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Effect of planting time on mentha growth, yield, and oil content: A review

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Abstract

Mentha, the fragrant member of the Lamiaceae family, consists of important species such as *Mentha arvensis*, *Mentha piperita*, and *Mentha spicata*. These crops are grown on a large scale for their essential oil content. Among various agricultural practices, the timing of planting is an important factor as it influences the growth of the plants, the yield of the crop, and the content of the essential oil. This article will highlight the importance of the timing of planting on the growth and oil content of the crop. Proper selection of the planting time will lead to better growth of the plants. Parameters such as the height of the plants, the number of branches, leaf area, and dry matter content will be influenced by the timing of planting. Early planting will lead to better vegetative growth of the plants due to the prevailing temperature and exposure to sunlight. This will lead to more leaf matter, which will be reflected in the yield of the crop. Several research articles have proven that plants grown during the optimal time of the year, i.e., the end of December and the start of spring season, will have more yield compared to plants grown during unfavorable times.

The same pattern is observed when considering the oil content and the oil yield. It is noted that crops planted early will result in a higher oil yield. This is attributed to the fact that the plants will have a larger biomass and a higher physiological activity. The conducive conditions during the vegetative stage enhance the photosynthesis process and the formation of secondary metabolites. This results in a higher concentration of essential oils in the glandular trichomes. Planting time is not only responsible for the quantity of the oil produced by the plants. It is also responsible for the quality of the oil. Planting time influences the concentration of the main constituents present in the oil. These are menthol, menthone, menthyl acetate and carvone. Studies have shown that crops planted at the optimal season have a higher level of the desirable constituents. This enhances the price of the oil and the market demand. The performance of the mentha crops due to the effect of the planting time might be explained by a variety of factors. These are temperature, photoperiod and soil moisture and duration of the plants. Plants planted early have an opportunity of taking advantage of the favorable climatic conditions.

Although a significant amount of research has been done, it is possible that additional research is necessary to comprehend the impacts of climate change on planting windows, the relationship between planting time and nutrient management, as well as the possibilities of precision agricultural technologies to optimize the sowing dates. It will also be relevant to develop better varieties of mentha that are resistant to late planting and environmental stress to maintain the productivity. In general, the previous review shows that the ability to choose an appropriate planting time based on the climatic conditions of the area is crucial to ensure the maximum growth of mentha, herbage yield, essential oil content, and the quality of the oil. The productivity and profitability of mentha cultivation can be greatly improved by adopting the best planting schedules and also through better agronomic practices.

Keywords: Mentha cultivation, planting time, herbage yield, essential oil content, oil quality, menthol, biomass production, aromatic crops, and agronomic management

Introduction

Mentha is a high-valued aromatic plant that belongs to mint family, Lamiaceae. The genus Mentha comprises various species of economic value in the world to produce essential oils. Particularly, *Mentha arvensis* (Japanese mint), *Mentha piperita* (peppermint), and *Mentha spicata* (spearmint) are the most widely commercialized ones. These are crops that are greatly demanded in other industries such as pharmaceuticals, cosmetics, food processing, perfumery, and confectionery. *Mentha arvensis* Menthol-rich oil, which is the essential oil of the plant, is

extensively utilized in toothpaste, chewing gum, mouth fresheners, pain balms, cough syrups and aromatics ((Singh, *et al.*, 1995) ^[46].

The production of mentha has gained prominence throughout the world as a result of the growing need of natural essential oils and herbal products. India is also amongst the largest manufacturers and exporters of mentha oil.

The production of mentha has gained prominence throughout the world as a result of the growing need of natural essential oils and herbal products. India is also amongst the largest manufacturers and exporters of mentha oil. This is a crop that grows in the fertile Indo-Gangetic plains, particularly in such states as Uttar Pradesh, Bihar, Punjab and Haryana. These areas have favorable climate, fertile alluvial soils and irrigation facilities that make them conducive to grow mentha. The short growing cycle, high biomass production, and good returns on oil extraction have made mentha a profitable cash crop to farmers over the years (Akhtar, *et al.*, 2009) ^[4].

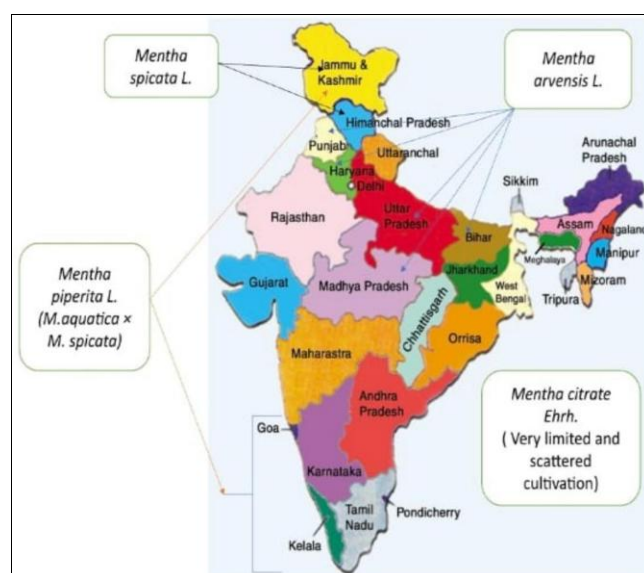
Mentha is propagated by stolons or root suckers and is cultivated seasonally either in the spring or in summer in subtropical areas. The crop needs moderate temperature, adequate sunlight, and soil moisture to grow and produce oil optimally. The productivity of mentha is highly influenced by such agronomic activities as the selection of the right variety, nutrient management, irrigation scheduling, and pest control (Mansoori, 2014) ^[32]. The time of planting is one of these practices, the timing of which is important in the growth, development and the production of essential oils in mentha plants. The time of planting determines the environmental conditions that the crop will undergo during the growth stages. The timely scheduling will make sure that the crop will experience favorable conditions in its vegetative growth, canopy development, and oil production stages (Kumar, *et al.*, 2025) ^[29]. Early or late planting may subject the crop to inappropriate temperatures, day length, or moisture stress, which may damage the growth of the plant and the quantity and quality of the essential oil. Therefore, it is important to identify the most suitable time to plant so that the crop growth can fit the favorable environment (Singh, *et al.*, 1998) ^[48].

The growth and functioning of the mentha plants require temperature. Optimal temperatures favor a rapid vegetative growth, expansion of the leaves, and increased photosynthetic rates resulting in increased biomass accumulation. The sufficient lighting intensity also enhances the production of chlorophyll and enhances photosynthesis, which enhances the production of essential oils. On the other hand, late planting can expose the crop to increased temperatures later in its growth cycles and this leads to reduced growth, reduced area of leaves and decreased oil content (Özel, and ÖZGÜVEN, (2002) ^[38].

Planting time also influences important physiological and biochemical activities such as photosynthesis, respiration, nutrient uptake and secondary metabolites synthesis. Mentha produces the essential oils mainly in glandular trichomes on the leaves and stems. Environmental factors like temperature, humidity and the length of the day are very sensitive to the production and accumulation of such oils. Early planted crops tend to give rise to bigger plants having more leaf area and increase in oil yield and menthol content. Conversely, late planting will result in reduced biomass production as the plants will be shorter with fewer branches, thereby reducing oil

productivity (Sharma, and Kanjilal, (1999) ^[43]. Also, the interaction between planting time and such agronomic variables as irrigation, fertilization, and the crop variety also influences the success of mentha crops in general. Different varieties will react differently to the planting date as they will have different growth habits and oil production pathways. Consequently, to achieve the best productivity and to maintain the quality of oil at a constant level, it is very important to find the appropriate planting time of certain climates (Chauhan, *et al.*, 2012) ^[11].

With the increasing demand of mentha oil both locally and internationally, there is the need to enhance the cultivation practices. The simplest yet practical of these practices is the maximization of the growing time in plants to increase growth, biomass generation, and essential oil. The relation of planting time and crop performance can help farmers and researchers create more effective production technologies and sustainable farming practices related to Mentha (Soltanbeigi, *et al.*, 2021) ^[49].



Importance of Mentha as an Aromatic Crop

Mentha is also considered as one of the major aromatic crops used in the world to produce essential oils and natural flavoring substances. Mentha genus belongs to the family Lamiaceae, which contains numerous species, which are rich in volatile oils, in particular, menthol, menthone and other aromatic compounds. *Mentha arvensis*, *Mentha piperita* and *Mentha spicata* are some of the most common plants which are grown to produce essential oils. Such oils are very prized in the domestic and international markets since they have numerous applications in various industries (Salim, *et al.*, 2014) ^[42].

Mentha oil is primarily a product of the leaves and tender stems extracted by steam distillation. *Mentha arvensis* oil is mainly rich in menthol that is widely used in food and pharmaceuticals (Amano, and Belete, 2022) ^[7]. Due to its cooling property, antimicrobial properties, and pleasant smell, menthol has become an ingredient of most consumer products. The emerging demand of natural and herbal products in the world has also enhanced the commercial significance of the cultivation of mentha (Kumar, and Sood, 2011) ^[28].

Table 1: Effect of Planting Time on Growth Parameters of Mentha

Planting Time	Plant Height	Number of Branches	Leaf Area	Biomass Production
Early planting (Dec-Jan)	High	High	Large	Maximum
Optimum planting (Jan-Feb)	Moderate-High	Moderate-High	Moderate	High
Late planting (Feb-Mar)	Reduced	Reduced	Small	Low
Very late planting	Very low	Poor	Very small	Minimum

Mentha has many industrial applications, and this is one of the primary factors which made this plant popular as an aromatic crop. The mentha oil and extracts are used in a variety of industries, so it is economically important to the farmers and the agro-based industries. The major applications of mentha include:

1. Production of Menthol and Essential Oils

Mentha is cultivated mainly as a source of essential oil that contains menthol as the key element. Menthol is consumed as a flavor additive, coolant and as medicine in different industrial products. High menthol value raises the marketability and export capacity of mentha oil (Zheljaskov, and Astatkie, 2012) ^[55].

Table 2: Influence of Planting Time on Mentha Yield and Oil Content

Planting Time	Herbage Yield (t/ha)	Essential Oil (%)	Oil Yield (kg/ha)
Early winter planting	20-30	0.6-0.8	High
Mid-winter planting	18-25	0.5-0.7	Moderate
Late winter planting	15-20	0.4-0.6	Low
Spring planting	10-15	0.3-0.5	Very low



Japanese mint (*Mentha arvensis*)

Common name: corn mint, field mint

Inflorescence: verticillasters

Distribution: Uttar Pradesh, Harayana, Bihar, Uttrakhand

Oil percentage: 0.7% to 6%



Spearmint (*Mentha spicata*)

Common name: garden mint, common mint, or lamb mint

Inflorescence: verticillasters

Distribution: Major producer is Uttar Pradesh

Oil percentage: 0.2% to 2.6%



Bergamot mint (*Mentha citrate*)

Common name: bergamot mint

Inflorescence: Verticillaster

Distribution: Uttar Pradesh, Punjab, Haryana, Some parts of Himachal Pradesh

Oil percentage: 0.5% to 1.0%



Peppermint (*Mentha piperita*)

Common name: Brandy mint

Inflorescence: verticillasters

Distribution: Uttar Pradesh is the dominant state

Oil percentage: 0.4% to 4%

2. Pharmaceutical and Medicinal Preparations

Mentha oil also possesses a variety of health effects such as antiseptic, analgesic, carminative and digestive stimulant effects. It is generally applied in cough syrups, pain relieving balm, inhalers, digestive pills, and other medical preparations. Menthol ointments and balms are commonly applied in the treatment of headache, muscular pain, breathing complications (Brar, *et al.*, 2014) ^[9].

3. Flavoring Agents in Food and Beverages

Mentha extracts and essential oils are also commonly used as food flavors in the food and beverage market. These are found as chewing gums, candies, chocolates, ice creams, mouth fresheners, herbal teas, and many other drinks. Mentha is a significant component of confections because of its refreshing and cooling effect and its flavor (Ostadi, *et al.*, 2020) ^[37].

4. Cosmetics and Oral Care Industry

Mentha oil is commonly used in Cosmetic care products such as toothpaste, mouthwash, shaving creams, soaps, lotions and shampoos. It has antimicrobial and cooling effect and is used to improve oral health and give a cooling effect to cosmetic

products (Ebrahimghochi, *et al.*, 2018) ^[19].

5. Aromatherapy and Perfumery

Mentha oil is commonly utilized in aromatherapy and perfumery since it has a pleasant smell and enjoys a calming effect. Mentha essential oils are applied in perfumes, air fresheners, massage oils, and therapeutic products that may help to decrease the stress and induce relaxation. This diversity of application has contributed to the importance of mentha farming in enhancing the revenue of farmers in most areas (Aishwath, and Tarafdar, 2017) ^[3]. Mentha is a high-value commercial crop in India especially in the Indo-Gangetic Plains where the climate favors the production of high biomass and the accumulation of oil. The country is also a major producer of mentha oil in the world and is also an important International Menthol trade partner (Sharma, 2012) ^[44].

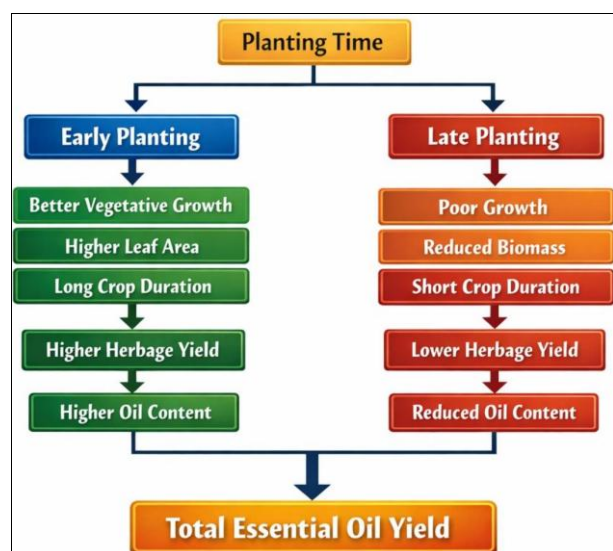
The economic feasibility of mentha planting will be largely determined by two aspects, namely herbage yield (biomass production) and content of essential oils. The increase in vegetation results in an increase in leaf biomass, which directly impacts oil yield as the essential oils are mostly stored in the leaf glands. These two parameters are also sensitive to environmental

and agronomic conditions like temperature, soil quality, irrigation and agronomy practice (Hayes, *et al.*, 2007) ^[24]. Planting time is one of them and is considered essential to growth and oil productiveness of mentha crops. Timely planting assists the crop to enjoy the good weather conditions when it is in the vegetative growth and the oil production stage. The use of early or optimal planting normally leads to improved plant establishment, high leaf area, and biomass production. Conversely, late planting may subject the crop to adverse weather patterns, damaging the crop, the quantity of oils produced, and overall yield (Desai, *et al.*, 2018) ^[16].

Influence of Planting Time on Mentha Growth

The time of planting is a major determinant of growth and development of mentha crops. The climatic conditions of such plants at the initial stages of production determine the growth performance (McKay, and Blumberg, 2006) ^[35]. When the appropriate planting time is selected, the crop can grow in favourable temperature, light and soil moisture. These significantly contribute to vegetative growth and biomass generation. *Mentha arvensis*, *Mentha piperita*, and *Mentha spicata* are very sensitive species that are also dependent on climate and therefore respond to change in the time of planting (Abbaszadeh *et al.*, 2014) ^[1].

Effect of Planting Time on Mentha Productivity



The time of planting influences different vegetative development factors which eventually determine the productivity of mentha crops. Important growth attributes include:

1. Plant height
2. Number of branches per plant
3. Leaf area index (LAI)
4. Dry matter accumulation
5. Overall biomass production

These factors are directly connected with the effectiveness of the plant in photosynthesis and the production of the essential oils. These characteristics are directly influenced by shifts in the environmental conditions the crop may encounter during its growth due to variations in planting time.

Mentha crops have high vegetative growth when they are planted early. Planting these plants at the proper time mean that they enjoy moderate temperatures and abundant sunlight during their initial stages of development that stimulates rapid cell

division, elongation and leaf growth. This leads to higher plants having more branches and bigger leaves. An increase in leaf area enhances the photosynthetic level of the plant which leads to the production of carbohydrates and biomass (Singh, and Saini, 2008) ^[45].

Studies have found out that the earlier a mentha crop is planted, the greater the height and branching enhancement of the plant. Early-season plants will have more time to grow and thus have a more developed canopy with a high density of leaves (Srivastava, *et al.*, 2022). This additional period of growth helps the crops to accumulate more dry matter and have high herbage yields than those planted later in the year. The other growth parameter, which is influenced by the time of planting, is the leaf area index (LAI). Early planted crops usually possess a higher LAI because of growth of more and bigger leaves. The mentha essential oils are primarily accumulated in glandular trichomes of leaves, and thus, increased leaf area results in more yield of oils. Conversely, late planting may lead to a low number of leaves, which leaves a negative influence on biomass and oil content (Clark, and Menary, 1979) ^[12].

The time of planting also has a significant effect on the dry matter accumulation. Mentha crops planted early would tend to yield more dry matter due to the extended growth time and efficient utilization of the environmental resources. Sunlight and good temperatures increase photosynthesis, which enhances the production of carbohydrates in plant tissues and their storage. These carbohydrates are required in the production of essential oils (Luță, *et al.*, 2022) ^[30]. Late planting may be detrimental to the vegetative development of the mentha plants. Crops planted later are exposed to extreme temperatures or reduced growth, which restricts their growth. Such conditions may result in reduced growth of plants, growth of fewer branches, and reduced growth of leaves. This can in turn reduce the total biomass and herbage yield by a huge margin (Mekonnen, and Kassahun, 2011) ^[36].

Experiments of *Mentha piperita* (peppermint), *Mentha spicata* (spearmint) have indicated that crops that are planted earlier in the winter months or early spring have improved growth rates than those that are planted later. Planting early can take advantage of good climate conditions when the plant is being established and in its initial stages of growth like moderate temperatures, increased daylight, and adequate soil moisture. These advantages result in the improvement of root growth, nutrient uptake and coverage development, which improves the growth and productivity of plants (Rohloff, *et al.*, 2005) ^[40]. Moreover, early planting aligns the crop growth cycle with favorable conditions at critical growth stages. This leads to improved photosynthesis, increased leaf yield and enhanced biomass accretion. On the other hand, late planting also reduces the growth period and exposes the crop to unfavorable conditions at important growth stages, and decreases the vigor of the plant and yield potential (Yeşil, 2021) ^[53, 54].

Thus, the selection of the optimal time of planting plays an important role in ensuring a high level of vegetative growth and biomass production in mentha crops. The relationship between growth parameters and planting date may help farmers and researchers develop effective cultivation management that would facilitate the maximization of productivity and profitability of mentha farming.

Effect of Planting Time on Herbage Yield

One of the major economic characteristics in growing mentha is herbage yield because it directly affects the amount of essential oil that can be obtained. Essential oil is primarily obtained

through leaves, and the tender stems, and consequently, an increase in biomass of the product will usually result in an increase in the production of the product, the oil. Thus, one of the key objectives in mentha farming is an increase in herbage production. There is significant variation in herbage production by species of *Mentha* genus (*Mentha arvensis*, *Mentha piperita*, and *Mentha spicata*) depending on the farming techniques and the environment (Telci, *et al.*, 2011) ^[52].

The factors influencing herbage yield in mentha are mainly the height, number of branches, the area of the leaf and the total biomass of the plant. All these are closely related to the planting of the crop. Ideal planting means that plants get to enjoy the favourable conditions during their growth and thus enhanced development and increased biomass (Court, *et al.*, 1993) ^[14].

Various researchers have demonstrated that fresh and dry herbage is more when mentha crops are planted at the right time. Properly timed plants can utilize the ideal temperature, sunshine and soil moisture in youthful growth. These have positive effects by improving photosynthesis, nutrient absorption as well as canopy development resulting to increased biomass production (Kahkashan, *et al.*, 2016) ^[26].

In experimental study of *Mentha spicata* (spearmint), it was found out that crops planted at the end of December yielded maximum biomass. In one study spearmint planted in this period yielded approximately 27,500 kg of fresh herbage per hectare which was vastly better than when crops were planted later. The higher production as a result of early planting was attributed to the improved vegetative growth, higher leaf area, and extended duration of growth (Al-Zyadi, 2019) ^[5].

On the same note, research of *Mentha piperita* (peppermint) revealed higher dry matter and herbage output of crops planted at the end of December compared to those planted earlier or later. Planting at this time enables crops to be well established and enjoy the advantage of good climate at the stage of growth (Zheljaskov, and Topalov, 1997) ^[56]. This leads to the growth of a dense canopy of plants, which results in the generation of higher biomass. Planting early has a number of advantages, which result in increased herbage yield. At the correct time, the crops grow longer, and their stems are stronger, with abundant foliage and a higher leaf area index. The increased canopy will increase light interception and photosynthetic efficiency resulting in greater carbohydrate production and biomass. This leads to an increase in herbage yield (Duriyaprapan, *et al.*, 1986) ^[18].

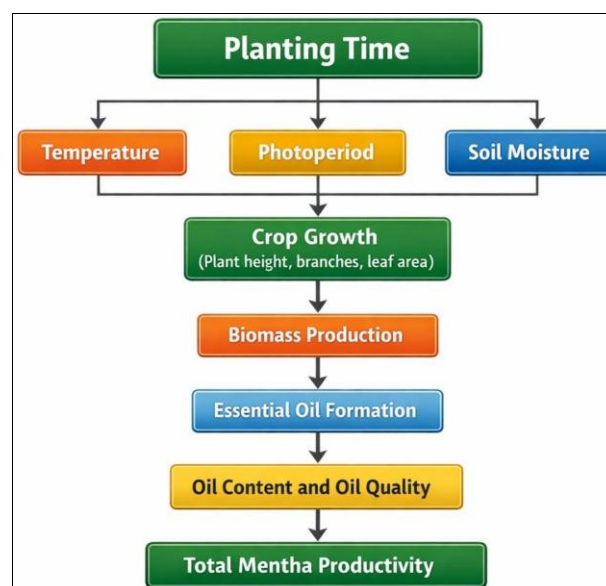
On the contrary, late planting tends to result in low herbage yields. Late planting reduces the vegetative growth period, which reduces plant growth and biomass. There is also the possibility of high temperatures or moisture stress in late-planted crops in the critical growth phases, which leads to a negative impact on their development and productivity (Desai, *et al.*, 2018) ^[16]. In these conditions plants may have a reduced number of branches, reduced size of leaves, and reduced biomass. Delayed planting can cause changes in temperature that lower photosynthesis and accelerate the maturity of plants. This causes a reduction in the growth cycle without attaining optimum vegetative growth resulting in reduced fresh and dry herbage production (Al-Zyabi, and Hilo, 2025) ^[6].

In addition to this, the adverse influence of late planting on herbage crop may affect the economic outcome of mentha crops. Essential oil production is closely connected with the biomass of the leaves; therefore, a decline in growth will result in oil production as well as loss of profit (Gupt, *et al.*, 2025) ^[23]. To achieve the maximum herbage production in mentha crops, it is necessary to make the appropriate selection of the best planting

time. Planting at the right time provides good growth conditions, healthy growth of a plant and enables an increase in biomass. When the time of planting is properly matched with the appropriate climate, herbage yield and economic viability of the mentha farming can be highly enhanced (Brar, *et al.*, 2025) ^[8].

Effect of Planting Time on Essential Oil Content

The most useful product of mentha plants is essential oil which determines the commercial value of the crop. *Mentha arvensis*, *Mentha piperita* and *Mentha spicata* are species in the genus *Mentha* that are usually cultivated because of their aromatic oils. These oils have significant substances such as menthol, menthone, and menthyl acetate (Yeşil, 2021) ^[53, 54]. Oil preferentially accumulates in the glandular trichomes of the leaves and young stems. Therefore, whatever influences the growth and leaf development of plants also influences the level of production of essential oils (Kumar, *et al.*, 2025) ^[29].



Planting time is critically important in deciding the amount of essential oil and total yield of oil in mentha crops among other farming procedures. Planting time influences environmental conditions such as temperature, intensity of light, photoperiod and humidity in the growth period. The conditions have a significant impact on physiological activities occurring during the photosynthesis process, nutrient uptake, and the synthesis of secondary metabolites that regulate the production of essential oils (Gordanić, *et al.*, 2025) ^[22]. It has been found that of the mentha crops planted early, a greater quantity of essential oil is usually obtained compared to those that are planted late. Planting early enables the plants to take advantage of the favorable climatic conditions of the growth and oil production processes. Moderate temperatures, adequate sunlight and adequate soil moisture promote robust vegetative growth thus resulting in increased leaf area and increased biomass. Because the essential oil is majorly produced and kept in plant tissues (mainly leaf), this means that the larger the leaf mass, the more oil is accumulated (Soltanbeigi, *et al.*, 2021) ^[49].

The percentage of essential oil and total oil yield are strongly correlated with factors of vegetative growth such as plant height, number of branches and leaf area index. Plants planted in the correct season usually acquire full canopy and abundant in foliage thereby increasing photosynthetic ability and carbohydrate generation. These are necessary carbohydrates that are required in the production of essential oil compounds. Thus,

the better vegetative growth results in the increase of essential oil concentration and the oil yield. Research on *Mentha piperita* (peppermint) indicates that early planting will enhance herbage and essential oil production greatly (Singh, *et al.*, 2008) ^[45]. Early planted peppermint crops often also contain better oil composition along with increased biomass. Major quality ingredients such as menthol and menthyl acetate are usually higher when the crops are planted on time. Such an improvement in the quality of oil increases the market price and demand of peppermint oil in industries (Majkowska-Gadomska *et al.*, 2024) ^[31].

Studies of different mint species also suggest that spring planted crops tend to accumulate more leaf biomass and essential oil when compared to autumn planted crops. Good weather conditions such as moderate temperatures and abundant sunlight promote vegetative growth and efficient oil production (Soltanbeigi, *et al.*, 2021) ^[49]. Such conditions also help in the formation of glandular trichomes that are essential oil repositories. Conversely, late planting tends to decrease the essential oils and the yield of oils. Coupled with the temperatures and moisture stress towards the later stages of growth, late planted crops may experience high temperatures and moisture stress. Such adverse environments may affect physiological activities negatively and reduce the production and storage of essential oils. It can also result in a shorter growing season as high temperatures can accelerate the maturity of the plants reducing the time available to achieve peak oil production (Kumar *et al.*, 2024) ^[27].

Also, late planting can reduce leaf development and biomass production, reducing the overall oil production per acre. Because the production of mentha essential oil is influenced by the biomass of the leaves, there is a direct effect of vegetative growth on the oil accumulation (Marques, *et al.*, 2023) ^[33]. The selection of appropriate planting time is also a key factor towards maximizing the quantity and quality of essential oil in the mentha farming. Early or the ideal planting enables crops to develop under favorable conditions, which contribute to the healthy growth in the vegetation and boost the production of oil. When the timing is appropriate and in accordance with the appropriate environmental factors, the yields and quality of oil can increase significantly, which leads to higher economic returns of mentha farming (Ostadi *et al.*, 2020) ^[37].

Table 3: Environmental Factors Influencing Mentha Growth and Oil Production

Factor	Influence on Crop
Temperature	Regulates vegetative growth and oil synthesis
Photoperiod	Affects photosynthesis and biomass
Soil moisture	Supports plant establishment and leaf growth
Crop duration	Determines biomass accumulation
Nutrient availability	Enhances growth and oil yield

Effect of Planting Time on Oil Quality

In addition to having an influence on the oil yield, the planting time has a significant effect on the chemical composition and quality of mentha essential oil. The marketability of mentha oil is not only based on the quantity of the oils produced but also on the presence of certain chemical constituents which give it aroma, flavor and health benefits. *Mentha arvensis*, *Mentha piperita*, and *Mentha spicata* species possess numerous volatile compounds that define the quality of oils and industrial application (Yeşil, and Özcan, 2021) ^[53, 54].

The chemical composition of the mentha oil largely depends on the genetic factors, environmental factors, and practices in

farming like planting time. The production of secondary metabolites that form the essential oil composition can be significantly influenced by changes of temperature, sunlight and humidity during growth (Herb, 2022) ^[25]. Major compounds of mentha essential oil which are affected by the time of planting include:

1. Menthol - the main compound that gives mint oil its cooling sensation and medicinal properties.
2. Menthone - an important intermediate in menthol production.
3. Menthyl acetate - adds to the pleasant aroma and taste of mint oil.
4. Carvone - a key aromatic compound especially prevalent in spearmint oil.

These substances are produced in the plant on complicated biochemical pathways and their concentration is extremely sensitive to the environmental conditions under which the plant grows. It has been discovered that when timing of planting is correct, the essential oils produce a higher concentration of desired compounds that promote the overall quality and market value of the oil (Salim, *et al.*, 2014) ^[42]. The yield of *Mentha* crops also enjoys optimum conditions when they are planted at the right time in the vegetative growth and the production of the oils. Such conditions contribute to the effectiveness of metabolic processes, promoting the synthesis of essential aromatic products (Singh, *et al.*, 2022) ^[47].

Indicatively, research carried out on *Mentha piperita* (peppermint) observed that crops that were planted in December yielded essential oil with a higher concentration of menthol as compared to those planted later. The most useful ingredient of peppermint oil is menthol, and its increased concentration is important to improve the commercial qualities of the given oil (Salehi, *et al.*, 2018) ^[41].

Similarly, the balance of menthol and menthone in mint oil is enhanced by optimum planting time. One of the most important criteria of quality that is used in the market of essential oil is a favorable Menthol-to-menthone ratio. Planting early will enable the plants to grow at moderate temperatures and sufficient sunlight supporting efficient transformation of menthone to menthol at the time of production of oils. Late planting, on the contrary, can have a negative impact on the chemical composition of mentha oil (Charles, 2012) ^[10]. Late planted crops are more subjected to temperature and stress at critical growth stages which interferes with metabolic pathways in which essential oils are produced. The quantities of the desirable compounds such as menthol and menthyl acetate can therefore be reduced and the less preferred compounds can increase.

Late-stage temperature stress may also modify terpene-forming enzyme activity, which results in modifications in the composition of oil. These changes can decrease the quality of the aroma and industrialism of the oil (Ebrahimghochi, *et al.*, 2018) ^[19]. Moreover, the timing of planting may affect the growth of the glandular trichomes which play a vital role in the production of the essential oils. Planting the crops earlier will have more glandular trichomes on the leaves and lead to higher concentration of the oil and quality of the oil (Clark, and Menary, 1980) ^[13].

Therefore, appropriate planting time is crucial in ensuring the optimum yield of essential oil as well as ensuring the high quality of oil in mentha crops. The optimal planting will provide the best environmental conditions in which the production of oil will take place thus increasing the concentration of desired chemical compounds. This ends up adding to commercial value

and industrial demand of mentha essential oil (Clark, and Menary, 1980) ^[13].

Agronomic Reasons for the Effect of Planting Time

The response of mentha crops to planting time can be justified on the basis of various agronomic factors that directly impact plant growth and development. Plants belonging to the mentha family, including *Mentha arvensis*, *Mentha piperita*, and *Mentha spicata*, are particularly vulnerable to environmental conditions during plant growth (Ostadi, *et al.*, 2020) ^[37] Planting time is a critical agronomic practice that affects environmental conditions during germination and plant growth. There are various agronomic reasons that explain the impact of planting time on mentha crops (Franz, and Novak, 2020) ^[21].

1. Temperature

Temperature is one of the critical environmental conditions that impact plant growth and development in mentha crops. Mint plants are known to perform optimally under moderate temperature conditions. Such conditions promote rapid plant growth and development. Planting mentha crops during the initial stages allows them to germinate under optimal temperature conditions (Kumar, *et al.*, 2024) ^[27]. Optimal temperatures promote plant growth by facilitating root development, leaf expansion, and stem elongation. Optimal temperatures enhance plant growth by stimulating enzymatic activities and photosynthesis, resulting in high biomass production and oil content (Franz, and Novak, 2015) ^[20].

2. Photoperiod

The duration of daylight hours, referred to as the photoperiod, is a critical factor in the regulation of plant growth and metabolic development in mentha crops. Longer periods of daylight are beneficial in improving the efficiency of photosynthesis. Improved efficiency of photosynthesis increases the production of carbohydrates and leads to enhanced plant growth. Crops planted early in the season benefit from the increasing photoperiod during the growth season (Singh, *et al.*, 2022) ^[47]. As a result, the plants are able to develop more leaves and branches. Since the production of essential oils in mentha plants occurs mainly in the leaves, the development of more leaves leads to the production of more essential oils. In addition, adequate sunlight is required for the development of glandular trichomes, the structures that store essential oils (DAS, 2018) ^[15].

3. Soil Moisture

The availability of soil moisture during the early stages of growth is a critical factor that is affected by the time of planting. Early planting is often done during a time when soil moisture levels are relatively adequate. Soil moisture is necessary for the development of healthy seedlings. Healthy seedlings are necessary for the development of healthy roots. Improved efficiency of root development increases the uptake of water and nutrients from the soil. Improved uptake of water and nutrients from the soil leads to enhanced development of the plants (Dilipbhai, 2015) ^[17].

4. Crop Duration

The duration of crops directly depends on the time of planting and strongly affects mentha yield. Plants that grow early will tend to have a longer vegetative period and this allows the plants to achieve more biomass prior to harvesting (Maurya, *et al.*, 2024) ^[34]. This long growth cycle increases the development of

the leaves, increases the production of dry matter, and synthesis of essential oils. Late planting on the contrary reduces the time of crop growth, and it minimizes time of vegetative growth and time of accumulating oil. Consequently, the late planting usually results in herbage loss and low concentration of essential oils (Prasad, *et al.*, 2024) ^[39].

**Optimum Planting Time for Mentha in Different Regions
Although the ideal planting time varies by region, general recommendations include**

Region	Recommended Planting Time
Northern India	Late December - January
Subtropical regions	December - February
Temperate regions	Early spring
Mediterranean climate	April - early May

Future Research Needs

We have made good headway in understanding how planting times impact mentha growth and oil content. However, there is much to be researched to take mentha yields and oil content to even greater heights. As a matter of fact, mentha species such as *Mentha arvensis*, *Mentha piperita*, and *Mentha spicata* are highly environment-sensitive and management-sensitive plants. As such, considering that climate change is a reality and farming technology is advancing rapidly, an integrated approach to research is crucial to take mentha to greater heights in the future. One area to be researched is how mentha is impacted by climate change. As a matter of fact, climate change is likely to impact planting times for mentha. As such, planting times are likely to change in favor of warmer or colder climates. As such, future research should be aimed at understanding how mentha grows under changing climates characterized by rainfall and extreme weather conditions. On the other hand, another area to be researched is how planting times impact nutrient management. As a matter of fact, integrated nutrient management is likely to be impacted by planting times. As such, integrated nutrient management involving organic manures, chemical fertilizers, and biofertilizers is likely to be impacted by planting times. Precision farming also has potential for optimizing the sowing schedule. Technologies like remote sensing, GIS, soil sensors, and decision support systems can help in identifying the best sowing schedule based on climate and soil conditions. If these technologies are applied in mentha farming, it would be beneficial.

Another area where research is required is in developing new mentha varieties with resistance to late sowing. If new mentha varieties are developed with resistance to late sowing, it would be beneficial for farmers.

Another area where research is required is in understanding the impact of sowing schedule on the quality and composition of the essential oil. While the impact of sowing schedule on oil content is well understood, its impact on the composition and quality of the oil is not well understood. If the impact of environmental conditions on the biosynthesis of specific compounds like menthol, menthone, and carvone is well understood, it would be beneficial in developing high-quality oil.

Lastly, this would necessitate a multidisciplinary methodology in the production of new mentha cultivation methods. This would facilitate optimization of the sowing schedule, biomass and the quality and content of the oil.

Conclusion

One example of agronomic factors that influence the growth, productivity and essential oil properties of mentha crops is the

planting time. The importance of optimum planting time is that it ensures that the crop develops at favorable conditions at both vegetative and reproductive stages. There is always an advantage of planting early as it enhances vigorous growth, leaf area development and biomass. These eventually translate to high production of herbs and essential oils.

This has been demonstrated in the research done on different species such as *Mentha arvensis*, *Mentha piperita* and *Mentha spicata* where early planting favors vegetative growth, essential oil production, and yields high quality essential oils which are of high market value. Early planting takes advantage of favorable conditions that ensure efficient photosynthesis and biosynthesis. Such conditions are moderate temperatures, sufficient moisture of soils and prolonged photoperiods at the initial stages of growth.

Late planting, conversely, leads to a shorter period of growth and subjecting of the crop to unfavorable conditions such as high temperatures at later stages of growths. The conditions may result in a decrease of vegetative cover, decrease of biomass production and essential oil production.

It is therefore significant that the planting time is well chosen based on the climatic conditions in the areas. This has the potential to make the mentha crops more productive and economically beneficial.

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