (Hassan and Mahfouz 2010, Miele et al 2001).

The results discussed above show that basil flavour profile is driven by the temperature during growth and the post-harvest temperature.

Conclusions

The results gathered so far have helped to have a better idea of how the volatile profiles of the three herbs vary depending on the growing variables. From what has been previously stated, experiments so far have shed some light on how the volatile profile might change for the three herbs, giving a better idea on what significantly influences the volatile profile.

It is clear that potted herbs develop a different flavour profile to cut herbs, not in the presence or absence of compounds but in their relative abundance. This is probably due to lack of exposure to stress-inducing conditions for pot herbs. The season in which the herbs were produced (summer, autumn) also showed an effect on the flavour of the samples. From the results it was also possible to see a clear separation between samples produced in the year of 2018 and those produced in 2019; this might be due to the differences in the average temperature from one year to the other. Rosemary result differences might be because not all the samples are from the same variety. Further analysis needs to be carried out and more growing variables need to be included to better understand what causes the differences across samples.

The results have given some light on how the type of volatiles compounds present in the herbs vary and is a step forward for the growers to understand their products better. Other analyses need to be done in order to complement what has been found and also to draw more definitive conclusions. A consumer study will be carried out in order to understand their preferences and which sensory attributes are more relevant. This will help determine how definite these differences are for those who buy these products.

Knowledge and Technology Transfer

Presentations:

- AHDB PhD conference, January 2021
- Food and Nutritional Sciences Research Symposium, November 2020

Glossary

SPME: Solid-Phase Microextraction

GC-MS: Gas Chromatography- Mass Spectrometry

UK: United Kingdom

HPS: High-Pressure Sodium

MH: Metal Halide

LED: Light-Emitting Diode

LRIs: Linear Retention Indices

PCA: Principal Component Analysis

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Appendices

Updated form given to growers to provide information about the herb sample.

FV / PE 455 Herb flavours project

Product life cycle and submission information

1. **Herb species and variety:**

☐Rosemary ☐Coriander ☐Basil

a. Herb variety:

☐Perigord ☐Miss Jessops ☐Unknown
☐Cruiser ☐Santo ☐Chetchnya
☐Sweet Genovese ☐Other:________________

2. **Grower:**

☐Vitacress ☐Herbs Unlimited ☐Liconlshire ☐Valley Produce ☐J Bond & Son ☐NV Produce ☐Red Deer Herbs

3. **Production Method:**

☐Organic ☐Conventional ☐Hydroponic ☐Soil Protected ☐Pots

4. **Planting date: ___/___/_____**
5. **Harvesting date: ___/___/2020**
6. **Temperature average during growth:**

☐<0 ˚C ☐0-5˚C ☐6-10 ˚C ☐11-15 ˚C ☐16-20 ˚C ☐20-25 ˚C ☐ >25 ˚C ☐No records

7. **Light exposure (protected crops):**
   a. Type: ☐Natural ☐LED ☐HPS ☐MH
   Other:______________
   b. Time of exposure: ____hour(s) of lights on.
8. **Water supply**: ☐Rainfall ☐Irrigation
   a. Quantity (if known) :_________/week
9. **Fertiliser and crop protection product application (please provide records if available)**

☐CAN _______/day ☐CN_____/day ☐SOP_____/day ☐None ☐ Records provided

10. **Shipping date: ___/___/2020**
11. **Duration between harvest and cooling**: ______minutes
12. **Average temperature during transport (if known)**

☐<0 ˚C ☐0-5 ˚C ☐6-10 ˚C ☐11-15 ˚C ☐>15 ˚C ☐Unknown

13. **Crop stage/maturity when harvested: (select all that apply)**

☐First cut ☐Second cut ☐Fully matured ☐Target____cm

14. **Pot production :product used as soil or growing media:**

☐Peat ☐Coir ☐Mixture ☐Other:___________