Journal of Medicinal and Aromatic Plant Sciences 46 (1) : 23-32, 2024
ISSN 3048-5843 (Print)
https://doi.org/10.62029/jmaps.v46i1.chaudhary

Original Research Article

Cultivation of rose-scented geranium (*Pelargonium graveolens* L.) as a multi-harvest perennial crop under the sub-tropical condition of northern Indian plains

Archana Chaudhary[1,2], Kirti Verma[1,2] Anjali Singh[1,2], Devendra Kumar[1,2], Kushal Pal Singh[1,2], Parminder Kaur[1,2], Anil Kumar Singh[1], Saudan Singh[1,2,*]

[1]Crop Production and Protection Division, CSIR-Central Institute of Medicinal and Aromatic Plants (Council of Scientific and Industrial Research) PO-CIMAP, Lucknow, Uttar Pradesh, India.
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh, India.

Abstract

Pelargonium graveolens L., frequently known as rose-scented geranium (family: Geraniaceae; 2n = 88), is an herbaceous medicinal and aromatic plant cultivated for its highly valued and significant volatile essential oil. It widely excels in the food, cosmetics, aromatherapy, and medicinal industries. The present study focuses on the perennial cultivation of geranium for taking multi-harvest in a year by the novel shed-saving agro technology (SSAT) technology for generating a higher yield of essential oils. A 5 year field experiment was carried out at the research farm of CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, India. During experimentation, two geranium varieties, V1 (CIM-Pawan) and V2 (Bourbon), were grown under a semi-protected polythene shed and harvested 14 times at various intervals. The study found that the maximum fresh herbage yield (14.04 t ha^{-1}) was recorded in variety V1 at IIIrd harvest. The highest essential oil yield (23.76 kg ha^{-1}) was recorded in variety V1 at the Ist harvest. After carefuly examining the trial results, it is suggested that geranium cultivation can be continued as a perennial crop for multiple harvests under a semi-protective shed to obtain higher yields with better financial returns. In contrast, only 1 or 2 harvests are possible under open (natural) conditions of northern Indian plains.

Keywords: *Pelargonium graveolens,* Production technology, Perennial crop, North Indian plains, Low-cost novel technology, Shed-saving agro-technology.

Introduction

Rose-scented geranium (*Pelargonium graveolens* L.) is a crucial herbaceous, aromatic, and medicinal plant belonging to the family Geraniaceae. It is grown commercially to produce high-quality essential oil for use in the fragrance, perfumery, and therapeutic industries (Rao, 2002; Kumar *et al*., 2022). Generally, geranium is typically grown as a perennial or annual crop, depending on the growing environment. Though, the growth pattern of geranium is varied as annual and perennial according to climatic factors. In India, geranium cultivation is practiced throughout the year as a perennial crop at high altitudes in south India under rain-fed conditions. In North Indian plains, it is cultivated as a short-duration winter and/or season annual crop under irrigated conditions.

Moreover, in its perennial cultivation, harvests are performed 3 to 4 times a year, and the plantation is kept alive for 8 to 10 years on hills of south India and 2 to 3 years in south Indian plains. However, in northern Indian plains, only one or two harvests are performed yearly, and fresh planting is required every year to grow (Rao, 2009). The main issue with its cultivation in North India's plains are mortality during the rainy season and the lack of new, healthy planting material for producing the crop the following season. Mortality during the rainy season and unavailability of fresh, healthy planting material for growing the next season's crop is a major problems associated with its cultivation in North Indian plains. Hence, the protection of plants and planting material from adverse effects of rains during the monsoon season is a must for the availability of an abundant quantity of planting material.

Low-cost novel technology, i.e., shed-saving agro-technology (SSAT) can protect plants from rain (Nilofer

Received: 01st December, 2023 Accepted: 01st April, 2024

*Corresponding author; email: s.singh@cimap.res.in

et al., 2018). Further, in northern Indian plains, single-harvest geranium from the mother plant is generally adopted for a seasonal/annual crop. However, multi-harvest as a perennial crop under a semi-protective shed that can extend the mother plant cuttings supply and essential oil production throughout the years are possible under northern Indian plains. The number of harvests in perennial multi-harvest geranium will ultimately decide commercial production's longevity and future potential. Geranium can be more profitable if cultivated as a perennial crop as its repeated harvests at closer intervals provide a maximum essential oil output (Singh *et al.*, 2014). Therefore, the adoption of perennial cultivation of geranium in northern Indian plains may be economically viable. Thus, there is obvious merit in exploring the possibilities of perennial-oriented geranium cultivation in the northern plains under the semi-protective shed.

Further, the survivability of perennial multi-harvest geranium under semi-protective shed conditions depends upon the productivity and availability of quality oil, which is an essential factor for increased production. Our aim in this study is to follow the maximum harvest from the geranium mother plant over the years and to save the cost and availability of fresh planting materials/ cuttings for the next planting season. The agronomic suitability of geranium as a perennial multi-harvest crop under semi-protective shed conditions has not been tested systematically. The hypothesis arises that if we save, survive and grow geranium mother plant as perennial under the shed, then it may give multiple harvests economically and affordable way over the years. Considering above, the current investigation has been planned to grow *Pelargonium graveolens* as perennial under shed by taking it as multi-harvest in a year and to estimate the effect of multi-harvest on yield and quality of geranium oil as perennial crop under semi-protective shed. However, the economics of geranium cultivation as perennial crop under the semi-protective shed is yet to be worked out.

Materials and Methods

The experimental site

From 2018 to 2022, the experiment was conducted at the CSIR-Central Institute of Medicinal and Aromatic Plants research farm in Lucknow, India. Lucknow has a subtropical climate typical of North India. The research farm is positioned at 26°5′N latitude and 80°5′E longitude, roughly 120 m above sea level. The soil in the experimental field was a sandy loam with a pH of 8.1 and a moderate fertility condition, with 76.5 kg ha^{-1} of available nitrogen (N), 56.7 kg ha^{-1} of phosphorus (P), 20 kg ha^{-1} of potassium (K) and 0.20% organic carbon (OC). The experimental site had hot summers and somewhat cold winters, with an average of 700 to 800 mm precipitation per year. The monsoon season in this area begins during the last week of June and lasts through the end of September. Due to cyclonic disturbances, there may be a few showers in the winter and pre-monsoon showers in March.

Experimental details

Preparation of field and raising of stem cutting

The fresh and healthy vegetative stem cuttings (10–15 cm long with two nodes and 3–5 leaves) of geranium were taken from the two geranium varieties cv. CIM-Pawan (V1) and Bourbon (V2) from the commercial field in the last week of January and uniformly planted in the nursery bed mixed with rotten FYM for rooting. The irrigations were provided by the sprinkler method when required. All recommended agricultural techniques, such as weeding and hoeing, were carried out physically for growing the nursery. All necessary elements were sprayed for proper growth under nutrient-deficient soil.

Preparation of semi-protective shed

The shed was constructed using bamboo 2 to 3 m height from the side and 4 m high in the center. The top of the shed was covered with transparent polythene to maintain brightness, high temperature, and low relative humidity. The shed's primary purpose was to fully shield the plants from direct rain so they could survive throughout the rainy season. The schematic diagram of the semi-protective shed is illustrated in Figure 1.

Treatments

The experiment comprises the two mainly trendy varieties of geranium, i.e., (i) CIM–Pawan (V1) and (ii) Bourbon (V2), and harvested at fourteen dates *viz*., Ist harvesting (June 10, 2018), IInd harvesting (October 23, 2018), IIIrd harvesting (February 12, 2019,) IVth harvesting date (June 28, 2019), Vth harvesting (October 25, 2019), VIth harvesting (February 14, 2020), VIIth harvesting (June 28, 2020), VIIIth harvesting (October 30, 2020), IXth harvesting (February 15, 2021), Xth harvesting (June 25, 2021), XIth harvesting (October 28, 2021), XIIth harvesting (February 15, 2022), XIIIth harvesting (June 25, 2022) and XIVth harvesting (October 22, 2022) during the 5 years, i.e., 2018 to 2022 under the semi-protected shed. The cuttings of both the geranium varieties were taken from mother plants in January for rooting and transplanted in February. After proper root establishment, healthy plants were planted in the main plot in the last week of February at the spacing of 50×50 cm under the semi-protected shed for good crop growth. First, irrigation was applied just after transplanting. All recommended agricultural techniques, such as weeding, irrigation, and hoeing, were provided physically as per the crop requirement. A homogeneous 50 Kg/ha^{-1} treatment of nitrogen (in the form of urea) was made twice: once after transplanting and once after 30 to 60 days. Harvesting was done as per the schedule of dates. After each harvest and 30 days following a harvest, irrigation was provided, along with the appropriate fertilizer, to ensure that the previously harvested plants had enough moisture and nutrients for crop regeneration and improved growth and development.

Plant sampling and biometric observation

Six plants from each plot were randomly selected and sampled before each harvest to determine the bio-morphological parameters: plant height (cm), number of leaves plant^{-1}, number of branches plant^{-1}, and leaf area index (LAI). Plant height was considered from the plant's base to the stem's tip, leaf length (cm) from the base of the leaf to the tip, and plant spread were measured through measuring scale. The number of primary and secondary branches and leaves were counted manually from sampled plants. LI-COR's LAI 2200C analyzer was used to measure the LAI.

Harvesting of the crop

Throughout the experimental period, from February 2018 to February 2022, the crop was harvested fourteen times at 20 to 25 cm height above the ground. Fresh biomass, fresh leaf yield, and fresh stem yield (g) were recorded from each replicate during harvesting. Sampled plants were left for drying in the shade condition to record dry weight (g) until the constant weight arrived.

Analysis of the carotenoid and chlorophyll content

According to Arnon (1949), the total chlorophyll and carotenoid are extracted in 80% acetone, and the absorption was measured at wavelengths of 663, 645, 480, and 510 nm, respectively, using an ultraviolet spectrophotometer, as shown below:

(1) Chlorophyll *a*/g tissue in mg = 12.7 (A663 - 2.69 (A645) × V/1000 × w)

(2) Chlorophyll *b*/g tissue in mg = 22.9 (A645 - 4.68 (A663) × V/1000 × w)

(3) Total chlorophyll /g tissue in mg = 20.2 (A645 + 8.02 (A643) × V/1000 × w)

(4) Carotenoid /g tissue in mg = 7.6 (A480) – 1.49 (A510) × V/1000 × w)

Where,
A = Absorbance at a specific wavelength
V = Final volume of chlorophyll extract in 80% acetone
w = Fresh weight of tissue extracted

Electrolyte leakage estimation

To estimate electrolyte leakage (E L), 1 g of fresh leaves were chopped into small pieces and homogenised in a cold mortar. After that, the ready samples were put in a water bath that had been pre-heated to 32°C. A Consort c861 model, electrical conductivity metre, was used to test the initial electrical conductivity (EC1). Electrical conductivity (EC2) was measured after the sample was cooled to 25°C and put in a water bath at 100°C for 1-hour to release the electrolyte completely.
The E L was calculated as follows:

$$EL (\%) = [(EC1/EC2) \times 100]$$

where, EC1 and EC2 were the electrical conductivity of an un-boiled and boiled fresh leaf material solution, respectively,

Extraction of essential oils

Fresh herb from a mature geranium crop was utilised to extract essential oil by hydro-distillation using Clevenger's equipment (Clevenger, 1928). Six randomly selected plants were taken from each plot at the harvesting stage in each treatment and weighed promptly using an electronic scale to minimize moisture loss. Three plants were used for distillation on a fresh-weight basis. Freshly collected plant samples (200 g each) in 700 to 800 mL water were subjected to hydro-distillation for 3 hours in three replicates. The oil quantity was calculated directly within the extraction measuring device. The isolated essential oils were dehydrated with anhydrous sodium sulfate (Na_2SO_4) and kept in sealed bottles under 4°C until the GC analysis was carried out. Essential oil yield (kg h^{-1}) was calculated by multiplying the actual oil content (w/v) by fresh biomass yield according to the treatments.

Quality analysis

The GC analysis was carried out on a Varian CP 3800 system with an Elite-5 fused silica column (30 m × 0.25 mm × 0.25 m). The oven was set up to rise from 60°C at a rate of 3°C/min to 240°C with a 2 minutes hold time, then to 310°C with a 1-minute hold period. The injector and detector temperatures (FID) were 300°C, with a split ratio of 1:100, and hydrogen was utilized as the carrier gas (1-mL/min with a continuous flow). The samples were prepared in dichloromethane, and a 0.04 L sample was manually injected in a split and splitless injector. The relative quantities of each component found in the analyzed samples were determined based on response percent for GC peak area using the Galaxie chromatography data system (Varian Associates, USA)

Statistical analysis

Data were analyzed statistically by the Student's "t" test, as Panse and Sukhatme (1985) suggested. Student's t-test is a statistical test used to test whether the difference between the means values of two groups is statistically significant.

Results and Discussion

Effect of different harvests on growth attributes of perennial geranium grown under the semi-protective shed

Harvesting dates and semi-protective sheds have significantly impacted the growth characteristics of two geranium varieties, i.e., V1 (CIM-Pawan) and V2 (Bourbon). The data (Table 1) showed that maximum plant height (65.11 cm) was recorded from variety V1 at IIIrd harvest compared to V2. This increase in plant height in V1 at IIIrd harvest may be the ideal harvest date under inappropriate shed conditions, which promote vigorous plant growth. These findings are under earlier reports of Motsa (2006), Blank *et al.*(2012), and Gebremeskel (2014), they stated that the increase in geranium plant height depends on the optimal time to harvest them in under favorable climatic environments. The lowest plant height (23.10 cm) was recorded with the XIVth harvest in V2. The lower height might be due to repeated harvesting at short intervals, leading to a short growth period.

Significant increases in the number of primary branches (42.74), secondary branches (304.87), plant spread (88.30 cm), number of leaves per plant (1339.26), and leaf area index (4.15) were recorded in variety V1 at XIVth harvesting. The same growth parameters were recorded lowest in variety V2 at Ist harvesting. Thus, variety V1 was statistically superior over variety V2. It may be due to the prolonged developmental phase and subsequent harvests, which stimulated the promotion of extra buds to regenerate new branches and to develop more new leaves on branches retained with advances in multi-harvesting. According to Ma and Li (2019), numerous photoreceptors and downstream components can react quickly to dynamic changes in ambient light. Several species display shed avoidance behaviors under shed circumstances, which encourage stem and petiole elongation and help plants reach the sunlight. The control mechanisms driving shed avoidance responses that involve auxin-mediated cell elongation. Auxin production, transport, and sensitivity are all quickly stimulated in the early response to shed signals, enabling cell elongation of the hypocotyls and other organs. Increased axing sensitivity rather than enhanced auxin production has a significant impact in cell elongation under extended shed. The number of branches per plant was significantly and favorably associated with the number of leaves per plant. Hence, the largest number of branches/plants and leaves/plants offer the maximum plant spread and leaf area index at the delayed harvesting stage of XIVth.

Furthermore, the increase in these growth characteristics may also be attributed to favorable climatic conditions prevalent during the subsequent harvesting, which facilitated the plant growth characteristics. Similar

Table 1: Growth parameters as influenced by different harvest in perennial *Pelargonium graveolens* L. grown inside the protective shed under subtropical climate of northern Indian plains

Observations		*Harvest number*													
		Ist	*IInd*	*IIIrd*	*Ivrth*	*Vth*	*VIth*	*VIIth*	*VIIIth*	*IXth*	*Xth*	*XIth*	*XIIth*	*XIIIth*	*XIVth*
Plant height (cm)	V1	54.33**	56.89**	65.11**	52.56**	56.33**	64.78**	40.00**	45.11**	49.11**	39.28**	35.09**	30.90**	27.68**	23.81**
	V2	52.70	55.18	63.16	50.98	54.64	62.84	38.80	43.76	47.64	37.10	34.03	28.33	26.85	23.10
No of main branches	V1	35.33**	36.00**	36.67**	37.33**	38.16**	38.33**	39.05**	39.22**	40.16**	40.61**	41.17**	41.74**	42.21**	42.74**
	V2	33.27	35.33	35.57	36.21	37.02	37.18	37.88	38.04	38.96	39.33	39.94	40.67	40.94	41.46
No of secondary branches	V1	280.50**	284.67**	286.17**	287.67**	289.17**	290.33**	291.33**	293.50**	296.00**	297.59**	299.50**	301.42**	303.05**	304.87**
	V2	274.33	276.67	277.58	279.04	280.49	281.62	282.59	284.70	287.12	288.66	292.52	295.38	293.95	295.72
Plant spread (cm)	V1	60.77**	62.50**	63.28**	64.63**	66.50**	67.05**	69.83**	73.22**	75.00**	78.09**	80.81**	83.53**	85.75**	88.30**
	V2	59.95	60.98	61.38	62.69	64.51	65.04	67.74	71.02	72.75	75.74	78.67	82.51	83.18	85.65
No of leaves / plant	V1	1225.33**	1248.50**	1258.16**	1262.50**	1269.53**	1274.87**	1280.33**	1288.33**	1300.33**	1307.06**	1315.50**	1323.94**	1331.21**	1339.26**
	V2	1200.57	1215.51	1220.42	1224.63	1231.44	1236.62	1241.92	1249.68	1261.32	1267.85	1278.83	1290.52	1291.27	1299.08
Leaf area index	V1	4.12**	4.12**	4.12**	4.12**	4.13**	4.13**	4.12**	4.12**	4.12**	4.12**	4.13**	4.13**	4.13**	4.15**
	V2	4.02	4.02	4.02	4.00	4.01	4.01	4.00	4.02	4.02	4.02	4.05	4.08	4.01	4.09

Significant * = $p > 0.05$, ** = $p > 0.01$

findings have also been reported by Kothari *et al*., (2004) in *O. tenuiflorum*, Mastiholi (2008) in coleus; Venugopal (2006) in patchouli,Gebremeskel (2014) in geranium; and Kakaraparthi *et al.,* (2014) in citronella. According to their findings, multiple harvesting at a closer interval produced the greatest number of branches/plants, leaves/plants, plant spread, and LAI with the advanced harvesting stage. They also reported a significant correlation between the number of leaves/plants and the quantity of branches/plants. Upadhyay *et al*., (2016) also reported that the shed significantly affected the growth parameters as maximum leaves were recorded under the shed.

Effect of different harvests on chlorophyll, carotenoid, chlorophyll fluorescence, and electrolyte leakage in perennial geranium grown under the semi-protective shed

Significant variation in chlorophyll, carotenoid, chlorophyll fluorescence (Fv/Fm) and electrolyte leakage content were noted during the repeated harvesting of perennial geranium crop grown under semi protective shed and the data recorded at each harvest are depicted in Figure 2. The maximum total chlorophyll (2.62 mg chl gm^{-1} leaf) and carotenoids content (1.19 mg chl gm^{-1} leaf) was recorded in V1 at VIIth harvesting. The same contents recorded lowest in V2. The maximum chlorophyll fluorescence (Fv/Fm) (0.95 ms) was found under Ist harvesting in V1 as compare to V2. In the case of electrolyte leakage (EL), the highest value (44.00%) of EL was recorded in V1 at VIIth harvesting whereas the lowest EL (35.00 %) was recorded in V2 at VIth harvesting. The reason behind the recordable of maximum total chlorophyll, carotenoids, Fv/Fm, and electrolyte leakage may be due to the warm, bright weather conditions and availability of high temperature throughout harvesting month in which plant respond well to temperature, causes changes in most of their physiological activities such as chlorophyll synthesis. These findings confirm with the results of Murtagh (1996) and Langton *et al.,* (2003) who found that photoperiods had a significant impact on chlorophyll synthesis as well as other metabolic processes like photosynthesis and respiration; because these processes respond well to moderate temperatures. Nilofer *et al.,* (2021) also reported that most of a plant's metabolic processes respond to temperature variations, as temperature plays a significant role in the growth and development of a plant.

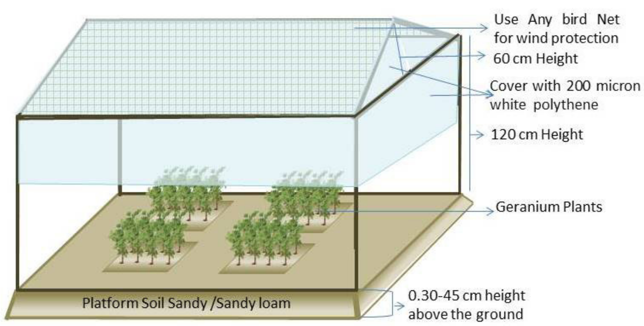

Figure 1: The schematic diagram of the semi-protective shed

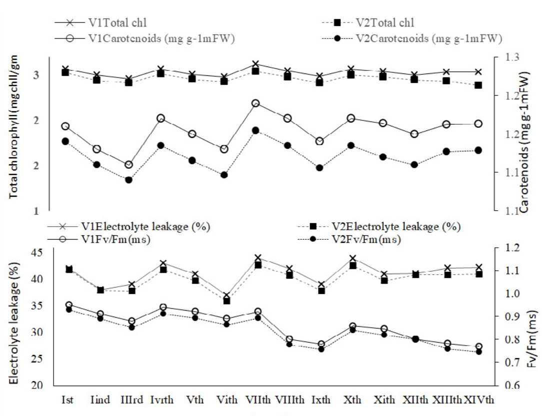

Figure 2: Chl/a, Chl/b, or total chl and carotenoids (mg g-1 FW), Fv/Fm (m-^{2}s^{-1}) and electrolyte leakage (%) as influenced by different harvest in perennial *Pelargonium graveolens* L. grown inside the protective shed under subtropical climate of northern Indian plains

Effect of different harvests on herbage yield in perennial geranium grown under the semi-protective shed

Herbage yield was considerably impacted by multi-harvesting of perennial geranium crop grown under semi-protective shed, as the total 14 harvests were taken as per harvesting of the crop, and herbage of each harvest for both varieties was computed and shown in Table 2. Among the total of fourteen harvests (Ist–XIVth) of perennial geranium, the highest fresh herbage yield (14.04 t ha^{-1}) was recorded in variety V1 at IIIrd harvesting. The same biological yield recorded low in V2 variety at XIV harvesting. Interestingly, the leaves and stem of perennial geranium contribute to the geranium crop's herbage and are also an essential oil-bearing plant part.

Consequently, the highest fresh yield of leaves (9.44 t ha^{-1}) and fresh yield of stem (4.88 t ha^{-1}) was also obtained in V1 during IIIrd harvesting. The reason behind the best fresh production of perennial geranium achieved in V1 during the IIIrd harvesting period may be the cultivar's ability, and favourable seasonal climatic conditions of the harvesting month, such as the perfect day temperature of 25 to 30°C beneath the shed which support its vegetative growth attributes such as an increase in the proportion of leaves and stem that leads to higher productivity of geranium. Similar findings were also reported by Misra *et al.,* (2000) and Motsa and Nilofer *et al*., (2021). According to their findings, the biggest leaf-to-stem ratio, which in turn contributed to the highest herbage yield, was created by a combination of high daytime and low nighttime temperatures. Further,

Table 2: Yield attributes as influenced by different harvest in perennial *P. graveolens* L. grown inside the protective shed under subtropical climate of northern Indian plains

Observations		Harvest number													
		Ist	*IInd*	*IIIrd*	*IVth*	*Vth*	*VIth*	*VIIth*	*VIIIth*	*Ixth*	*Xth*	*XIth*	*XIIth*	*XIIIth*	*XIVth*
Fresh herbage yield (t/ha)	V1	13.80**	13.60**	14.04**	12.80**	13.54**	13.80**	10.60**	10.90**	12.10**	10.65**	10.27**	10.89**	10.00**	9.50**
	V2	12.80	13.19	13.62	12.42	13.13	13.39	9.24	10.51	11.74	10.33	9.96	10.56	9.70	9.22
Fresh leaves yield (t/h)	V1	9.00**	9.20**	9.44**	8.84**	9.12**	9.4**	6.4**	7.44**	8.92**	7.94**	7.9**	7.86**	7.58**	7.45**
	V2	8.73	8.92	9.16	8.57	8.85	9.12	6.14	7.15	8.65	7.34	7.56	7.26	7.35	7.23
Fresh stem yield (t/ha)	V1	4.59**	4.68**	4.88**	4.16**	4.68**	4.68**	3.29**	3.59**	3.49**	3.89**	3.54**	3.54**	3.89**	3.59**
	V2	4.42	4.28	4.68	4.02	4.40	4.28	3.15	3.40	3.25	3.72	3.40	3.20	3.80	3.40
L/S ratio (Fwt basis)	V1	1.98**	2.09**	1.96**	2.13**	2.01**	2.13**	1.95**	2.10**	2.66**	1.97**	2.22**	2.27**	1.93**	2.13**
	V2	1.96	1.97	1.93	2.13	1.95	2.01	1.95	2.07	2.56	2.04	2.23	2.22	1.95	2.08
Dry herbage yield (t/ha)	V1	2.24**	2.31**	2.39**	2.18**	2.30**	2.35**	1.80**	1.85**	2.06**	1.81**	1.75**	1.85**	1.70**	1.62**
	V2	2.18	2.24	2.32	2.11	2.23	2.28	1.57	1.79	2.00	1.76	1.69	1.80	1.65	1.57
Dry leaves yield (t/h)	V1	1.98**	2.02**	2.08**	1.94**	2.01**	2.07**	1.41**	1.64**	1.96**	1.75**	1.74**	1.73**	1.67**	1.64**
	V2	1.92	1.96	2.01	1.89	1.95	2.01	1.35	1.57	1.90	1.61	1.66	1.60	1.62	1.59
Dry stem yield (t/ha)	V1	0.60**	0.61**	0.63**	0.54**	0.61**	0.61**	0.43**	0.47**	0.45**	0.51**	0.46**	0.46**	0.51**	0.47**
	V2	0.57	0.56	0.61	0.52	0.57	0.56	0.41	0.44	0.42	0.48	0.44	0.42	0.49	0.44
L/s ratio (Dwt basis)	V1	3.34**	3.53**	3.31**	3.61**	3.40**	3.61**	3.30**	3.56**	4.51**	3.34	3.76	3.84**	3.27	3.60**
	V2	3.32	3.33	3.27	3.60	3.30	3.40	3.29	3.51	4.33	3.45	3.78	3.76	3.30	3.51

Significant * = $p > 0.05$, ** = $p > 0.01$

the reason behind the lowest fresh herbage yield recorded in V2 at XIVth harvesting which might be due to late crop age, multiple harvesting and the adverse climatic conditions, in which geranium was subjected to atmospheric stresses and moisture that hampered its growth as well as yield that led to a diminish the quantity of leaves, stems, and fallen off some leaves, consequently, low herb yield obtained. Similar findings also reported by Rao *et al.,* (1996); Motsa (2006) and Nilofer *et al.*, (2021). They found that crop age and frequent harvesting at a short- duration also had a destructive effect on herbage yield, causes reduction in biomass output**.** According to Kothari *et al.,* (2004), biomass output was subsequently decreased in the succeeding harvests of *Ocimum tenuiflorum*. Interestingly, on the fresh yield basis, the maximum leaf:stem ratio (L/S) (2.66) was recorded in V1 under IXth harvesting as compare to V2.

Similarly like fresh herbage yield, the highest dry herbage yield (2.39 t ha^{-1}), dry yield of leaf (2.08 t ha^{-1}) and dry yield of stem (0.63 t ha^{-1}) were obtained in V1 during the IIIrd harvesting. The same dry yield recorded low in V2. The reason behind this is that samples of perennial geranium were dried in a shed at room temperature because the temperature significantly impact the plant dry material. Amazingly, the dry yield of leaves was higher than the dry yield of stem due to the loss of less moisture content in leaves compared to stem. These results are in accordance with Motsa (2006); and Nilofer *et al.* (2021), where they found that temperature affects plant production in general because majority of plant metabolic processes, including respiration, photosynthesis, and transpiration, are responsive to temperature changes (Murtagh, 1996). On the dry yield basis, the highest L/S ratio (4.51) recorded in V1 at IXth harvesting as compare to V2.

Effect of different harvests on essential oil content (%) and oil yield (kg/ha) in perennial geranium grown under the semi protective shed

Data on oil content and the average of every harvest have been shown in Table 3. From the prescribed data, the highest essential oil (EO) content (0.19 %) was observed in variety V1 at VIIth harvesting as compare to variety V2 .This might happened due to multiple harvestings and also due to the bright sunny circumstances, as high temperatures of summer seasons in which plants were in stress condition, causes enough recovery of considerable oil content in geranium plant. These findings align with Weiss (1997) and N. M. Motsa (2006). They reported that geranium produces maximum oil content under warm bright conditions and the frequency of oil content synthesis in plants increased with high temperature as oil content responded positively to

Table 3: Oil content (%) and yield and major aroma ingredients of geranium as influenced by different harvest in perennial *P. graveolens* L. grown inside the protective shed under subtropical climate of northern Indian plains

Observations		*Harvest number*													
		Ist	*IInd*	*IIIrd*	*IVth*	*Vth*	*VIth*	*VIIth*	*VIIIth*	*IXth*	*Xth*	*XIth*	*XIIth*	*XIIIth*	*XIVth*
Oil content (%)	V1	0.18**	0.16	0.16	0.18**	0.17**	0.16	0.19**	0.16**	0.16	0.16	0.16	0.16**	0.16**	0.15
	V2	0.17	0.16	0.16	0.17	0.16	0.16	0.18	0.16	0.16	0.16	0.16	0.15	0.15	0.15
Estimated oil yield (kg/ha)	V1	23.76**	21.76**	22.46**	23.04**	23.02**	22.08**	20.14**	17.44**	19.36**	17.25**	16.43**	17.21**	15.60**	14.63**
	V2	22.36	20.47	21.14	21.68	21.66	20.78	17.03	16.31	18.22	16.23	15.46	16.19	14.68	13.77
Geraniol (%)	V1	16.24**	18.28**	20.01**	17.32**	18.25**	20.24**	18.08**	19.28**	21.21**	20.90**	21.40**	21.89**	22.39**	22.88**
	V2	14.75	16.73	19.67	16.80	17.70	19.63	17.54	18.70	20.57	20.27	20.75	21.24	21.72	22.20
Citronellol (%)	V1	45.54**	45.23**	45.92**	41.17**	45.72**	45.85**	42.31**	46.16**	46.25**	45.67**	45.81**	45.94**	46.08**	46.22**
	V2	40.13	42.87	43.54	38.33	43.35	43.35	40.01	43.38	43.86	43.30	43.38	43.38	43.58	43.70
Geraniol (kg/ha)	V1	3.86**	3.98**	4.50**	3.99**	4.20**	4.47**	3.64**	3.36**	4.11**	3.61**	3.52**	3.77**	3.49**	3.35**
	V2	3.30	3.43	4.16	3.64	3.83	4.08	2.99	3.05	3.75	3.29	3.21	3.44	3.19	3.06
Citronellol (kg/ha)	V1	10.82**	9.84**	10.32**	9.49**	10.52**	10.12**	8.52****	8.05**	8.95**	7.88**	7.53**	7.91**	7.19**	6.76**
	V2	8.97	8.78	9.20	8.31	9.39	9.01	6.81	7.08	7.99	7.03	6.71	7.02	6.40	6.02
C/G ratio	V1	2.80	2.47	2.29**	2.38**	2.51**	2.27**	2.34**	2.39**	2.18**	2.19**	2.14**	2.10**	2.06**	2.02**
	V2	2.72	2.56	2.21	2.28	2.45	2.21	2.28	2.32	2.13	2.14	2.09	2.04	2.01	1.97

Significant * = $p > 0.05$, ** = $p > 0.01$

higher temperatures and multiple harvests. Kumar *et al*. (2001) and Kothari, *et al.* (2004) also observed that essential oil content increased gradually in subsequent harvests.

Table 4's prescription data show that, maximum essential oil yield (23.76 kg ha^{-1}) recorded in variety V1 at Ist harvesting whereas the minimum essential oil yield (13.77 kg ha^{-1}) recorded in V2 at XIVth harvesting. Thus, the variety V1 was superior over V2. The reason behind the maximum oil yield at Ist harvesting in V1 was the warm sunny conditions and high temperature of summer season, causes an adequate recovery of more herbage yield and significant oil content that led to higher oil yield as essential oil yield is product of the herbage yield and the essential oil content.

Kumar *et al*., (2001) and Runkle (2002),also observed similar findings. They discovered that photoperiod had a considerable impact on herbage productivity and oil content, which in turn influenced the recovery of geranium essential oil yield. According to Badi *et al*., (2003) were in view that the recovery of fresh herbage yield and oil content was impacted by the harvesting period, which also had an impact on oil output. As the lowest essential oil output recorded at XIVth harvesting in V2 because of crop ageing and a lack of or restricted access to photoperiods, causes detrimental effect on essential oil yield by diminishing the herbage yield and oil content. Similar findings also reported by Albrecht and Marvin, 1995; Rajeswara Rao, 2000, Turk *et al*., (2009). They discovered that harvesting at late stages may cause decrease in the quality of the herbage as a result of the lower leaves' senescence or the disease damage to the leaves,. R.Rao, 2000 also observed that to avoid oil yield loss due to leaf senescence, harvesting should be practiced at close interval like multi-harvesting. According to Nilofer *et al*., 2018, when herbage declines, the total output of secondary metabolites, i.e., essential oil, also decreases in medicinal and aromatic plants (MAPs).

Additionally, the predominant climatic conditions, soil fertility and type, weather, moisture availability in the soil, leaf-to-stem ratio, physiological traits, and morphological traits, harvesting method, isolation techniques employed, moisture level of the plants at harvest, and current steam distillation process, among other factors, may all be taken into account which can affect the oil content and production (Nilofer *et al*., 2021).

Effect of different harvests on chemical constituents of essential oil of perennial geranium grown under the semi-protective shed

In this study, geraniol and citronellol are found in major quantities (Table 3) while isomenthane, citronelyll formate, 10-epi-y-eudesmol, and linalool (Table 4) were found in the minor quantity. Data shown

Table 4: Other chemical constituents (content/ha) of geranium essential oil as influenced by different harvest in perennial *P. graveolens* L. grown inside the protective shed under subtropical climate of northern Indian plains

Observations		*Harvest number*													
		*I^st^*	*II^nd^*	*III^rd^*	*IV^th^*	*V^th^*	*VI^th^*	*VII^th^*	*VIII^th^*	*IX^th^*	*X^th^*	*XI^th^*	*XII^th^*	*XIII^th^*	*XIV^th^*
Isomenthone (%)	V1	6.20**	6.52**	8.71**	6.33**	7.12**	8.24**	6.18**	7.38**	8.63**	8.16**	8.37**	8.59**	8.80**	9.02**
	V2	5.01	5.32	7.45	5.14	6.91	7.99	5.99	7.16	7.37	7.34	7.37	8.12	7.80	7.91
Isomenthone (kg/ha)	V1	1.47**	1.42**	1.96**	1.46**	1.64**	1.82**	1.24**	1.29**	1.67**	1.41**	1.38**	1.48**	1.37**	1.32**
	V2	1.12	1.09	1.57	1.11	1.5	1.66	1.02	1.17	1.34	1.19	1.14	1.31	1.14	1.09
Citronellyl formate (%)	V1	5.12**	6.23**	7.54**	5.64**	7.45**	7.02**	6.26**	7.12**	7.29**	6.96**	6.94**	6.92**	6.90**	6.87**
	V2	4.97	6.04	7.31	5.47	7.11	6.14	6.07	6.91	7.07	6.15	6.40	6.42	6.37	6.33
Citronellyl formate (kg/ha)	V1	1.22**	1.36**	1.69**	1.30**	1.71**	1.55**	1.26**	1.24**	1.41**	1.20**	1.14**	1.19**	1.08**	1.01**
	V2	1.11	1.24	1.55	1.19	1.54	1.28	1.03	1.13	1.29	1.00	0.99	1.04	0.93	0.87
10-epi-y-eudesmol (%)	V1	5.48**	5.72**	6.29**	5.77**	5.98**	6.15**	5.64**	6.31**	6.35**	6.36**	6.45**	6.54**	6.63**	6.72**
	V2	5.11	5.55	6.10	5.60	5.80	5.42	5.47	6.00	6.16	6.17	6.25	5.54	6.10	6.15
10-epi-y-eudesmol (kg/ha)	V1	1.30**	1.24**	1.41**	1.33**	1.38**	1.36**	1.14**	1.10**	1.23**	1.10**	1.06**	1.12**	1.03**	0.98**
	V2	1.14	1.14	1.29	1.21	1.26	1.13	0.93	0.98	1.12	1.00	0.97	0.90	0.89	0.85
Linalool (%)	V1	2.97**	3.64**	3.84**	3.14**	3.49**	3.84**	3.18**	3.64**	3.81**	3.72**	3.77**	3.81**	3.86**	3.90**
	V2	2.41	3.04	3.19	3.05	3.39	3.11	3.08	3.13	3.17	3.06	3.15	3.12	3.06	3.04
Linalool (kg/ha)	V1	0.71**	0.79**	0.86**	0.72**	0.80**	0.85**	0.64**	0.63**	0.74**	0.64**	0.62**	0.66**	0.60**	0.57**
	V2	0.54	0.62	0.67	0.66	0.73	0.65	0.53	0.51	0.58	0.50	0.49	0.51	0.45	0.42

Significant * = $p > 0.05$, ** = $p > 0.01$

in Table 3 revealed that the maximum content of geraniol (22.88%) and citronellol (46.22%) were recorded in variety V1 at XIVth harvesting stage whereas their lowest value were recorded in V2 at Ist harvesting stage. The reason behind the highest geraniol and citronellol content at XIVth harvesting may be better response of the crop to late age, multiple harvesting and favorable environmental conditions *viz.* moderate temperature. consequently, all of these had a significantly and positively affect these two components. These findings align with Rao *et al.* (1996), Verma *et al.* (2013) on *Pelargonium graveolens,* and Sastry *et al.*, 2013; Kakaraparthi *et al.*, 2014 on citronella. They reported that these constituents are high during moderate temperature. In the terms of yield, since the oil yield is a product of the content, the yields of geraniol and citronellol were estimated by multiplying the content by the oil yield.

Consequently, with respect to their own content and oil yield, various essential oil constituents have varying yields. Owing to higher oil output, maximum geraniol yield (4.50 kg ha^{-1}) recorded in V1 as compare to V2 at IIIrd harvesting whereas the maximum citronellol yield (10.52 kg ha^{-1}) found at Vth harvesting in variety V1 than V2. The ratio of citronellol to geraniol (C/G) is crucial in determining the quality of geranium essential oil. In general, geranium oil with a C/G ratio of (0.8–2.88) has a pleasant aroma (Saxena *et al.*, 2000). Thus the present study showed that the variety V1 with a C/G ratio (2.80) was superior to variety V2. Other components, such as isomenthone, citronelyllformate,10-epi-y-eudesmol, and linalool were also determined by multiplying their own contents with the oil yield.

Data presented in Table 4 showed that the maximum iso-menthone's content (9.02%) recorded in V1 at XIV harvesting whereas the iso-menthone yield also recorded maximum (1.96 kg ha^{-1}) in V1 at IIIrd harvesting.The maximum content of citronellyl-formate (7.54%) recorded in V1 at IIIrd harvesting whereas the its maximum yield (1.71 kg ha^{-1}) also recorded in V1 at Vth harvesting. The 10-epi-y-eudesmol recorded maximum (6.72%) in V1 at XIV harvesting while maximum yield (1.41 kg ha^{-1}) recorded in V1 at IIIrd harvesting. The linalool content recorded maximum (3.90%) in V1 at XIV harvesting whereas it yield recorded maximum (0.86 kg/ha) in V1. The lowest value of these components and their yield recorded in

Table 5: Economics of geranium as influenced by different harvest in perennial *P. graveolens* L. grown inside the protective shed under subtropical climate of northern Indian plains

		Ist	*IInd*	*IIIrd*	*IVth*	*Vth*	*VIth*	*VIIth*	*VIIIth*	*IXth*	*Xth*	*XIth*	*XIIth*	*XIIIth*	*XIVth*
Estimated oil yield (kg/ha)	V1	23.76	21.76	22.46	23.04	23.02	22.08	20.14	17.44	19.36	17.25	16.43	17.21	15.60	14.63
	V2	22.36	20.47	21.14	21.68	21.66	20.78	17.03	16.31	18.22	16.23	15.46	16.19	14.68	13.77
Cost of cultivation (INR/ha)	V1	250,000	52000	48000	48000	47000	45000	44000	42000	42000	41000	40000	40000	38000	37000
	V2	250,000	52000	48000	48000	47000	45000	44000	42000	42000	41000	40000	40000	38000	37000
Gorss return (INR/ha)	V1	237600	217600	224600	230400	230200	220800	201400	174400	193600	172500	164300	172100	156000	146300
	V2	223600	204700	211400	216800	216600	207800	170300	163100	182200	162300	154600	161900	146800	137700
Net return (INR/ha)	V1	-12,400	165,600	176,600	182,400	183,200	175,800	157,400	132,400	151,600	131,500	124,300	132,100	118,000	109,300
	V2	-26,400	152,700	163,400	168,800	169,600	162,800	126,300	121,100	140,200	121,300	114,600	121,900	108,800	100,700
B/C ratio	V1	-0.05	3.18	3.68	3.80	3.90	3.91	3.58	3.15	3.61	3.21	3.11	3.30	3.11	2.95
	V2	-0.11	2.94	3.40	3.52	3.61	3.62	2.87	2.88	3.34	2.96	2.87	3.05	2.86	2.72

*Geranium's Oil : 10000 INR kg^{-1}

variety V2. Thus, the oil composition which assessed by citronellol, geraniol, citronellylformate, isomenthone and l0-epi-y-eudesmol was significantly affected by multi-harvesting of crop under the semi-protective shed. The chemical makeup of EO varied significantly, possibly due to the genetic makeup of the cultivars (Ram *et al*., 2004).

Further, any plant's chemical makeup is influenced by its stage of development and crop age, especially medicinal and fragrant plants. Similar findings also reported by Nilofer *et al*., 2018. Geranium yield and quality were also impacted by harvesting occurrence, population density, seasonal changes, shed, weeds, plant parts that were distilled, isolation techniques used, season weather parameters (such as temperature, light), length of exposure to sunlight, accessibility of water, elevation and the occurrence of insects and fungal diseases. The agricultural factors have also significant impact on the quantitative and qualitative properties of medicinal and aromatic plants, including available moisture in the soil, leaf: stem ratio, soil fertility and type, the amount of moisture in the plants at harvest, single or a combination of plant/crop types (Nilofer *et al*.,2021).

Economics of perennial geranium grown under the semi-protective shed

The cost of production of the propagules and semi-protective shed required for one-hectare commercial plantations of rose-scented geranium was worked out for the field. Data pertaining to gross return, net return and B:C ratio are presented in (Table 5) which showed that the maximum gross returns (237600 Rs/ha) was recorded at Ist harvesting in V1. The maximum net returns (183200 Rs/ha) was recorded at Vth harvesting in V1. The highest B:C ratio (3.91) was recorded at VIth harvesting in V1. The result showed variation at different harvesting in gross return, net return and B:C ratio due to the variation in herbage yield and oil yield.

Conclusion

Geranium can be grown as a perennial crop under the shed, according to the findings of the current study. This experimental study leads to the novel technology shed-saving agrotechnology (SSAT) by which a total of fourteen harvests were produced over the course of 5 years (February 2018- February 2022). Compared to the conventional method of harvesting, this approach produced the highest herbage and oil yields with better quality. As a result, it may prove better for both present and future practice as compared to traditional practice. This attracts the farmers for geranium cultivation with great economic returns and minimum cost of cultivation.

Consequently, the higher production of its essential oil may play a key role in the pharma and cosmetic industries to produce various types of medicine and cosmetic product respectively.

Acknowledgments

The authors are highly thankful to Council of Scientific and Industrial Research New Delhi, for financial support and to Director, CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, India, for providing essential facilities during the course of study. The CIMAP publication communication number is CIMAP/PUB/2023/64.

Author Contribution

Archana Chaudhary: Actual experimentation and manuscript draft preparation; Kirti Verma: Help in recording field observations; Anjali Singh: Formal analysis; Devendra Kumar: Recorded observation; Kushal Pal Singh: Data recording: Parminder Kaur: Formal analysis; Anil Kumar Singh: Statical analysis of data; Saudan Singh: Planning of experiment.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

Badi, H. N., Yazdani, D., Ali, S. M., and Nazari, F. (2004). Effects of spacing and harvesting time on herbage yield and quality/quantity of oil in thyme, *Thymus vulgaris* L. *Industrial Crops and Products*, *19*(3), 231-236.

Blank, A. F., Silva, A. D. C., Arrigoni-Blank, M. D. F., dos Santos, W. M., and de Santana, A. D. D. (2012). Plant spacing and harvest intervals on biomass and essential oil of geranium. *Horticultura Brasileira*, *30*, 740-746.

Chauhan, A., and Verma, R. S. (2010). Cultivation potential of three rose-scented geranium (*Pelargonium graveolens*) cultivars in the Kumaon region of western Himalayas. *Medicinal and Aromatic Plant Science and Biotechnology*, *4*, 77-79.

CK, V. (2006). *Performance of patchouli (Pogostemon patchouli Pellet.) as influenced by nitrogen, spacing, shade, growth regulators and harvest techniques* (Doctoral dissertation, UAS Dharwad).

Gebremeskel, H., and Woldetsadik, K. (2015). Effect of plant spacing and harvesting age on growth, biomass and oil yield of rose-scented geranium (*Pelargonium graveolens* L. Herit). *Basic Research Journal of Agricultural Science and Review*, 4(3), 39.

Jain, N., Aggarwal, K. K., Syamasundar, K. V., Srivastava, S. K., and Kumar, S. (2001). Essential oil composition of geranium (*Pelargonium* sp.) from the plains of Northern India. *Flavour and Fragrance Journal*, *16*(1), 44-46.

Kakaraparthi, P. S., Srinivas, K. V. N. S., Kumar, J. K., Kumar, A. N., Rajput, D. K., and Sarma, V. U. M. (2014). Variation in the essential oil content and composition of Citronella (*Cymbopogon winterianus* Jowitt.) in relation to time of harvest and weather conditions. *Industrial Crops and Products*, *61*, 240-248.

Kumar, A., Verma, N., Kaur, P., Kumar, D., Ghosh, D., Singh, A., Siddiqui, A., Kumar, N., Singh, A. K., Khare, P., and Singh, S. (2022). Physiological and chemical changes induced by transparent polythene+ green net shed on *Pelargonium graveolens* L. mother plants during monsoon season. *Industrial Crops and Products*, *188*, 115686.

Motsa, N. M. (2006). *Essential oil yield and composition of rose-scented geranium (Pelargonium sp.) as influenced by harvesting frequency and plant shoot age*. University of Pretoria (South Africa).

Mastiholi, A. B. (2008). *Effect of spacing, time of harvest and NPK levels on growth, yield and quality of medicinal coleus (Coleus forskohlii Briq.) under irrigated condition* (Doctoral dissertation, PhD thesis, Department of Agronomy, University of Agricultural Sciences, Dharwad), India.

Nilofer, A., Singh, A. K., Kumar, D., Kaur, P., Kumar, A., Singh, A., Khare, P., Sangwan, N. S., Kalra, A., and Singh, S. (2018). A novel method for survival of rose-scented geranium (*Pelargonium graveolens* L.) mother plants under extreme climatic conditions. *Industrial Crops and Products*, *126*, 227-237.

Pandey, P., Upadhyay, R. K., Singh, V. R., Padalia, R. C., Kumar, R., Venkatesha, K. T., Tiwari, A. K., Singh, S., and Tewari, S. K. (2020). *Pelargonium graveolens* L. (Rose-scented geranium): New hope for doubling Indian farmers' income. *Environment Conservation Journal*, *21*(1&2), 141-146.

Rao, B. R. (2009). Chemical composition and uses of Indian rose-scented Geranium (*Pelargonium* species) essential oil-A review. *Journal of Essential Oil Bearing Plants*, *12*(4), 381-394.

Singh, A. K., Kaur, P., Kumar, D., Verma, K., Kumar, R., Anandakumar, T. M., Chanotiya, C. S., and Singh, S. (2021). Productivity and quality of *Cymbopogon martinii* (Roxb.) Wats. as influenced by harvesting at different phenological stages. *Industrial Crops and Products*, *174*, 114215.

Upadhyay, R. K., Verma, R. S., Singh, V. R., Bahl, J. R., Sharma, S. K., and Tewari, S. K. (2016). New agrotechnology for quality planting material production of rose-scented geranium (*Pelargonium graveolens* L. Herit.). *Journal of Applied Research on Medicinal and Aromatic Plants*, *3*(3), 128-130.

Verma, R. S., Rahman, L. U., Verma, R. K., Chauhan, A., and Singh, A. (2013). Essential oil composition of *Pelargonium graveolens* L'Her ex Ait. cultivars harvested in different seasons. *Journal of Essential Oil Research*, *25*(5), 372-379.