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Research Paper

Agronomic evaluation of peppermint varieties under different planting time and harvesting schedule

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ABSTRACT

A field experiment was carried out to assess the ideal time of planting and harvesting schedule of peppermint to realize higher herb yield and quality essential oil of peppermint during spring seasons of 2019 and 2020 at two locations viz. Ludhiana and Bathinda. The experiment was laid out in split-plot design with the combinations of two varieties (Local and 'Kukrail') and three dates of planting (January 15, January 30 and February 15) in the main plots and three harvesting schedules [120, 130 and 140 days after planting (DAP)] in sub-plots. Delayed planting of peppermint on Feb 15 significantly improved growth and development in terms of plant height and stool count thereby resulting in 29 and 35.9% higher herb yield at Ludhiana and Bathinda respectively as compared to Jan 15 planting. However, planting on Feb 15 produced herb yield statistically at par with Jan 30 planting. Harvesting the peppermint at 140 DAP produced significantly higher herb yield by 16.3 and 31.2% than 130 and 120 DAP respectively at Ludhiana and by 11.3% and 20.2% respectively at Bathinda. The 'Kukrail' variety demonstrated significantly higher oil yield across locations, influenced by delayed planting and extended harvesting schedules, with maximum yield achieved at 140 DAP. These findings highlight the importance of optimizing planting and harvesting schedules to enhance peppermint productivity and oil yield. Adopting the 'Kukrail' variety with delayed planting and extended harvesting can maximize economic returns and ensure efficient utilization of agricultural land, offering a practical approach for farmers to improve peppermint cultivation outcomes.

Key words: Harvesting schedule, *Mentha piperita* L., Oil yield, Planting date

Peppermint (*Mentha piperita* L.) is one of the most popular and widely consumed aromatic and medicinal plants and cultivated in large areas of the world. India is one of the major producers and exporters of oil in the global market and during 2023-24, an area of 348.68 thousand hectares was dedicated to mentha cultivation, resulting in a production of 35.15 thousand tons of natural mentha oil (Government of India, 2024). Peppermint oil is widely used in food, preparation of liqueurs, candies etc. Peppermint oil contains high levels of essential active menthol (Patrui and Tabara 2011). Menthol, a crystalline compound obtained from peppermint oil, has a pleasant flavor and aroma, cooling anesthetic effect and is used in confectioneries, pharmaceuticals, oral health care products, cosmetics, teas and tobacco products (Santoro *et al.,* 2013). Planting time plays a significant role in realizing the potential yield of mint crop because in northern India, mint when grown during spring season experiences low temperature accompanied by short day length during early stages of crop growth, which largely affects germination as well as early vegetative growth. These prevailing climatic conditions can be easily manipulated by changing the time of planting (Brar *et al.,* 2014). Production efficiency of a crop greatly differs under different date of planting depending upon foliage characteristics and canopy structure. A crop which attains optimum leaf area index and retains it for a longer period, is considered more efficient for harvesting solar energy during the crop season. The time of planting not only provides a competitive advantage to the crop w.r.t fresh herbage yield (Saha *et al.,* 1999) and oil yield (Ram *et al.,* 2001), but also influences weed population indirectly through early canopy development and possible smothering effects. The autumn planting date produces more essential oil in peppermint than spring date (Ebrahimghochi *et al.,* 2018) because long days improves quantity and quality of essential oil of mint.

An effective material of peppermint plant includes essence as essential oil (1–2%), tanon, flavonoid, colien and

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bitter materials (Sheykholeslami *et al.,* 2014). Medicinal effects of this plant is related to chemical compounds of essence in leaves which is more than 20 types such as menthol (40-60%), menthofuran, menthone, piperitone, pulygone and cineole. So, the growth restricted factors which affect the essence content of the plant include temperature stresses, nutrient deficiency in the soil, moisture deficiency, planting and harvesting schedule. The essential oil composition of aromatic plants is largely affected by the genotype and agronomic factors, such as harvesting time, plant age, soil fertility and crop density (Marotti *et al.,* 1994). Likewise, the yield and essential oil composition of mint species are also influenced by the interactive effects of the genotype and environment, crop age, time of harvest and season. In general, the time of harvest has a close relation to yield as well as quality of oil and it varies with the existing environment and available genotype. The planting time and harvesting schedule influence the yield potential of peppermint due to varied temperature conditions with altered planting time as well as difference in crop longevity due to early or delayed harvesting.

This study specifically aims to investigate the ideal planting and harvesting times for different peppermint varieties to optimize both herb yield and essential oil production. While previous research has shown that planting time can influence the growth patterns and oil yield of peppermint, the relationship between these variables and how they interact with environmental conditions, such as temperature and soil fertility, remains complex. Different planting dates can lead to variations in plant growth due to changing climatic conditions, particularly temperature and day length, which in turn affect the crop's ability to produce essential oil. For example, autumn planting may result in higher oil yield compared to spring planting due to the longer duration of daylight and warmer temperatures during the growing season, which promote more efficient photosynthesis and oil synthesis. By focusing on this specific aspect of peppermint cultivation, this investigation aims to bridge the knowledge gap surrounding the optimal planting and harvesting schedules. The study will examine how the timing of planting affects key factors such as canopy development, leaf area index, and the overall ability of the plant to capture solar energy—crucial elements for both high herb yield and oil production. Additionally, the impact of harvest timing on the oil's composition and quantity will be explored, with the objective of determining the most favorable conditions for maximizing both yield and quality. This research is crucial for improving agricultural practices and enhancing the profitability of peppermint cultivation, particularly for growers looking to optimize the production of high-quality essential oil.

MATERIALS AND METHODS

Field experiments were conducted at two different locations *viz*. Research Area, School of Organic Farming, Punjab Agricultural University at Ludhiana and Regional Research Station at Bathinda during spring seasons of 2019 and 2020. Ludhiana is situated in a trans-gangetic agroclimatic zone, representing the Indo-Gangetic alluvial plains at 30°54' N latitude, 75°48' E longitude and 247 m above average sea level. This district has four distinct seasons namely; spring, summer, autumn and winter. The climate of this region is characterized as sub-tropical semi-arid with hot summer and cold winters. Bathinda falls in the southwestern region of Punjab and situated at 30°36' N latitude and 74°28' E longitude at 211m above mean sea level in trans-gangetic plains of India. The climate of Bathinda is mainly characterized by very high temperatures during the summer, with daily maximum often exceeding 40°C, a short rainy season and a bracingly cold winter with temperatures dropping as low as 3°C. Summer season starts from the month of March and continues till June. Being close to the Thar Desert of Rajasthan, the region experiences extreme temperatures during the summer season.

The experiment was laid-out in a split-plot design, where the main-plots consisted of the combinations of different varieties and time of planting. The main-plots were further divided into sub-plots that included different harvesting schedules. The varieties and planting times were the primary factors being tested, while the harvesting schedules were the secondary factor. Each treatment combination was replicated three times. Soil of the experimental sites at Ludhiana and Bathinda was well drained loamy sand (79.7% and 80.67% sand), with slightly alkaline in reaction (*p*H 8.2 and 8.4) and electrical conductivity (0.29 dS/m and 0.26 dS/m), low in organic carbon (0.35 and 0.22%) and available nitrogen (116.5 and 140.3 kg/ha), medium in available phosphorous (20.2 kg/ha and 17.7 kg/ha) and potassium (253.6 kg/ha and 250.1 kg/ha). Local cultivar and 'Kukrail' were used for planting at different dates (Jan 15, Jan 30 and Feb 15) using 5.0 q/ha runners having 2–4 nodes each. For planting, freshly cut runners were laid end-to-end joined to each other or at 2-3 cm spacing between them at a depth of 4–5 cm in open furrow made with the help of a single tined drill and then covered with soil. The row-to-row spacing of 45 cm was taken as per recommendation practices. A basal dose of 37.5 kg N/ha and 40 kg P_2O_5/ha was applied through urea and di ammonium phosphate at the time of planting. Later, 37.5 kg N/ha was applied at 40 days after planting as top-dressing. First irrigation of 5 cm was applied immediately after planting to ensure proper moisture for sprouting of the runners and thereafter irrigation was assured according to the need of the crop. A total of 9–11 irrigations, each of 5-7.5 cm, were given throughout the crop cycle. Two hand weedings were done 30 and 55 DAP to keep the weeds under check. The crop was harvested manually with a sickle about 5 cm above the ground level as per the harvesting schedule (120, 130 and 140 DAP) and fresh weight from plots was taken immediately. The emergence and stool count were recorded from two spots of one metre row length selected randomly in each plot. The plant height was recorded from randomly selected five plants in each plot. Essential oil was extracted using Clevenger's apparatus from samples of 500 g of fresh herb taken from each plot at the harvesting stage of the crop. The test samples were chemically analyzed on gas chromatography mass spectrometry using capillary column (30 m × 0.25 mm, 0.25 µm). The oven temperature was kept at 250°C and those of detector and injector at 270°C. The temperature was arranged as: injector temperature 250°C; column temperature was raised from 60 to 270°C at 4°C/min thereafter held at 270°C for 5 min; carrier gas N_2; ignition gas H_2; injection volume 2 µl. The standards of compounds, namely, menthol, menthone and menthofuran (S & G lab supplier) were used to note down the retention times for attaining peaks of above mentioned three constitutes in the essential oil by dissolving in acetone for standard curve preparation to visualise the reproducibility of the results. The identification of compound was recorded on the basis of retention time of enlisted standard compounds (menthol, menthone and menthofuran). The relative contents (peak area per cent basis) of menthol, menthone and menthofuran were calculated from peak per cent area without FID response factor corrections. Oil content (%) was calculated on v/w basis on fresh herb weight basis. Analysis of variance was carried out for growth, yield and quality parameters using PROC GLM procedure of SAS software version 9.3 of SAS system of windows. The difference between means of various treatments was compared with Fisher's least significant difference test at 5% probability level.

RESULTS AND DISCUSSION

Emergence Count

The data on emergence count (Table 1) was recorded at 10, 15 and 20 days after planting. The emergence count increased consistently from 10 DAP to 20 DAP however, the varietal variation did not show any significant difference at any stage of growth during both years at both the locations.

The delayed planting had a significant effect on the emergence count of the crop. Higher emergence count of Jan 30 and Feb 15 planted crop might be due to higher soil temperature conditions available for crop which improved

Table 1. Effect of varieties and time of planting on emergence count of peppermint

Treatment	Emergence count (per meter row length)								
	10 DAP			15 DAP			20 DAP		
	2019	2020	MEAN	2019	2020	MEAN	2019	2020	MEAN
					LUDHIANA				
Varieties									
Local	3.53	3.30	3.41	4.72	4.63	4.68	9.61	10.23	9.92
Kukrail	3.51	3.54	3.53	4.78	4.47	4.62	9.61	9.99	9.80
LSD(p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Time of planting									
Jan 15	2.53	2.24	2.38	3.53	3.33	3.43	8.19	8.28	8.24
Jan 30	3.87	3.89	3.88	5.19	5.05	5.12	10.11	10.79	10.45
Feb 15	4.15	4.14	4.14	5.53	5.27	5.40	10.53	11.25	10.89
CD (P=0.05)	0.36	0.35	0.23	0.45	0.40	0.29	0.66	0.62	0.43
					BATHINDA				
Varieties									
Local	3.60	3.94	3.77	4.32	5.24	4.78	9.36	9.96	9.66
Kukrail	3.58	3.95	3.77	4.35	5.24	4.80	9.35	9.85	9.60
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Time of planting									
Jan 15	2.43	3.06	2.75	2.94	4.82	3.88	7.86	7.95	7.90
Jan 30	4.08	4.33	4.21	4.88	5.44	5.16	9.82	10.68	10.25
Feb 15	4.25	4.45	4.35	5.19	5.45	5.32	10.39	11.08	10.73
CD (P=0.05)	0.21	0.20	0.15	0.39	0.24	0.22	0.87	0.46	0.45

the enzymatic activity for sprouting as compared to January 15 planted crop during both years. To assess this, a comparison of soil temperatures at different planting times is essential. Higher soil temperatures typically enhance enzymatic activity, promoting better germination and faster emergence. Therefore, the higher emergence count observed in the January 30 and February 15 planted crops can be linked to more optimal soil temperatures. A correlation analysis between the emergence count and soil temperature data for each planting date would provide further insight into the relationship between these factors.

The emergence count at 20 DAP at Ludhiana in Jan 30 and Feb 15 planted crop was 26.8 and 32.2% higher than the Jan 15 planted crop, respectively. The corresponding increase in the emergence count at 20 DAP at Bhatinda was 29.8 and 35.8% thereby indicated that late planting could be beneficial for the seedling emergence. Mahal (1991) observed a significantly higher number of sprouts per unit area in late planted spearmint as compared to early plantings and mentioned that late planted crops consumed more heat units against early planted crops at PAU, Ludhiana. Harke *et al.* (2021) also concluded Feb 15 as the best planting time for *M. piperita* as compared to Jan 15 at Solan, HP.

Plant Height

The varietal variation in plant height recorded at harvesting was significant (Table 2). The 'Kukrail' variety showed significantly higher plant height as compared to local variety at harvesting during both the years and locations. At Ludhiana, the mean values of plant height of the 'Kukrail' was 4.3% higher than that of 'Local' variety, whereas the corresponding increase in plant height at Bathinda was 4.7%. The planting on Feb15 being at par with Jan 30, showed a significant increase in the plant height as compared to the early planting on Jan 15 at both locations. Based on two years mean values, Feb15 planted crop attained 27.2 and 22.5% increase in plant height than the crop planted on Jan 15 at Ludhiana and Bathinda, respectively. The increase in plant height on Feb 15 planted crop might have resulted from quick and better crop establishment due to conducive temperature conditions as compared to Jan 15 planted crop. Kumar and Sood (2011) at Solan reported a significant increase in plant height of *M. piperita* planted on February 15 compared to January 15. This was likely due to the relatively higher temperatures in February, which promoted faster growth and development, whereas the lower temperatures during early growth stages in January slowed down the initial growth, affecting the plant's overall development. Zyadi (2019) also concluded that the peppermint planted at 15 February gained significantly higher plant height.

Among different harvesting schedules, the crop harvested at 140 DAP showed 5.7 and 33.3% increase in plant height than that harvested at 130 DAP and 120 DAP respectively at Ludhiana while the corresponding increase in plant height at Bathinda was 7.8 and 19.9%. The longer crop duration i.e. 140 day might have benefited the crop in terms of plant height as mint species have tendency to grow vegetatively. Mahal (1991) also observed significantly taller plants when the crop was harvested at 150 DAP as compared to that of 105, 120 and 135 DAP and

Table 2. Effect of varieties, time of planting and harvesting schedule on plant height of peppermint

Treatment	Plant height (cm) at harvest					
	LUDHIANA			BATHINDA		
	2019	2020	MEAN	2019	2020	MEAN
Varieties						
Local	71.58	72.25	71.92	70.54	71.32	70.93
Kukrail	74.42	75.63	75.03	75.90	75.26	75.58
CD (P=0.05)	2.75	2.82	1.76	3.50	3.01	2.05
Time of planting						
Jan 15	62.44	62.87	62.66	66.78	61.93	64.36
Jan 30	77.44	78.66	78.05	75.36	77.81	76.58
Feb 15	79.12	80.30	79.71	77.53	80.13	78.83
CD (P=0.05)	3.37	3.45	2.15	4.29	3.68	2.51
Harvesting schedule						
120 DAP	61.41	61.21	61.31	66.92	65.86	66.39
130 DAP	76.66	78.07	77.36	72.50	74.11	73.80
140 DAP	80.94	82.55	81.74	78.25	79.90	79.58
CD (P=0.05)	2.26	2.54	1.65	4.38	2.98	2.58

reported that later harvested crop (150 DAP) got longer growth period and consumed more heat units. Thus, late planting and delayed harvesting could be beneficial to have the plants with taller height.

Stool Count

The varietal variation showed a significant effect on plant population as observed in terms of number of stools per meter row length. 'Kukrail' variety registered significantly higher stool count/meter row length as compared to local variety (Table 3). Based on mean analysis, the average stool count for 'Kukrail' variety was about 6.9% higher than that of local variety both at Ludhiana and Bathinda.

The stool count under delayed planting of February 15 at harvest showed an increase of 20.9 and 17.4% than that obtained under early planting of January 15 at Ludhiana and Bathinda, respectively, while it was statistically at par with that of crop planted on January 30. This might be due to optimum and high soil and air temperature conditions available for better emergence which lead to proper flourishment of crops and eventually higher numbers of stools. Mahal (1991) also observed a significantly higher number of stool counts in late planted spearmint crop as compared to early planting at the same location. Similarly, Singh and Saini (2008) also reported higher plantlets and dry matter content in delayed planted crops.

Different harvesting schedules showed a significant effect on stool count. Crop harvested at 140 DAP produced a significantly higher stool counts than the crop harvested at 130 and 120 DAP. Crop harvested at 140 DAP registered 25.4 and 20.2% higher stool count than that harvested at 120 DAP at Ludhiana and Bathinda, respectively. This might be attributed to longer crop growth duration resulting in the formation of a greater number of stools even at later stages. Sekhon (1995) and Kaur (1993) observed the maximum plant population of *M. arvensis* when harvested at 150 DAP. Brar *et al.* (2014) also reported that the stool count, plant height and dry matter accumulation increased significantly and progressively with progressive delay in the planting and harvesting from 120 to 150 DAP.

Leaf to stem ratio

The varietal variation did not exhibit any significant difference in leaf to stem ratio during both years and locations. Based on two year mean, the different dates of planting recorded comparable leaf stem ratio as the variation was non-significant however, early planting on January 15 showed a little higher leaf to stem ratio values at Ludhiana and Bathinda (Table 4) during both years. Singh (2003) also obtained a slightly higher leaf to stem ratio in early planted crops on December 10 as compared to later planting dates of Dec 30 and Jan 20.

Leaf to stem ratio increased significantly with progressive increase in crop duration. The harvesting of peppermint at 140 DAP recorded significantly higher leaf to stem ratio than that of early harvesting of the crop at 120 and 130 DAP at Ludhiana and Bathinda during both years. This might be due to increased leaf growth and fully developed canopy cover at later stages due to longer crop duration in the field as compared to early 120 DAP harvesting.

Table 3. Effect of varieties, time of planting and harvesting schedule on stool count of peppermint

Treatment	Stool count at harvest/meter row length)					
	LUDHIANA			BATHINDA		
	2019	2020	MEAN	2019	2020	MEAN
Varieties						
Local	70.63	74.02	72.32	71.17	70.67	70.92
Kukrail	74.85	79.87	77.36	76.44	75.26	75.85
CD (P=0.05)	2.75	3.31	1.98	3.51	2.98	2.10
Time of planting						
Jan 15	64.33	68.16	66.25	67.72	65.10	66.41
Jan 30	76.00	80.28	78.14	75.44	76.10	75.77
Feb 15	77.89	82.39	80.13	78.25	77.71	77.98
CD (P=0.05)	3.36	4.06	2.43	4.30	3.66	2.58
Harvesting schedule						
120 DAP	65.94	64.93	65.44	65.72	67.05	66.39
130 DAP	74.06	79.94	77.00	74.05	73.94	74.00
140 DAP	78.22	85.94	82.08	81.64	77.91	79.77
CD (P=0.05)	2.93	5.21	2.91	4.55	3.40	2.77

Table 4. Effect of varieties, time of planting and harvesting schedule on leaf stem ratio of peppermint

Treatment	Leaf stem ratio at harvest					
	LUDHIANA			BATHINDA		
	2019	2020	MEAN	2019	2020	MEAN
Varieties						
Local	0.97	0.98	0.97	0.89	0.89	0.89
Kukrail	0.97	0.97	0.97	0.88	0.88	0.88
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Time of planting						
Jan 15	0.98	0.99	0.99	0.89	0.91	0.90
Jan 30	0.96	0.98	0.97	0.88	0.87	0.88
Feb 15	0.96	0.96	0.96	0.87	0.88	0.88
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Harvesting schedule						
120 DAP	0.92	0.93	0.92	0.86	0.85	0.85
130 DAP	0.97	0.98	0.97	0.87	0.85	0.86
140 DAP	1.03	1.02	1.03	0.92	0.96	0.94
CD (P=0.05)	0.02	0.03	0.02	0.04	0.06	0.03

Fresh herb yield

Based on two years mean (Table 5), it was observed that the herb yield of the variety 'Kukrail' was significantly higher than 'local' variety both at Ludhiana (8.3%) and Bathinda (10.7%). This might be due to better growth and development of 'Kukrail' variety in terms of growth parameters like plant height, stool count etc thereby overall contributing to higher fresh herb yield of the crop. Among the planting dates, the herb yield increased significantly when the planting was done on January 30 as compared to January 15 during both years as well as locations. Further delay in planting i.e. February 15 maintained its significance over January 15 but did not show any significant effect on fresh herb yield when compared with January 30.

The mean values of the fresh herb yield indicated that planting on Feb 15 produced 29 and 35.9% higher herb yield as compared to the crop planted on Jan 15 at Ludhiana and Bathinda, respectively. Higher fresh herb yield in Feb 15 planted crop might be due to significantly higher stool count and plant height because of better estab-

Table 5. Effect of varieties, time of planting and harvesting schedule on fresh herb yield of peppermint

Treatment	Fresh herb yield (q/ha)					
	LUDHIANA			BATHINDA		
	2019	2020	MEAN	2019	2020	MEAN
Varieties						
Local	160.83	162.93	161.88	189.17	193.42	190.84
Kukrail	173.09	177.63	175.36	206.93	215.77	211.35
CD (P=0.05)	7.57	9.13	5.33	10.30	13.07	7.25
Time of planting						
Jan 15	140.67	145.24	142.96	156.11	172.91	163.83
Jan 30	177.78	179.21	178.50	215.68	217.84	216.76
Feb 15	182.42	186.38	184.40	222.36	223.04	222.70
CD (P=0.05)	9.27	11.18	6.52	12.61	16.00	8.88
Harvesting schedule						
120 DAP	143.68	150.46	147.07	180.35	188.68	183.83
130 DAP	168.65	163.11	165.88	199.36	197.74	198.55
140 DAP	188.54	197.27	192.90	214.45	227.37	220.91
CD (P=0.05)	6.84	9.12	5.55	12.54	24.81	14.51

lishment of crop due to favorable soil and air temperature at initial growth stages as compared to Jan 15 and Jan 30 plantings during both years of study. Kumar and Sood (2011) reported that the maximum herb yield of *M. piperita* was obtained from crops planted on February 15, compared to those planted on January 15. This difference in yield was attributed to the lower temperatures during the initial growth stages of the crop in January. The cold temperatures during this period slowed crop development, resulting in fewer stools per unit area and consequently a lower herb yield. In contrast, crops planted in February experienced relatively higher temperatures during their early growth phases, which promoted faster growth and improved yield. These findings align with the present study, where a similar trend was observed in the herb yield between the January- and February-planted crops. A similar effect was reported by Ram *et al.* (2001), who observed significantly higher herb yield of *M. arvensis* in crops planted on February 5 compared to those planted on January 20. The enhanced yield in the later-planted crop was attributed to the warmer temperatures during the crucial early growth stages, which facilitated improved crop development. The effect of planting date on herb yield is largely influenced by the temperature conditions during the crop's growth period. In locations where lower temperatures prevailed during the early growth stages, such as those experienced by the January-planted crops, plant development was slower, resulting in reduced stool formation and lower herb yields. Conversely, the February-planted crops, which benefited from relatively warmer temperatures, exhibited improved growth and greater biomass accumulation. These temperature variations directly influenced physiological processes like germination, growth rate, and biomass accumulation, all of which are critical to determining final herb yield.The late harvesting of peppermint at 140 DAP accounted for 16.3 and 11.3% higher fresh herb yield than harvesting it on 130 DAP and the values were 31.2 and 20.2% higher than harvesting it early at 120 DAP at Ludhiana and Bathinda, respectively. This could be due to fact that crop harvested at 140 DAP remained for longer period in field resulting in better growth and development of plants with higher and taller stools under delayed harvesting. In Finland, too the herb yield was significantly better in all the peppermint species in the delayed harvested crop during full bloom compared with the yield from the first harvest (Aflatuni *et al.,* 2006). Court *et al.* (1993) worked on the harvesting dates for peppermint and reported that delayed harvesting was beneficial for peppermint crop in terms of yield and yield attributes.

The interaction effect of time of planting and harvesting schedule on fresh herb yield of peppermint was found significant (Table 6). The planting of peppermint on Jan 30 and Feb15 being harvested at 120 DAP was statistically at par with each other while the fresh herb yield obtained from delayed planted crop was significantly higher than that obtained under early planted crop of Jan15 at all the harvest schedules. Planting the crop late (Feb 15) and harvesting it early at 120 days produced comparable fresh herb yield to the crop planted on Jan 30 and Jan 15 being harvested at 130 and 140 DAP, respectively, thereby, indicating that delayed planting could compensate 10 to 20 days crop duration as the yield difference were non-significant.

Table 6. Interactive effect of time of planting and harvesting schedule on fresh herb yield of peppermint at Ludhiana during 2019–20

Treatment	Fresh herb yield (q/ha)		
	Harvesting schedule		
	120 DAP	130 DAP	140 DAP
Time of planting			
Jan 15	128.91	146.48	153.48
Jan 30	154.81	169.32	211.35
Feb 15	157.50	181.84	213.88
CD (P=0.05)		10.84	

Oil Content

The varietal variation, based on two years mean values, showed significant effect on oil content at Ludhiana (Table 7). The variety 'Kukrail' recorded significantly higher oil content (3.6%) than local variety. However, individual year data further revealed that oil content of both local and 'Kukrail' varieties were statistically at par with each other during both years and locations which ranged from 0.52 to 0.57% except the oil content of 'Kukrail' variety in 2019 at Ludhiana which showed significantly better higher oil content.

The time of planting did not show any significant effect on oil content at Ludhiana however, at Bathinda, the oil content in case of crop planted on Jan 30 being at par with Feb 15 was significantly higher. Bhardwaj *et al.* (1980) and Singh *et al.* (1986) also observed non-significant differences in oil content in mint herb under different planting dates.

Among the harvesting schedules, based on mean values, the oil content in the crop harvested with maximum crop duration of 140 days resulted in significantly higher oil content than shorter duration of 120 days however, the differences were non-significant with that of 130 days at both locations. This might be due to moisture content variations with the difference in crop growth period and different harvesting schedules. Further, based on mean values, the interaction effect between delayed planting along with late harvesting at 140 DAP resulted in significantly higher fresh

Table 7. Effect of varieties, time of planting and harvesting schedule on oil content of peppermint

Treatment	Oil content (%)					
	LUDHIANA			BATHINDA		
	2019	2020	MEAN	2019	2020	MEAN
Varieties						
Local	0.54	0.56	0.55	0.52	0.54	0.53
Kukrail	0.57	0.57	0.57	0.53	0.54	0.54
CD (P=0.05)	0.03	NS	0.02	NS	NS	NS
Time of planting						
Jan 15	0.54	0.55	0.55	0.50	0.53	0.51
Jan 30	0.56	0.57	0.56	0.54	0.54	0.54
Feb 15	0.56	0.58	0.57	0.54	0.55	0.55
CD (P=0.05)	NS	NS	NS	0.02	NS	0.02
Harvesting schedule						
120 DAP	0.54	0.55	0.54	0.51	0.53	0.52
130 DAP	0.54	0.57	0.56	0.53	0.54	0.54
140 DAP	0.58	0.58	0.58	0.54	0.55	0.55
CD (P=0.05)	0.04	NS	0.03	0.01	NS	0.02

herb yield of peppermint. Brar *et al.* (2014) reported decreasing trend in the oil content with late harvesting owing to the decreased proportion of leaves in the total biomass which are the principle sites of oil extraction. But, it was not influenced by the change in the planting dates. Similar findings were also stated by Solomon and Beemnet (2011) that there was a statistically sharp increase in the oil content from 0.5 to 1.4 and 0.8 to 2% (w/w) with delayed harvesting from 60 to 90 and to 120 days after planting, respectively.

Oil Yield

The 'Kukrail' variety showed significantly higher oil yield (Table 8) at both locations with an increase of 13.5 and 10.9% over local variety at Ludhiana and Bathinda, respectively. This might be due to significantly higher fresh herb yield of peppermint in case of 'Kukrail' variety and its comparatively higher oil content as compared to local variety. The oil yield increased with delay in planting from Jan 15 to Feb 15 while the late planting on Jan 30 and Feb 15 were statistically at par with each other. At Ludhiana,

Table 8. Effect of varieties, time of planting and harvesting schedule on oil yield of peppermint

Treatment	Oil yield (l/ha)					
	LUDHIANA			BATHINDA		
	2019	2020	MEAN	2019	2020	MEAN
Varieties						
Local	85.92	92.06	88.99	99.51	105.52	102.28
Kukrail	100.10	101.95	101.03	110.84	116.01	113.43
CD (P=0.05)	8.85	6.67	5.02	6.13	NS	5.48
Time of planting						
Jan 15	76.35	80.32	78.34	78.47	91.59	84.68
Jan 30	100.35	101.74	101.04	116.46	118.28	117.37
Feb 15	102.33	108.96	105.64	120.60	122.43	121.52
CD (P=0.05)	10.83	8.17	6.15	7.51	13.31	6.72
Harvesting schedule						
120 DAP	77.60	82.43	80.01	91.81	99.54	95.32
130 DAP	91.91	93.32	92.61	106.22	107.58	106.90
140 DAP	109.52	115.27	112.40	117.50	125.18	121.34
CD (P=0.05)	6.35	8.31	5.09	8.41	15.49	8.97

the oil yield increased significantly under delayed planting on Feb 15 with 4.5 and 34.8% higher oil yield than Jan 30 and Jan 15 planting, respectively. Similarly at Bathinda, the planting on Feb 15 showed an increase of 3.5 and 43.5% in oil yield over Jan 30 and Jan 15 respectively. The significantly higher oil yield recorded in February planted crop could be attributed to significantly higher fresh herb yield and relatively higher oil content as oil yield is a function of herb yield and oil content. Among the harvesting schedules, the delayed harvesting at 140 DAP revealed significantly higher oil yield as compared to harvest at 130 DAP and 120 DAP. The mean analysis depicted that the oil yield was 40.5 and 27.3% more in crop harvested at 140 DAP than crop harvested at 120 DAP at Ludhiana and Bathinda, respectively while an increase of 21.37 and 13.51% in oil yield of harvest at 140 DAP than 130 DAP harvest was observed at Ludhiana and Bathinda, respectively. Progressive and significant increase in oil yield with each delay in the planting time from Jan 1 to Feb 15 has also been reported by Brar *et al.* (2014). Rohloff *et al.* (2005) also stated that Peppermint oil yield increased from early to full bloom and late blooms. Mekonnen and Kassahun (2011) also reported that oil yield was significantly higher when harvested at 180 and 150 DAT, respectively.

The interaction effect of varieties and harvesting schedule on oil yield of peppermint at Ludhiana was found to be significant (Table 9). The oil yield of both varieties being harvested at 120 DAP was statistically at par with each other as well as local variety being harvested at all stages gave equivalent oil yield while late harvesting at 130 DAP and 140 DAP gave significantly higher oil yield of Kukrail variety as compared to local variety with a maximum oil yield of 123.65 l/ha at 140 DAP harvest of Kukrail variety. The Kukrail variety being harvested at early 120 DAP gave oil yield of peppermint equivalent to oil yield of local variety obtained at 130 DAP and 140 DAP *i.e.* statistically at par with each other. The similar interactions of varieties and harvesting schedule on oil yield of peppermint were found significant at Bathinda where the 'Kukrail' variety being harvested at 120 DAP gave significantly higher oil yield than local variety being harvested at same schedule while the oil yield of both varieties was statistically at par with each other either harvested at130 DAP or 140 DAP. Also, Kukrail variety being harvested at 130 DAP gave equivalent oil yield with local variety being harvested at 130 DAP or 140 DAP that indicated that 'Kukrail' variety was better in terms of oil yield when the shorter duration crop is to be taken or field is to be made free for succeeding crop.

The findings from this study demonstrate the significant influence of planting dates, variety and harvesting schedules on the growth, yield and oil content of peppermint (*Mentha piperita*). Delayed planting, particularly on January 30 and February 15, resulted in higher emergence counts compared to the early planting on January 15. This can be attributed to more favorable soil temperatures during the later planting periods, which likely enhanced enzymatic activity and improved germination rates. In terms of plant growth, the *Kukrail* variety consistently outperformed the local variety in both plant height and stool count, with significant increases observed in the later-planted crops. This growth was further enhanced by delayed planting, particularly in February, which provided optimal conditions for crop establishment, resulting in taller plants and a higher number of stools per unit area. Moreover, the fresh herb yield was significantly higher in crops planted on February 15 compared to those planted on January 15, which could be explained by the better crop establishment, longer growing period, and more favorable temperature conditions for growth. The highest herb yields were observed when crops were harvested at 140 days after planting (DAP), which coincided with improved plant development and higher biomass accumulation. Additionally, the oil yield was significantly higher in the *Kukrail* variety, especially in crops planted later in the season. The February 15 planting, coupled with a 140 DAP harvest, resulted in the highest oil yields due to both increased fresh herb yield and relatively higher oil content. These results suggest that later planting dates, particularly February 15, coupled with delayed harvesting, can optimize both herb and oil yields, making it a promising practice for enhancing peppermint production. The interaction between variety, planting date,

Table 9. Interaction effect of varieties and harvesting schedule on oil yield of peppermint

Treatment	Oil yield (l/ha) (2019–20)					
	Harvesting schedule			Harvesting schedule		
	120 DAP	130 DAP	140 DAP	120 DAP	130 DAP	140 DAP
Varieties						
Local	80.151	85.67	85.67	72.89	113.30	121.36
Kukrail	79.88	99.55	123.65	97.17	121.44	121.68
CD (P=0.05)		9.16			11.35	

and harvesting schedule also underscores the importance of considering these factors for maximizing production. Future research should further investigate the physiological mechanisms behind these temperature-related effects on growth and yield and explore the long-term sustainability of these practices under varying climatic conditions to optimize peppermint cultivation in different regions.

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