lISSN 2709–3662 (Print)
ISSN 2709–3670 (Online)
https://doi.org/10.52587/JAF060113
Journal of Agriculture and Food
2025, Volume 6, No.1, pp. 195–209

Comparative Analysis of Essential Oil Yield in Diverse Ocimum Species

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Abstract

The study aimed to compare the morphological characteristics and oil content of four Ocimum varieties: Red Opal, Lettuce Leaf, Genovese, and Local variety, from two species, *Ocimum basilicum* and *Ocimum tenuiflorum*. Genovese exhibited the tallest plants (53.87 cm), while Red Opal was the shortest (33.79 cm). The Local variety had the highest number of branches (17) and leaves per plant (221), which were 21% and 87% more than those of Red Opal and Genovese, respectively. Lettuce Leaf had the largest leaves, with an area of 86.99 cm². The Local variety also produced the most inflorescences and had the longest inflorescence length. The oil content was similar across most varieties, except for Lettuce Leaf, which had a significantly lower oil yield (8.2 ml/kg), 83%, 66%, and 64% less than the Local variety, Genovese, and Red Opal, respectively. The morphological and oil content variability among the Ocimum varieties suggests further research is needed to understand the underlying causes and phenomena affecting these traits.

Keywords: Variability, Land races, Variety, Oil contents

Article History: **Received:** 4rt[h] February 2025**; Revised:** 16[th] April, 2025; **Accepted:** 6[th] June, 2025

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Introduction

Ocimum species serve medicinal and aromatic purposes. Basil is used in herbal tea, remedies, cosmetics, perfumes, food preservation, and as a flavoring agent (Anbarasu & Vijayalakshmi, 2007). Spices like basil, thyme, and oregano enrich oils with phenolic compounds (Jayasinghe et al., 2003). Eugenol, a phytogenic compound, acts as an antimicrobial agent in tulsi. Thai basil oil treats insect bites and ringworm (Viyoch et al., 2006). These plants help reduce crop pest infestations (Bekele & Hassanali, 2001). Innovations include edible films made from basil seed gum, which extend food shelf life, enhance biocompatibility, biodegradability, and cost efficiency (Ghasemlou et al., 2011). Seeds are rich in mucilage gum, offering advantages over other films (Mirhosseini & Amid, 2012). Basil includes annual and perennial herbs, native to warm temperate and tropical regions of India, Africa, and Southern Asia. Ocimum, especially O. tenuiflorum L. (tulsi, holy basil), is revered among Hindus in India. The genus has 50 to 150 species with various varieties (Runyoro et al., 2010). Taxonomic classification is complex due to the presence of hybridization and polyploidy (Tucker, 1986). The flowers' corolla can be white, pale pink, or violet, blooming daily and attracting pollinators like honeybees (Chwil, 2003). While grown globally, the crop suffers from chill injuries in winter when temperatures drop below 10 °C, which affects yield and export quality (Shah et al., 2019; Ribeiro & Simon, 2007; Kenigsbuch et al., 2010).

Extracted oil contains substances such as methyl cinnamate, linoleol, eugenol, and estragol, which enhance its economic value (El-Soud et al., 2015; Khan et al., 2020; Mehmood et al., 2021). These essential oils include aromatic compounds and terpenes that generate aromatic substances in basil. Though volatile and present in low concentrations, they do not dissolve easily in water and are mainly extracted via distillation (Yesil-Celiktas et al., 2009). Descriptor systems combining morphological, economic, and biochemical traits have also been proposed. Besides their ornamental value, cultivars may be rich in essential oils, offering a new source for industrial production. Over the last few decades, basil's importance as an ornamental plant has increased, resulting in a greater availability of cultivars with various habits, colors, and flavors. It undergoes abundant cross-pollination, resulting in numerous subspecies and varieties with distinct essential oil compositions and morphological traits, which complicates the taxonomy of this group (Bozek, 2000).

Morphological characterization is an essential tool for phylogenetic studies even in the current period of molecular systematics (Kirchoff *et al.,* 2007; Lee *et al.*, 2005; Mehmood et al., 2022; Nazir et al., 2023). Numerous basil cultivars differ from each other in leaf and flower color, leaf size and shape, plant height and habit (Nurzynska-Wierdak, 2007; Abduelrahman *et al.*, 2009). Variation in pigmentation, leaf shape and size reported in different basil cultivars has been accumulated through centuries of its cultivation. Basil plants also differ in terms of essential oil chemical composition (Hussain *et al.,* 2008). The same author again demonstrated that seasonal changes have a significant effect on genetic variations related to the quantitative and qualitative composition of essential oil. Analysis of morphological characters, the essential oil composition, and molecular markers is the basis for the optimal verification of taxonomy (Labra *et al.*, 2004). Morphologically indistinguishable types represented from diverse ecological regions have different chemical constituents (Ali and Ali, 2012).

Environmental factors and harvest time alter chemical content and oil yield (Julian et al., 1994; Mehmood et al., 2020; Zia et al., 2023). The tropical chemotypes from India, Pakistan, and Guatemala are rich in methyl cinnamate, while the Reunion chemotype from Thailand, Madagascar, and Vietnam has high concentrations of methyl chavicol (Simon et al., 1999). Climate during growth affects essential oil production of basil (Kothari et al., 2004). Environmental stresses, especially drought, negatively impact plant morphology, biochemistry, and other characteristics (Shao et al., 2008). Water deficit reduces carbohydrate, protein, proline contents, and dry weight in herbs. Drought stress hinders photosynthesis by altering chlorophyll and impairing the process. In arid and semiarid areas, medicinal and aromatic plants suffer from low water availability. Mild to moderate water stress increases essential oil content and alters composition in basil (Simon et al., 1992). The levels of eugenol and methyl eugenol decline as Holy basil matures (Dey and Choudhuri, 1983). Eugenol is the major constitutes 30-70% of basil (Kelm and Nair, 1998). Essential oil concentration in basil is linked to cultivation conditions. Main components are linalool, methyl chavicol, camphor, and methyl eugenol, varying by plant chemotype (Gill & Randahawa, 1997). Basil extracts should contain 3 % linalool and 85% methyl chavicol for international standards (Mindaryani & Rahayu, 2007).

Herb essential oils are extracted through distillation, expression, extraction, cold pressing, or supercritical CO2 methods. Heat can change chemical constituents, causing loss of volatile compounds, depending on the method. Yields may decrease due to thermal degradation of unsaturated compounds (Lucchesi et al., 2004). Maximum oil concentration is in leaves; branches and stems yield less economically. Extraction methods include conventional (hydrodistillation, steam distillation, solvent extraction) and non-conventional techniques (Carrilho et al., 2006). Steam distillation with solvents like methanol and ethanol is common but has a major drawback of undesirable residues affecting sensory properties, so supercritical CO2 is increasingly popular (Guan et al., 2007). Microwave-assisted extraction (MWAE) is a green, low-cost method yielding eugenol and essential oils comparable to conventional approaches (Li et al., 2014). Coaxial microwave hydrodistillation (MWHD) is more efficient, reducing heating time and energy demands, making it safer and cheaper than traditional methods. This study estimates variability in morphological characteristics and essential oil yield of different Ocimum varieties.

Materials and Methods

The experiment was conducted on two Ocimum species (Ocimum basilicum var. Genovese, var. Red Opal, Lettuce leaf, and Ocimum tenuiflorum local cultivar) under greenhouse conditions in the experimental area of Horticulture PMAS-AAUR during the years 2017-2018 to characterize the physio-morphological responses and essential oil yield. Nurseries were established in the first week of February 2018, and seedlings of each variety were moved to polythene bags filled with media at the two true leaves stage. Other cultural operations like irrigation, weeding, and hoeing were performed as recommended. Seeds of basil cultivars from two different species were obtained from the market. Twenty-five seeds of each variety were sown in seedling trays containing standard soil media for germination. The trays were irrigated once a day, early in the morning. Seven kilograms of media mixture, composed of 1:1:1 (Soil: Sand: Leaf manure), were filled into polythene bags. Germinated seedlings at the two true leaf stages were transplanted into pots. A presowing soil sample was collected, air-dried, sieved, and then analyzed for various soil properties (Table 1).

Table 1. Physico-chemical properties of soil used in the experiment

Soil Properties	Value
pH	7.98
Organic matter (%)	1.65
CaCO3 (%)	0.5
Sand (%)	54.3
Silt (%)	35.6
Clay (%)	10.1
Total nitrogen (%)	0.193
Available phosphorous (g kg^{-1})	6.6
Available potassium (g kg^{-1})	19.3

Qualitative parameters

Fully expanded mature leave color was determined by using the method (Svecova & Neugebauerova, 2010) through Royal Horticulture Society Color Charts Edition 5, Version 2 by taking randomly selected leaves collected at complete plant maturity stage and RHS color codes were matched by International Union for The Protection of New Plant Varieties (UPOV) described color groups. The color of inflorescence was determined through Royal Horticultural Society Color Charts Edition 5, Version 2, by taking randomly selected inflorescences collected at the whole plant maturity stage, and the RHS color codes were matched by the International Union for the Protection of New Plant Varieties (UPOV), which described color groups. Stem Color at the whole plant maturity level was noted by using Royal Horticultural Society Color Charts Edition 5, Version 2 by matching the plant stems of all varieties with the RHS paper and decoding the numbers with the International Union for the Protection of New Plant Varieties (UPOV) described color groups. The color of the extracted oil was determined through the Royal Horticulture Society Color Charts Edition 5, Version 2, measured with a spectrophotometer. Leaf surface was observed by following the method described by (Malav et al., 2015) by using a Hand-held Magnifier of Magnification power 10x. Leaf Margins were noted through direct observation.

Quantitative parameters

Data on plant height were measured using a measuring tape in centimeters from soil level to the terminal growing point of the main stem, and the mean values of ten plants were recorded and analyzed. The branches that arise from the main stem were counted at the time of plant maturity. Leaf area was measured with a Leaf Area Meter (Li-3100) and expressed in square centimeters (cm^2). The number of inflorescences from selected plants was calculated at the 100% flowering stage. The length of the inflorescence was determined using a measuring tape and expressed in centimeters (cm). The number of flowering days was counted from the first day of bud formation until its complete development into a flower. Oil yield was determined using the method described by Maridass (2008) with some modifications. Twenty grams of dried leaves were chopped in a plant grinder mill and placed in a cellulose extraction thimble of the Soxhlet apparatus. Two hundred fifty milliliters of hexane were used as a solvent in a round-bottom flask for each sample and heated to 70 °C. The extraction duration was set for four hours. The plant material was removed from the thimble and allowed to sit at room temperature to evaporate the solvent. It was then placed in an autoclave at 105°C for one hour and subsequently transferred to a desiccator chamber for ten minutes before being weighed again. The final oil yield was calculated using the formula:

Essential oils yield% = W1/W2 x 100

Where

W1 = Weight of extracted oil (g)

W2 = Total weight of fresh leaves (g)

Statistical analysis

Data regarding qualitative and quantitative analysis of basil plants were recorded. Data collected from the experiment were subjected to analysis of variance (ANOVA) in a completely randomized design. Variety means were compared using the least significant difference (LSD) test at a 5% level of probability. Statistical analysis was carried out by using Statistica 8.1. computer software (Steel et al., 1997).

Results

Table 2 presents the stem color of various Ocimum species, mainly in the green spectrum. The Ocimum tenuiflorum Local variety ranged from light brown to light green (RHS 140-D and 177-D). Red violet had light blue-violet stems (RHS 84-C). Varieties Lettuce leaf and Genovese displayed light green stems, with RHS numbers 142-D and 138-D for Genovese. Leaf colors are detailed in Table 2; three varieties showed dark green leaves: Ocimum tenuiflorum Local (RHS 143-A), Ocimum basilicum var. Lettuce leaf (RHS 141-C), and Ocimum basilicum var. Genovese (RHS 141-A). Var. Red Opal had a dark violet color (RHS 79-B). This color variation is mainly due to genetics, with environmental factors also potentially contributing. Inflorescence colors are shown in Table 2; Local, Lettuce leaf, and Genovese had light green inflorescences (RHS 142-B), while Red Opal was violet (RHS 77-A). The oil colors are presented in Table 2 and Fig. 1A, primarily located in the yellow spectrum, with some variability. The oil from *Ocimum tenuiflorum* Local was yellow (RHS 001-A), while Red Opal and Genovese oils were yellow-green (RHS 001-B and 003-D). Lettuce leaf displayed a light yellow oil (RHS 004-D).

Table 2. Comparative analysis of stem, leaf, inflorescence characteristics, and oil color in different varieties of *Ocimum sp.*

Variety	Stem		Leaf		Inflorescence		Oil colour	
	RHS -No.	**Colour**	**RHS -No.**	**Colour**	**RHS -No.**	**Colour**	**RHS -No.**	**Colour**
Ocimum tenuiflorum Local	140[d]	Light Green	143[a]	Dark Green	142[b]	Light Green	001[a]	Yellow
Ocimum basilicum var. Red Opal	84[c]	Light Blue Violet	79[b]	Dark Violet	77[a]	Violet	001[b]	Yellow green
Ocimum basilicum var.	142[d]	Light Green	141[c]	Dark Green	142[b]	Light Green	004[d]	Light yellow

Lettuce leaf								
Ocimum basilicum var. **Genovese**	142[d]	Light Green	141[a]	Dark Green	142[b]	Light Green	003[d]	Yellow green

Values with similar letters are statistically equal to each other.

The morphology of leaves from different Ocimum species is shown in Table 3; Fig. 1B. Generally, the four varieties displayed variability in morphology. All had egg-shaped oval leaves with varying sizes. Varieties Red Opal and Local had somewhat rough surfaces with small hairy structures and were pubescent, while Genovese and Lettuce leaf varieties were smooth and glabrous. Regarding leaf margins, Local, Red Opal, and Genovese had serrated margins, while Lettuce leaf had undulated or smooth margins.

Table 3. Morphology of leaves of four varieties of *Ocimum* species

Variety	Leaf shape	Leaf surface	Leaf margin
Ocimum tenuiflorum Local	Ovate	Pubescent	Serrate
Ocimum basilicum var. *Red Opal*	Ovate	Pubescent	Serrate
Ocimum basilicum var. *Lettuce leaf*	Ovate	Glabrous	Undulate
Ocimum basilicum var. *Genovese*	Ovate	Glabrous	Serrate

Data regarding the plant height of four different varieties of Ocimum species are presented in Fig. 2. In general, it was observed that the plant heights of all varieties varied significantly from one another. The Genovese variety of Ocimum species exhibited the tallest plants, with a height of 53.87 cm, which was found to be 11% (6.18 cm) higher than the Local variety. Additionally, it was 25% (13.73 cm) and 37% (20.08 cm) taller than the heights observed for var. Lettuce leaf and var. Red Opal, respectively. The Local variety, with a height of 47.69 cm, was 8% (7.55 cm) taller than var. Lettuce leaf and 14% (13.9 cm) taller than var. Red Opal. Lettuce leaf had a plant height of 40.14 cm, which was 6% (6.35 cm) higher than the height of 33.79 cm observed for var. Red Opal.

The branch count per plant for four Ocimum species is presented in Fig. 3. The number of branches per plant-1 ranged from 9 to 17 per plant-1. The Genovese variety had the lowest average at 9 branches per plant-1, while the Local variety had the highest. The Local variety's count exceeded that of the Red Opal, Lettuce leaf, and Genovese varieties by 24% (4 branches), 29% (5 branches), and 47% (8 branches), respectively. The Red Opal averaged 13 branches per plant-1, which is 8% (1 branch) and 31% (5 branches) more than the Genovese and Lettuce leaf varieties. The Genovese averaged 12 branches per plant-1, reflecting a 25% (3 branches) increase over the 9 branches per plant-1 seen in Lettuce leaf's average of 9 branches.

The number of leaves per plant^{-1} for the four varieties of Ocimum species in presented in Fig. 4. It shows that the number of leaves varied significantly across the varieties tested. The number of leaves plant-1 ranged from a maximum of 221 leaves to a minimum of 59. The highest number of leaves plant-1 was observed for the Ocimum tenuiflorum Local variety exhibited the value was 21% (47 leaves) more than that of leaves plant-1 observed for var. Red Opal, which had 174 leaves plant-1. Additionally, the Local variety had 87% (103 leaves) more than var. Genovese, which produced 118 leaves per plant-1. The greatest disparity in leaf count was between the Local variety and var. Lettuce leaf, where the latter produced 59 leaves plant-1 were produced which was almost three times fewer (162 leaves) than the Local variety. Var. Red Opal showed counts that were 47% (56 leaves) and 194% (115 leaves) higher than var. Genovese and var. Lettuce leaf, respectively, while var. Genovese had the lowest count of 118 leaves plant-1 produced by var. The lowest number of leaves was recorded for var. Lettuce leaf.

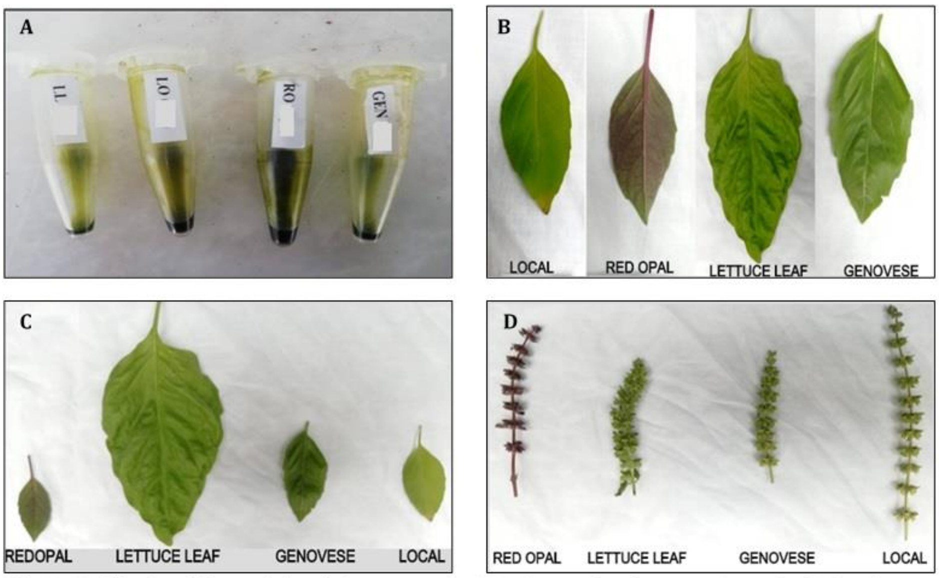

Fig. 1. (A) Oil color of four varieties of *Ocimum* species (LL= *Ocimum basilicum* var. *Lettuce leaf*, LO =*Ocimum tenuiflorum* Local Variety, RO= *Ocimum basilicum* var. *Red Opal*, GEN= *Ocimum basilicum* var. *Genovese*) (B) Leaf morphology of four varieties of *Ocimum* species (C) Leaf area of four varieties of *Ocimum* species (D) Inflorescence length of four varieties of *Ocimum* species

Data regarding the leaf area of different varieties of Ocimum species is presented in Fig. 1C and Fig. 5. In general, it was observed that the leaf area of the varieties used in the experiment varied significantly from one another. The leaf area of the varieties under observation ranged from a maximum of 86.99 cm² to a minimum of 6.86 cm². The maximum value was observed for var. Lettuce Leaf, while the minimum value was for var. Red Opal. It was evident from the data that var. Lettuce Leaf produced significantly larger leaves compared to the other varieties. The leaf area observed for var. Lettuce Leaf was followed by the 16.64 cm² leaf area observed for var. Genovese. The values for var. Lettuce Leaf were 137% (9.64 cm²) and 142% (9.78 cm²) higher compared to the leaf area observed for the Local variety and var. Red Opal, respectively. There was no significant difference in the leaf area between the Local variety and var. Red Opal.

Data regarding the inflorescence length of four different varieties of Ocimum species is presented in Fig. 1D and Fig. 6. In general, a significant difference was observed among the inflorescence lengths of the different varieties, ranging from a maximum value of 18.01

cm to a minimum value of 10.23 cm. The maximum inflorescence length was noted for the Local variety, which was 37% (4.85 cm), 70% (7.42 cm), and 71% (7.78 cm) higher than the lengths observed for var. Red Opal, var. Genovese, and var. Lettuce leaf, respectively. The inflorescence length of 13.16 cm recorded for var. Red Opal was 24% (2.57 cm) and 29% (2.93 cm) higher than that of var. Genovese and var. Lettuce leaf, respectively. The inflorescence lengths of the remaining two varieties, var. Genovese and var. Lettuce leaf, were not significantly different from each other, yielding similar results of 10.59 cm for var. Genovese and 10.23 cm for var. Lettuce leaf.

Data regarding the number of inflorescences per plant-1 observed for the four different Ocimum species is presented in Fig. 7. In general, a significant difference was noted among the four varieties used in the experiment for the number of inflorescences per plant-1. The highest value recorded was 16, while the lowest was 7. The maximum number of inflorescences was observed in the Local variety, where 16 inflorescences per plant-1 were produced. This value was 25% (4 inflorescences), 31% (5 inflorescences), and 56% (9 inflorescences) higher than the number of inflorescences recorded for var. Lettuce Leaf, var. Red Opal, and var. Genovese, respectively. The number of inflorescences produced by var. Lettuce Leaf and var. Red Opal was statistically similar, with 12 and 11 inflorescences per plant were produced, respectively. However, the results for both of these varieties were significantly different from the value recorded for var. Genovese, where 7 inflorescences per plant-1 were produced. This value was 57% (4 inflorescences) and 71 % (5 inflorescences) lower compared to the number of inflorescences observed for var. Red Opal and var. Lettuce Leaf, respectively.

Days to flowering for four Ocimum varieties are in Fig. 8. Considerable variability was observed in flower counts per plant, with a maximum of 65 and a minimum of 17. Var. Red Opal had the highest count at 65 flowers per plant-1 for the four different varieties of Ocimum species, as presented in Fig. 9. In general, significantly surpassing the other varieties. It outperformed var. Lettuce leaf by 23% (12 flowers) and var. Genovese by 58 % (24 flowers), and was nearly three times (48 flowers) the Local variety. Var. Lettuce leaf produced 53 flowers, 29% (12 flowers) more than var. Genovese and nearly double (36 flowers) compared to the Local variety. Var. Genovese yielded 41 flowers, about 1.5 times (24 flowers) higher than the Local variety, which produced only 17 plants plant-1 were produced.

Figure 10 illustrates the oil contents of four Ocimum species are shown in Fig. 10. Most varieties exhibited no significant differences in oil content. The Local variety topped the chart with an oil content of 15.03 g kg ^{1}, whereas the Lettuce leaf variety had the lowest at 8.23 ml kg ^{1}. The oil content of the Local variety was comparable to that of Red Opal and Genovese varieties, which yielded 13.47 and 13.67 ml kg ^{1}, respectively, with differences of only 12% (1.36 ml kg ^{1}) and 10 % (1.56 ml kg ^{1}). In contrast, the Lettuce leaf variety demonstrated significantly lower oil yields, being 83% (6.8 ml kg ^{1}), 66% (5.44 ml kg ^{1}), and 64 % (5.24 ml kg ^{1}) lower than the Local, Genovese, and Red Opal varieties, respectively. Although genetic factors contribute to the variation in oil yield among species, environmental conditions, soil quality, and nutrient efficiency are also significant influencers. The Local variety's higher yield may be attributed to its plant height, branch count, and number of leaves per plant-1, which suggest enhanced efficiency and greater oil production.

Discussion

Medicinal and aromatic plants are vital, supplying 25% of the pharmaceutical industry with extracts. Dietary supplements, teas, pills, and the fiber and pesticide industries also use these herbal extracts. It's essential for cultivation to meet international market standards to reduce economic losses. Establishing direct marketing channels helps maximize profits through contract cultivation. Initial stages should focus on small-scale production to maintain a steady supply of raw materials without threatening plant biodiversity. Producers must understand supply and demand to avoid profit losses while considering buyer expectations (Lubbe & Verpoorte, 2011).

Similar to our study, Saha et al. (2016) conducted experiments at Georgia Southern University, USA, in 2015, examining the growth potential and nutritional status of the basil (Ocimum basilicum L.) cultivar Aroma 2 in hydroponic (HyB) and crayfish-aquaponic (AqB) systems in polythene water tanks. Aquaponics resulted in higher plant height (9 cm) compared to hydroponics (9 cm). Average dry weights were 15 g in aquaponics and 9.6 g in hydroponics, with fresh weights of 150 g and 96 g, respectively. No significant differences in chlorophyll and leaf nutrient content were found, though maximum nitrogen was in AqB due to crayfish excretion and food supplement residues. Aquaponic cultivation with crayfish enhances basil yield and nutritional status, particularly in water-scarce regions affected by climate change. It was observed that different varieties showed different stem colors. *O. tenuiflorum* showed purple green stems while var. *thyrsiflora* showed light green stems. On the other hand, *O. gratissimum* had dark brown stems and *O. viride* had dark green stems. It was argued in the study that the color of different plant parts of *Ocimum* species depends on the genetic makeup of a particular species. Malav *et al.* (2015) observed that the most of the varieties of Holy basil used in the experiment had purplish green inflorescence. The difference in oil quality and yield may be attributed to environmental factors, genetic makeup, and nutritional status of the plants (Sajjadi, 2006).

Several factors determine plant height, mainly genetic variations and environmental influences. Height reflects nutrient availability- deficiencies correspond to stunted growth, while taller plants typically indicate better nutrient absorption and oil yields. Variability in height among Ocimum species exists; for example, Nurzynska-Wierdak (2007) reported heights from 32.7 cm for New Guinea to 53.4cm for sweet basil. Other studies mentioned heights of 51.46 cm for Ocimum tenuiflorum and 102.6 cm for Ocimum gratissimum (Rawat et al., 2016), whereas Nurzynska-Wierdak (2013) found heights ranging between 29.2 cm and 56.9 cm. Anyaoha (2013) noted that four basil varieties showed heights from 149.7 cm for Tree basil to 84.2 cm for Bush basil. Morphological variations, such as height, depend on factors like weather and genetics. Anyaoha (2013) stated branch counts ranged from 5 to 17 for Tree and Sweet basil. Nurzynska-Wierdak (2007) similarly reported branches per plant ranging from 11 to 16 across Ocimum varieties. In another study, branch counts per plant-1 ranged from 5 to 17 for Tree and Sweet basil. The number of branches per plant-1 ranged from 11 to 16 across different Ocimum varieties. Additionally, Nurzynska-Wierdak (2013) noted a range of branches per plant-1 varied from 10 for the Napoletano variety upto 16 for Bush variety. Malav et al. (2015) observed 7 to 14 branches in various Holy basil varieties.

The higher number of leaves in the local variety might also be the reason for the high oil yield, as it results in more interception of available light, leading to increased photosynthesis. This could contribute to the rapid production of essential elements required for producing different components. Another beneficial effect of a higher number of leaves on oil yield might be associated with a higher rate of transpiration. Increased transpiration results in greater water uptake, and essential plant nutrients like nitrogen, phosphorus, potassium, sulfur, etc. may have been absorbed in higher amounts. These nutrients could have enhanced plant growth on one hand, while on the other, they might have provided the plants with essential building blocks required for producing different components. Similar results have been reported by Malav et al. (2015), who observed significant variability in the number of leaves per plant-1 for basil varieties. Their study found that the number of leaves per plant-1 ranged from 18 to 71 for different varieties of Holy basil.

Leaf area is an important parameter that determines oil yield and its quality, as the process of photosynthesis has a direct relationship with it. A larger leaf area means more light interception, which leads to a higher rate of photosynthesis. Increased carbohydrates provide the plants with more energy to carry out essential functions and produce various components. This results in overall better performance, which may positively affect the final product. Malav et al. (2015) also reported similar findings, indicating that leaf size of different Holy basil varieties ranged from 3.3 to 8.84 cm². The results of the present study strongly agree with those reported by Nurzynska-Wierdak (2007), who found that the inflorescence length of different Ocimum varieties varied significantly from 9 for the Bush variety upto 17 for the Lemon variety of the Ocimum species. Anyaoha (2013) also reported variability in the inflorescence length among different basil varieties. In their study, it was observed that inflorescence length ranged from 11.3 to 23.5 cm for Tree and Bush basil, respectively.

Ocimum species exhibited significant morphological variability (Rawat et al., 2016). Previous studies support our findings. Nurzynska-Wierdak (2013) reported inflorescence counts ranging from 27 to 68 inflorescences per plant for Rubra. Another observed inflorescence plant-1 of 20 for Purple Ruffle, upto 52 for Bush. Our study aligns with Nurzynska-Wierdak (2007), who found notable variability in flower production, with Bush yielding the most. These traits indicate efficient resource use, enhancing oil yield. Our results match earlier studies. Marotti et al. (1996) noted oil content in some Italian basil varieties at 0.3 to 0.7%. Osinska and Suchorska (1996) found oil content of 36 basil varieties worldwide ranged from 0.3 to 0.8%. Basil from Central Africa had oil content from 0.02 to 2.1% (Tchoumbougnang et al., 2006). Nurzynska-Wierdak (2007) reported oil content from 0.35 to 1.15% for eight basil varieties, while another study showed it varied between 0.75 and 1.89%.

Conclusion

The current study's findings indicate that among the various types, the local variety of Ocimum tenuiflorum excelled in the study area's climatic conditions. While some other varieties exhibited better values in specific morphological traits, the local variety recorded the highest economic parameters for basil. Notable figures include leaves per plant-1 (221), branches (17), inflorescence length (18.01cm), inflorescences per plant^{-1} (16), and oil yield (15.3 ml kg-1). However, the oil yield of the local variety was not statistically significant when compared to Red Opal and Genovese. Hence, further research is recommended to evaluate the economic value of these varieties and to characterize the oil for quality estimation.

Dedication: Dedicated to late Ms. Najma Yousaf Zahid, who supervised the research of Muhammad Rehan. May her soul rest in peace.

Competing Interests

The authors declare that the research was conducted without any commercial or financial relationships that could be perceived as a potential conflict of interest.

Acknowledgement: Not applicable.

Funding: Not applicable.

Ethical statement: This article does not contain any studies involving human or Animal Subjects.

Code availability: Not applicable.

Consent to participate: All authors participated in this research study.

Consent for publication: All authors submitted consent to publish this research.

Data availability statement: The data presented in this study are available on request.

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Citation

Rehan, M., Qureshi, A. A., Qureshi, U. S., Shah, S. H., & Muhammad, S. (2025). Comparative analysis of essential oil yield in diverse *Ocimum* species. *Journal of Agriculture and Food*, *6*(1), 195 – 209. https://doi.org/10.52587/JAF060113.