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Assessment of yield and postharvest traits of three strawberry (*Fragaria* × *ananassa* Duch.) cultivars grown at farmer's field in Rawalakot, Azad Jammu and Kashmir

Asim Zulfiqar[1], Mehdi Maqbool[1], Noosheen Zahid[1]*, Abdul Khaliq[2], Imran Hassan[3], Asgar Ali[4], Ajit Singh[4] and Muhammad Riaz Khan[1]

[1]Department of Horticulture, Faculty of Agriculture, University of Poonch Rawalakot, 12350, Azad Jammu and Kashmir, Pakistan
[2]Department of Soil and Environmental Sciences, Faculty of Agriculture, University of Poonch Rawalakot, 12350, Azad Jammu and Kashmir, Pakistan
[3]Department of Horticulture, Faculty of Agriculture, PMAS-Arid Agriculture University Rawalpindi, Pakistan
[4]School of Biosciences, Faculty of Science, The University of Nottingham Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia

*Corresponding author: Noosheen Zahid (noosheen.zahid@upr.edu.pk)

Abstract

Strawberry (*Fragaria* × *ananassa* Duch.) is highly palatable berry fruit. It is a rich source of vitamins and minerals with fabulous flavour and tantalizing aroma. While previous research trials at departmental level demonstrated successful strawberry cultivation in Rawalakot, cultivar specific performance under open-field conditions at farmer's field has not been assessed. Therefore, the present study was conducted to evaluate the performance of three strawberry cultivars (Chandler, Seascape, Tribute) under open-field conditions. Runners of each cultivar were planted, and data were collected on vegetative growth, flowering, fruit yield, and postharvest attributes. The experimental arrangements were made in a randomized complete block design (RCBD) with three replications, and data analysis was performed using ANOVA in Statistix 8.1, with mean comparisons via LSD ($P \leq 0.05$). Results indicated that Chandler exhibited higher vegetative growth, with the highest survival rate (97%), number of runners (4.96), leaf area (42.63 cm²), and chlorophyll content (43.23 g/ml). It also produced the highest number of flowers (14.32), fruits per plant (10.32), and fruit yield (118.32 g/plant). Chandler also excelled in postharvest quality, showing the highest total soluble solids (7.56%), vitamin C (21.34 mg/100 g), total anthocyanins (4.02 mg/100 g FW), and antioxidant activity (102.12 µg/100 mg FW). Tribute required the longest duration for flowering (51.34 days) and harvesting (92.56 days). Overall, Chandler was the most promising cultivar for superior yield and postharvest quality in Rawalakot's open-field conditions. Moreover, the study highlights the potential future benefits for local farmers through the cultivation of strawberries.

Keywords: Cultivars, Fruit yield, Open-field conditions, Postharvest quality, Strawberry, Vegetative growth

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Introduction

Strawberry belongs to the family Rosaceae and is known as a soft fruit. Being a short-day herbaceous perennial plant, it can be grown successfully at optimal day temperatures of 22°C to 25°C (Farid et al., 2020; Choi et al., 2024). It is one of the strong sources of vitamins and minerals with sweet tangy flavor. Because of the medicinal properties (anti-carcinogenic, anti-diabetic and antioxidant), strawberry is one of the most popular fruits among consumers of all ages (Newerli-Guz et al., 2023). It has been grown successfully in many areas of the world but in Asia it was introduced in 1960 (Tantivit & Tatmala, 2024). Being a temperate and short-day loving fruit crop, it can be grown well in cold areas of Kashmir valley (Hayat et al., 2022). In Pakistan Chandler, Corona and Stuff are mainly cultivated varieties. They are usually grown in Charsadda, Gujrat, Haripur, Islamabad, Lahore, Mansehra, Mardan and Sawat. Among others, Chandler is the cultivar which is widely grown in Pothwar region. Under temperate climates, it acts as a perennial herb, while under subtropical climates it becomes annual herb (Katel et al., 2022).

Strawberry being a short-day plant, temperature is considered as an important factor for flower initiation and fruit development (Hayat et al., 2022). Strawberries are included as plants that require intensive care. Along with flower and fruit development planting time is an important issue in affecting the quality of strawberries. Different cultivars of strawberry require different day light and temperature for softening and ripening. The cultivar Tribute is sensitive to a photoperiod of 14 hours at a temperature of 23 °C but requires longer days at higher temperature (Palencia et al., 2021). As strawberry has a very short growing season, so it becomes popular among the farmers of Pakistan who get high profit on their investments on strawberry. In Pakistan, strawberries are produced in limited quantities which are used in processed food and eaten fresh. From all strawberry cultivars, Chandler' is only a short-day plant and seasonal fruiting

that gives single crop every summer. During this period, a small amount of vegetative growth occurs. The fruit produced during this short season doesn't have good quality and earn lesser prices in the market, thus producing losses to growers (Zahid et al., 2022).

In recent research trials at departmental level, successful plantation of strawberries was noted when grown under open-field conditions of Rawalakot. However, no studies have been reported to grow different strawberry cultivars at real farmer's field under open field conditions of Rawalakot poses a significant limitation to scaling production in the region. Therefore, the proposed study was planned to estimate the growth performance, fruit yield, and postharvest quality attributes of three strawberry cultivars (Chandler, Seascape, Tribute) grown at farmer's field of Rawalakot. The study will help to select the most promising strawberry cultivar for further multiplication and production in this region.

Materials and Methods

Current study was performed during the year 2022-2023 at the farmer's field. In this study runners of three strawberry cultivars (Chandler, Seascape, Tribute) were selected from the stock maintained at the Department of Horticulture, University of Poonch Rawalakot.

Site description

Strawberry plants were grown at a farmer's field located at Darek, Rawalakot (Latitude 33–36°N and Longitude 73–75°E) under open-field conditions. Prior to transplanting, farmyard manure, ammonium sulphate, super phosphate, and potassium sulphate were incorporated into the soil at the rates of 20 t/ha, 150 kg/ha, 300 kg/ha, and 150 kg/ha, respectively. The field was prepared into raised beds of 30 cm height and 50 cm width. Uniform and disease-free runners of each strawberry cultivar (*Chandler*, *Seascape*, and *Tribute*) were planted during the last week of March. A randomized complete block design (RCBD) was used with three replications per treatment. Each plot consisted of 15 plants, spaced at 20 cm apart within a single row on each bed. The plot size was approximately 3 meters in length and 0.5 meters in width. A buffer space of 1 meter was maintained between plots to minimize edge effects. Standard agronomic practices, including irrigation and manual weeding, were carried out twice a week throughout the growing season. Data was collected on both vegetative growth parameters (e.g., plant height, number of leaves, leaf area) and postharvest quality traits (e.g., fruit firmness, shelf life, total soluble solids), following standardized procedures.

Vegetative growth parameters

The survival percentage of strawberry plants was obtained by dividing survived plants with the total number of plants and multiplied the result with 100. The numbers of runners/plant grown were quantified and the average was determined. The leaf area per plant (cm^2) was measured by multiplying width and length of leaves measured using measuring scale and multiplied by 0.75. Total days to flowering were counted from planting to flower and average measured. Total flowers per plant were counted and average measured. Total fruits of each plant were counted and average measured. Total days from fruiting to harvest were counted and average measured. Fruit yield per plant was measured and expressed in grams. Weight of fruits from each plant was noted by digital weighing balance and average was taken as grams. The size of selected fruits was obtained by using a Vernier caliper and average of size was taken in mm.

Chlorophyll content (g/ml)

The chlorophyll contents were estimated by destructive sampling. Fresh leaf sample (1 g) was grinded with the help of mortar-pestle following the addition of 10 ml of chilling 80% acetone. Then a mixture was centrifuged at 3000 rpm for 15 minutes using UTECH centrifuge (UT-60B New York, USA). Supernatant extracted was used for absorbance readings at 646.60, 663.60 & 750.0 nm using a UV-Vis. spectrophotometer (UV-400 Spectrophotometer Hamburg, Germany). Calculations were done by using the equations provided by Zahid et al. (2014).

$$\text{Chlorophyll a (g/ml)} = 12.25 \times A_{663.6} - 2.25 \times A_{646.6}$$

$$\text{Chlorophyll b (g/ml.)} = 20.31 \times A_{646.6} - 4.91 \times A_{663.3}$$

$$\text{Total chlorophyll (g/ml)} = 17.76 \times A_{646.6} + 7.34 \times A_{663.6}$$

Where, 2.25, 20.31, 12.25, 7.34, 17.76 and 4.91 = constants

Postharvest quality parameters

The following postharvest parameters were used to determine quality of harvested fruits.

Total soluble solids (°Brix)

The method No. 960.20 [Association of Official Analytical Chemists (AOAC), 1990] was used to note total soluble solids using digital refractometer (Kyoto Company, Japan) at 25ºC. Fruit extract (single drop) was used to take readings and observations were recorded degree Brix.

Titratable acidity (%)

Titratable acidity was measured using the method No. 9720.21 (AOAC, 1990). Fruit pulp (5 g) was collected from each randomly selected fruit sample and mixed it with purified water (20 ml) and clear extract was gained by filtration of samples. The 5 ml of sample was titrated with the standard 0.1 Normality of NaOH and little drops of the phenolphthalein were used as a gauge until the light pink

colour appeared. The following equation was used to calculate titratable acidity:

$$\text{Titratable acidity (\%)} = \frac{\text{ml NaOH used} \times \text{Normality NaOH} \times \text{Equiv. wt. of ascorbic acid}}{\text{Sample weight} \times \text{Aliquot volume}}$$

pH

pH of fruit extract was determined using the method No. 981.12 (AOAC, 1990) with pH meter (Inolab, Germany). The instrument was adjusted with (4.0, 9.0 pH buffers) before recording observations. The cleaning and drying of electrode were done before each recording.

Vitamin C (mg/100 g)

The method No. 967.22 (AOAC, 1990) was used to measure vitamin C using dye (2, 6-dichlorophenol indophenol). 100 ml of 4.0% Meta-phosphoric acid was added in a conical flask and 5 ml of the extracted juice was also added. Dye was added and titration of sample was performed until the appearance of bright pink color. Vitamin C was expressed as mg/100 g.

Total carotenoids (mg/ 100g FW)

Strawberry fruit sample (2 g) was crushed using a mortar and pestle and then combined with 10 ml chilled acetone to determine total carotenoids. After passing the mixture through a filter paper, the total carotenoids were separated from the acetone using petroleum ether in a separating funnel. A UV-Vis spectrophotometer was used to detect absorbance at 450 nm (UV-4000 spectrophotometer; Hamburg, Germany). Trans-ß-carotene was used to create a standard calibration curve.

Total anthocyanins (mg of cyaniding-3-glucoside/L)

Two dilution method given by Zheng et al. (2007) was used to measure total anthocyanins. Potassium chloride buffer (pH 1.0) and sodium acetate buffer (pH 4.5) were used in comparison to blank. The absorbance of every dilution was measured with a spectrophotometer at 700 nm and 510 nm, respectively and expressed as mg of cyaniding-3-glucoside/L.

Total flavonoids (mg/100 g FW)

A homogenized mixture of strawberry fruit was prepared using a mortar and pestle. This mixture was combined with 1.5 ml of methanolic $AlCl_3.6H_2O$ in sealed tubes and kept in dark (15 minutes). The absorbance of this mixture was taken at 430 nm using spectrophotometer and expressed as mg/100 g FW (Ali et al., 2014).

Total phenolics (µg of gallic acid per FW)

For total phenolics, fruit juice (0.1 ml) was mixed with Folin-Ciocalteau (0.5 ml) following the addition of 1.5 ml Sodium Carbonate. 10 ml of volume of solution was maintained by mixing distilled water with the mixture. For two hours, the mixture was incubated at 40°C in a water bath. To test the absorbance at 750 nm, spectrophotometer was employed. The results were represented in µg of gallic acid/ FW of fruit (Ali et al., 2014).

Antioxidant activity (µg/100 mg FW)

Antioxidant activity was measured using modified Molyneux (2004) procedure, in which free radical 1,1–diphenyl-2-picrylhydrazyl (DPPH) was used. DPPH (0.1mM) methanolic-solution was added to 50 L methanoloic mixture-solution (diluted 1: 6) for each extract. For chemical reaction it was kept at room temperature in dark and then absorbance of DPPH at 517 nm was taken at 5 minutes intervals until the optical density stabilised after 30 minutes.

Statistical analysis

The experiment was arranged using randomized complete block design (RCBD). The analysis of variance (ANOVA) of collected data was done by application of statistical software (Statistix 8.1). Comparison of means was done by LSD test at 0.05 % probability level of significance (Steel et al., 1997).

Results and Discussion

Vegetative growth parameters

Survival percentage (%)

Results regarding survival percentage of three strawberry cultivars revealed that the survival percentage of "Chandler" was significantly higher than "Seascape" and "Tribue" at 0.05% probability level of significance. It was maximum in strawberry cultivar Chandler (97%) which was followed by Seascape (82%), while plants of Tribute showed the minimum survival percentage (75.50%) (Table 1). According to Palencia et al. (2021), young seedlings might not bear the transplanting shock, especially under suboptimal environmental conditions. For softening and ripening, various strawberry cultivars require specific combinations of daylight and temperature. For instance, the cultivar *Tribute* is sensitive to a 14-hour photoperiod at 23°C but demands longer daylight durations at higher temperatures for proper development. In this context, the survival differences observed at Darek, Rawalakot may be attributed to its unique microclimatic conditions which is characterized by relatively lower early-season temperatures and shorter photoperiods which is failed to meet the critical thresholds required by photoperiod and temperature-sensitive cultivars like *Tribute*. Consequently,

these conditions could have intensified transplanting shock and delayed physiological development, leading to lower survival rates in such cultivars at this location.

Table 1 Survival percentage of three strawberry (*Fragaria* × *ananassa* Duch.) cultivars grown under open field conditions at Darek, Rawalakot

Strawberry cultivars	Survival percentage
Chandler	97.00[a]
Seascape	82.00[b]
Tribute	75.50[c]

Means with no same lettering are different at 0.05% probability level using LSD test.

Number of runners per plant

Results regarding the number of runners per plant of three strawberry cultivars revealed that the number of runners per plant was found maximum in strawberry cultivar Chandler (4.96) which was followed by Seascape (4.23), while plants of Tribute showed the minimum number of runners per plant (3.44) (Table 2). Number of runners per plant depends on strawberry genotypes and climatic conditions (Rivero et al., 2021). Each cultivar responds uniquely to environmental factors such as temperature and photoperiod, which play a critical role in regulating vegetative propagation. Some genotypes tend to favor fruit development over runner formation, particularly when environmental conditions are not optimal for stolon initiation. The open-field conditions at Rawalakot are characterized by fluctuating temperatures and variable day lengths which may not have aligned with the specific requirements of certain cultivars, thereby limiting runner development.

Leaf area per plant (cm^2)

Results regarding leaf area per plant of three strawberry cultivars revealed that the leaf area per plant was found maximum in strawberry cultivar Chandler (42.63 cm^2) which was followed by Seascape (39.34 cm^2), while plants of Tribute showed the minimum leaf area per plant (37.98 cm^2) (Table 2). Leaf area per strawberry plant is highly dependent on growing conditions of plants as some plants require more sunlight for vegetative growth as compared with others (Petrakis et al., 2024). In the present study, the cultivar *Chandler* demonstrated a comparatively higher leaf area per plant, which can be attributed to its better adaptability to the prevailing environmental and soil conditions at the experimental site. Favorable factors such as adequate sunlight, optimal temperature range, well-aerated soil, and balanced nutrient availability likely contributed to enhanced photosynthetic activity and leaf expansion in *Chandler*. A larger leaf area, in turn, supports greater photosynthetic efficiency, which promotes robust vegetative development. These findings suggest that *Chandler* is well-suited to the agro-climatic conditions of Rawalakot, leading to superior vegetative performance compared to other cultivars evaluated.

Chlorophyll content of leaves

Results regarding chlorophyll content of leaves of three strawberry cultivars revealed that the maximum chlorophyll content of leaves was found in strawberry cultivar Chandler (43.23 g/ml) which was followed by Seascape (40.45 g/ml), while the minimum chlorophyll content of leaves of strawberry plants was observed in strawberry cultivar Tribute (37.89 g/ml) (Table 2). Generally, chlorophyll has been found to be responsible for photosynthetic activity. It is a commonly known fact that increase of chlorophyll constituent resulted in increase of photosynthetic activity which has been found positively correlated with crop growth and yield increase (Yang et al., 2022). Photosynthesis is attributed to chlorophyll, according to popular belief. By decreasing moisture loss, higher chlorophyll concentration leads to enhanced photosynthesis, which benefits crop growth, yield, and phytochemical activity.

Number of days to flowering

The maximum number of days to flowering were noted in strawberry cultivar Tribute (51.34), followed by Seascape (47.90), while Chandler showed the minimum number of days to flowering (45.89) (Table 2). The three strawberry cultivars exhibited noticeable differences in the number of days taken to initiate flowering. This variability in flowering period can be attributed primarily to differences in the chilling requirements of each cultivar, as previously reported by Ahn et al. (2021). Chilling plays a critical role in breaking dormancy and promoting floral induction in strawberries, and cultivars with higher chilling requirements may experience delayed flowering under insufficient cold exposure. Additionally, the genetic makeup of each cultivar also significantly influences its flowering mechanism, affecting hormonal regulation and the expression of flowering-related genes (Haynes et al., 2025). Therefore, both physiological responses to environmental cues and inherent genetic differences contribute to the variation in flowering time observed among the tested cultivars.

Number of flowers per plant

The highest number of flowers per plant of three strawberry cultivars were noted in strawberry cultivar Chandler (14.32), followed by Seascape (13.12), while plants of Tribute showed the lowest number of flowers per plant (10.98) (Table 2). Temperature plays an important role in flower production even among different genotypes (Krüger et al., 2022). Cervantes et al. (2020) reported that a small increase in day temperature paired with short day length supported flower initiation in strawberry plants. More favourable temperatures and more time were available for plant growth and development, which had a beneficial influence on plant growth and resulted in early blooming and fruiting (Khammayom et al., 2022).

Number of fruits per plant

Results regarding the number of fruits per plant of three strawberry cultivars revealed that it was found the maximum in Chandler (10.32) which were followed by Seascape (9.13), while Tribute showed the minimum number of fruits per plant (7.35) (Table 2). Fruit production is generally affected by temperature and other closely related factors. One of the main factors is temperature which plays an important role in fruit production even among different genotypes (Krüger et al., 2022). Khammayom et al. (2022) reported that favourable temperature and more time available for plant growth and development had significant impacts not only on plant growth but also on flower and fruit output.

Number of days to harvest

Results concerning the number of days to harvest of three strawberry cultivars revealed that the number of days to harvest were found in strawberry cultivar Tribute (92.56) which were followed by Seascape (89.90), while the least number of days to harvest of strawberry plants were observed in strawberry cultivar Chandler (85.89) (Table 2). Three different cultivars showed difference in number of days taken to harvest. This variability in harvesting period in different cultivars could be due to the difference in their chilling requirements (Ariza et al., 2021). Further, this variation could be attributed to the fact that genetic makeup of different cultivars had some effect on the number of days to harvest (Krüger et al., 2022).

Fruit yield per plant (g)

Results regarding fruit yield per plant of three strawberry cultivars revealed that it was found maximum in Chandler (118.32 g) which was followed by Seascape (112.45 g), while Tribute showed the minimum fruit yield per plant (105.35 g) (Table 2). Fruit yield is generally affected by growing conditions and other cultural practices. However, among other factors temperature of location plays an important role in fruit production even among different genotypes (Krüger et al., 2022). Favourable temperature and longer time available for plant growth and development have always positive effect on growth and production of fruits (Khammayom et al., 2022). Varietal yield variations are influenced by a variety of factors, including the cultivar's fruit producing capacity, plant development and climatic conditions.

Weight of fruit (g)

Results regarding the weight of fruit of three strawberry cultivars revealed that it was found maximum in Chandler (10.23 g) which was followed by Seascape (9.80 g), while Tribute showed the minimum weight of fruit (8.76 g) (Table 2). Characteristics of fruits are normally correlated positively with chlorophyll content of leaves. It is general perception that bigger leaf area is responsible for more fruit weight. However, sometimes variation in fruit weight is simply due to the inherent characteristic of a genotype (Haynes et al., 2025).

Size of fruit (mm)

Results regarding the size of fruit of three strawberry cultivars revealed that it was found maximum in Chandler (15.54 mm) which was followed by Seascape (13.23 mm), while Tribute showed the minimum size of fruit (11.89 mm) (Table 2). Among the three strawberry cultivars, the fruit size of Chandler was found bigger as compared with two other cultivars. This increase in size could be due to the fact that fruit size and fruit diameter are generally dependent on climatic conditions and vary with the cultivar. Further, it has been reported previously that the increase in temperature is negatively correlated with fruit size (Menzel, 2021).

Table 2 Vegetative growth parameters of three strawberry (*Fragaria* × *ananassa* Duch.) cultivars grown at farmer's field located at Darek, Rawalakot

Strawberry cultivars	No. of runners per plant	Leaf area per plant (cm^2)	Chlorophyll content (g/ml)	Number of days to flowering	Number of flowers per plant
Chandler	4.96^a	42.63^a	43.23^a	45.89^c	14.32^a
Seascape	4.23^b	39.34^b	40.45^b	47.90^b	13.12^b
Tribute	3.44^c	37.98^c	37.89^c	51.34^a	10.98^c

Means with no same lettering are different at 0.05% probability level using LSD test.

Table 2 continue

Strawberry cultivars	Number of fruits per plant	Number of days to harvest	Fruit yield per plant (g)	Weight of fruit (g)	Size of fruit (mm)
Chandler	10.32[a]	85.89[c]	118.32[a]	10.23[a]	15.54[a]
Seascape	9.13[b]	89.90[b]	112.45[b]	9.80[b]	13.23[b]
Tribute	7.35[c]	92.56[a]	105.35[c]	8.76[c]	11.89[c]

Means with no same lettering are different at 0.05% probability level using LSD test.

Postharvest quality parameters

Total soluble solids (%)

Results regarding total soluble solids of three strawberry cultivars revealed that they were found maximum in Chandler (7.56%), followed by Seascape (7.34%), while Tribute showed the minimum total soluble solids (6.89%) (Fig. 1a). In this study, higher amount of total soluble solids in cultivar Chandler could be attributed to the fact that genetic makeup of any fruit has a great role. Further, in a previous study it was reported that slightly higher temperature helped in improving the total soluble solids content (Cervantes et al., 2020). Similarly, the variation in total soluble solids among genotypes might be due to variation in genetic makeup of strawberry cultivars (Haynes et al., 2025).

Titratable acidity (%)

Results regarding titratable acidity of three strawberry cultivars revealed that it was found maximum in Chandler (0.78%), followed by Seascape (0.74%), while Tribute showed the minimum titratable acidity (0.68%) (Fig. 1b). Titratable acids and other organic acid contents are generally determined by the genetic make-up of particular genotypes and therefore, vary significantly among them. Moreover, they are very little influenced by environmental factors (Patel et al., 2023). Thus, higher values of titratable acids in cultivar Chandler could be linked with the genetic makeup of that particular cultivar.

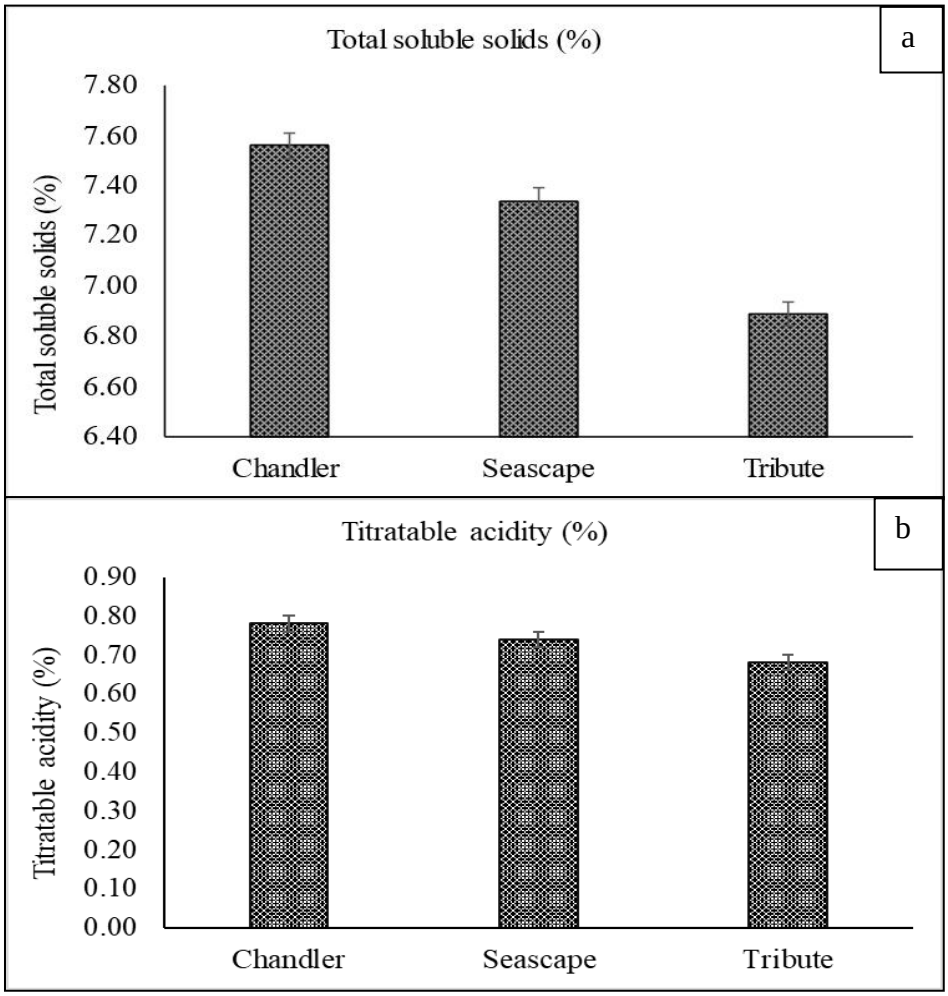

Fig. 1 Total soluble solids (a) and titratable acidity (b) of three strawberry (*Fragaria* × *ananassa* Duch.) cultivars grown under open-field conditions at Darek, Rawalakot.Vertical bars represent the standard error of means (n = 3) for three replicates)

pH

Results regarding pH of three strawberry cultivars revealed that it was found maximum in Tribute (4.14) which was followed by Seascape (3.96), while Tribute showed the minimum pH (3.78) (Fig. 2a). In this study, the cultivar *Tribute* recorded the highest fruit pH among the evaluated cultivars, which may be primarily attributed to its genetic makeup and inherent biochemical characteristics (Basak et al., 2022). The pH of strawberry fruit is influenced by the balance of organic acids and sugars, and genotypic variation plays a key role in regulating acid metabolism during fruit development and ripening. Higher pH values typically indicate lower acidity, which can affect fruit flavor and consumer preference. The elevated pH in *Tribute* suggests a milder acidic profile, potentially linked to its cultivar-specific enzymatic activity and metabolic pathways. These results highlight the importance of genetic factors in determining fruit quality traits such as pH in strawberries.

Vitamin C (mg/100 g)

Results regarding vitamin C of three strawberry cultivars revealed that the maximum vitamin C was found in strawberry cultivar Chandler (21.34 mg/100g) which was followed by Seascape (19.23 mg/100g), while the minimum vitamin C was observed in strawberry cultivar Tribute (17.87 mg/100g) (Fig. 2b). Strawberries have been found rich in vitamin C as compared with apples and grapes and this has been reported as much as 10 times (Newerli-Guz et al., 2023). The production of vitamin C is a genetic factor, and it is tissues specific. However, its production is anabolically done in plants by following the pathway of $_{L}$-galactose which is found to be related to photosynthesis activity in plants (Cervantes et al., 2020). This association arises because the intermediates of the L-galactose pathway are derived from photosynthetically produced sugars. In the present study, the higher vitamin C content observed in the cultivar Chandler could be attributed to its increased chlorophyll content, which likely enhanced photosynthetic efficiency and, in turn, stimulated the anabolic production of vitamin C. These findings underscore the interconnectedness of photosynthesis and vitamin C biosynthesis in strawberry plants.

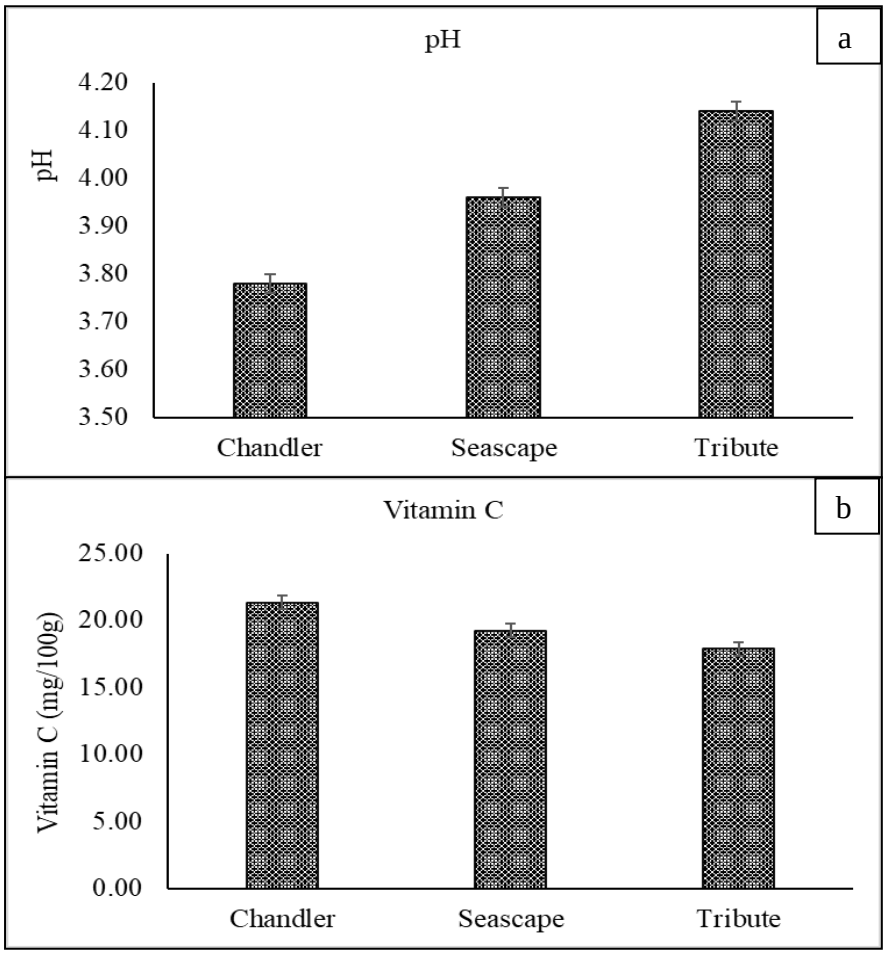

Fig. 2 pH (a) and Vitamin C (b) of three strawberry (*Fragaria* × *ananassa* Duch.) cultivars grown at farmer's field located at Darek, Rawalakot (Vertical bars represent the standard error of means for three replicates)

Total carotenoids (mg/100 g FW)

Results regarding total carotenoids of three strawberry cultivars revealed that they were found maximum in Chandler (4.21 mg/100 g FW) which were followed by Seascape (3.87 mg/100 g FW), while Tribute showed the minimum total carotenoids (2.34 mg/100 g FW) (Fig. 3a). Beneficial efficacy of fruits on humans is always dependent on the concentration of carotenoids, vitamin C, tocophenols and total flavonols (Newerli-Guz et al., 2023). Various bacteria develop in the root zone of strawberry in soilless culture, which might cause the difference in healthy compounds in strawberries sprayed with different growth regulators (Garza-Alonso et al., 2022). These bacterial populations are responsible for making sure the accessibility of wider range of nutrients (nitrogen, carbon, Fe etc.) which empower plants to absorb nutrients from the medium in suitable amounts. Carotenoids are one of the most critical antioxidants found in strawberry. It has been reported that photosynthesis process helps in increasing the amount of carotenoids (Rahim Doust et al., 2023). It is also considered that at final stages of ripening, colour development is contributed by the amount of carotenoids in fruits.

Total anthocyanins (mg/100 g FW)

Results regarding total anthocyanins of three strawberry cultivars revealed that they were found maximum in Chandler (4.02 mg/100 g FW) which were followed by Seascape (3.89 mg/100 g FW), while Tribute showed the minimum total anthocyanins (2.54 mg/100 g FW) (Fig. 3b). Anthocyanin contents are mainly dependent on genetic makeup of plants and a high variability in anthocyanin content among strawberry cultivars was described by Krüger et al., (2022). Difference of anthocyanin content in different strawberry cultivars in our results could be due to the adaptability potential of strawberry plants under Rawalakot climatic conditions or might be due to their genetic differences (Wang et al., 2025).

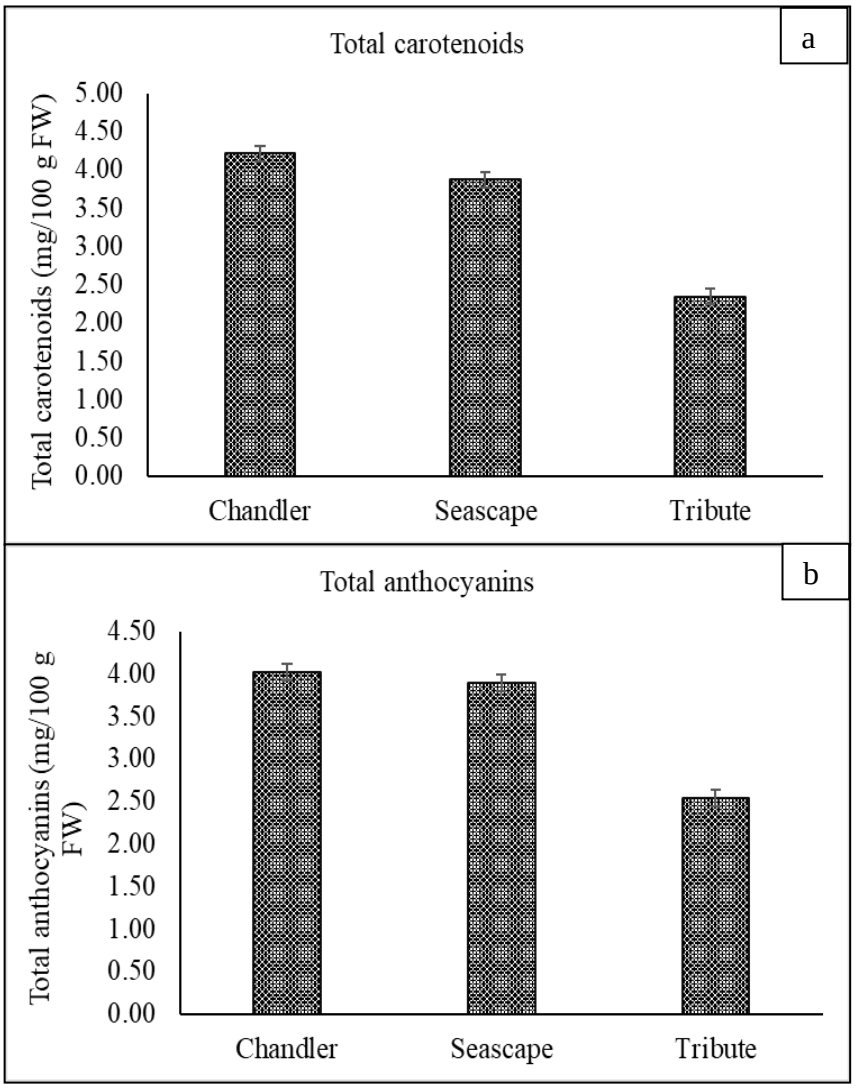

Fig. 3 Total carotenoids (a) and total anthocyanins (b) of three strawberry (*Fragaria* × *ananassa* Duch.) cultivars grown at farmer's field located at Darek, Rawalakot (Vertical bars represent the standard error of means for three replicates)

Total flavonoids (mg/100 g FW)

Results regarding total flavonoids of three strawberry cultivars revealed that they were found maximum in Chandler (8.67 mg/100 g FW) which were followed by Seascape (6.76 mg/100 g FW), while Tribute showed the minimum total flavonoids (5.78 mg/100 g FW) (Fig 4a). For the oxidation process, human body requires flavonoids which perform various functions as antioxidants. Besides their beneficial effects for human beings, flavonoids also provide additional function in fruits and reduce over-ripening process. An important role is also played by flavonoids in the case of climacteric fruits where they regulate the process of ethylene biosynthesis and help in regulating the fruit ripening (Newerli-Guz et al., 2023). High temperature is favourable for production of flavonoids (Cervantes et al., 2020).

Total phenolics (mg gallic acid/100 g)

Results regarding total phenolics of three strawberry cultivars revealed that they were found maximum in Chandler (8.61mg gallic acid/100 g) which were followed by Seascape (7.13 mg gallic acid/100 g), while Tribute showed the minimum total phenolics (6.20 mg gallic acid/100 g) (Fig. 4b). Phenolics are also considered very important health associated components which are found in strawberry. Strawberries are very rich in terms of polyphenols (Milosavljević et al., 2022). More than half of total phenols in strawberries are polyphenols. Strawberry fruits of cultivar Chandler had the highest quantity of total phenols in our study, which might be related to increased content of chlorophylls in leaves (Simkova et al., 2024). The fact that the amount of phenolic compounds in strawberries has altered and therefore, the antioxidant activity supports the opinion that the kind of farming is essential for antioxidants in strawberries (Milosavljević et al., 2022). Total phenolic content mainly depends on variety, growing and maturity season (Urün et al., 2021).

Antioxidant activity (µg/100 mg FW)

Results regarding antioxidant activity of three strawberry cultivars revealed that it was found maximum in Chandler (102.12 µg/100 mg FW) which was followed by Seascape (89.78 µg/100 mg FW), while Tribute showed the minimum antioxidant activity (78.67 µg/100 mg FW) (Fig. 4c). The difference in antioxidant activity could be linked with the cultivar as well as the environmental conditions including temperature and light intensity during the whole growing season of a crop (Urün et al., 2021). Quality of strawberry fruits has also been associated with altitude and environmental conditions (Patel et al., 2023).

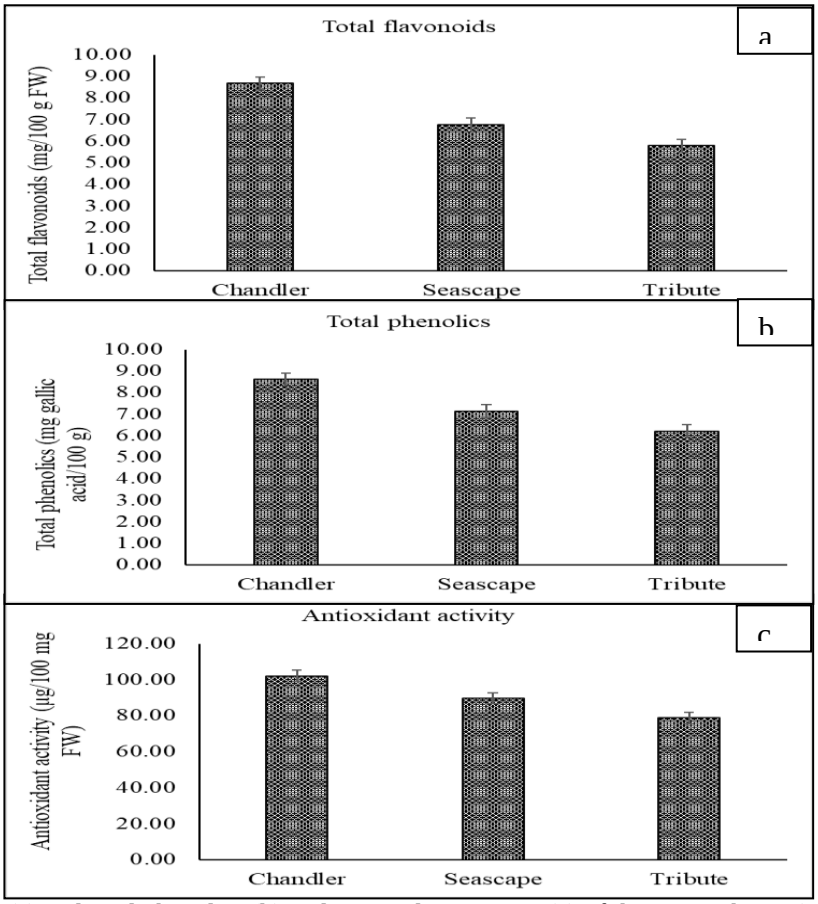

Fig. 4 Total flavonoids (a) and total phenolics (b) and antioxidant activity (c) of three strawberry (*Fragaria × ananassa* Duch.) cultivars grown at farmer's field located at Darek, Rawalakot (Vertical bars represent the standard error of means for three replicates)

Conclusion

It can be concluded that the strawberry cultivar *Chandler* outperformed *Seascape* and *Tribute* in terms of vegetative growth as well as key postharvest quality parameters. Notably, *Chandler* exhibited higher yield potential, produced uniformly larger fruits, and demonstrated better shelf life, making it more suitable for transportation and marketability. These characteristics are highly desirable for commercial production, especially under the open-field conditions of Rawalakot, where it adapted well to the prevailing climatic factors. Therefore, *Chandler* is recommended for large-scale cultivation in this region. Moreover, it is suggested that further studies be conducted to identify other agro-ecologically suitable locations across the region to expand commercial strawberry production and enhance regional fruit supply chains.

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