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ASSESSMENT OF MULCH AND GROWTH REGULATOR EFFECTS ON AGRO MORPHOLOGICAL AND QUALITY ATTRIBUTES IN STRAWBERRY (*FRAGARIA × ANANASSA*) CV. CAMAROSA UNDER PROTECTED CULTIVATION

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ABSTRACT

In strawberries grown using various mulches and growth regulators under protected conditions, the study examines the intricate link between quantitative and qualitative qualities. Least significant difference, Correlation analysis and principal component analysis (PCA) are used in the study to highlight important factors influencing overall variation in strawberry characteristics, identify direct and indirect effects on agro-morphological, yield and quality attributes and reveal the interdependencies between traits and treatments. GA_3 + Silver-black polyethylene mulch was best treatment achieving maximum plant height, number of leaves, number of runners, fruit length, total phenols and anthocyanin content. Further, GA_3 + Black polyethylene mulch was found to obtain maximum number of flowers, number of fruits and yield per plant. In contrast, NAA 50 ppm + Silver-black polyethylene mulch helped to achieve minimum days to first flowering, maximising fruit breadth, fruit weight and juice pH. Moreover, maximum leaf area, TSS, sugars (Total, reducing and non-reducing), ascorbic acid and reduction in titratable acidity was recorded with NAA 50 ppm + Black polyethylene mulch.

***Key words*:** Strawberry, Mulch, Growth regulator, Correlation, PCA

Introduction

Genus *Fragaria* contains various species with ploidy levels ranging from diploid (2n = 2x) to decaploid (2n = 10x) with basic chromosome number 7. These species can be found in both wild and domesticated forms (Qiao *et al*. 2021). While, commercially used strawberry cultivars are octaploid (2n = 8x = 56) in nature (Folta and Barbey, 2019). The modern strawberry (*Fragaria* × *ananassa* Duch.) is a hybrid between the 'Scarlet' or 'Virginia' strawberry (*Fragaria virginiana*) and the pistillate South American strawberry (*Fragaria chiloensis*). It is a dicotyledonous herb belonging to family Rosaceae, firstly originated in France (Debnath 2013). The plant is perennial herbaceous, with fibrous roots, a short crown attached to a bunched trifoliate leaf with a long petiole, and a runner that produces shoots (Pandey *et al.*, 2018). Strawberry is extremely specific to agronomic approaches, such as water requirement, nutrient management and proper light interception etc., because of its herbaceous nature. Therefore, meeting the needs for light, nutrients and water is essential for a larger production.

By controlling soil temperature, preserving moisture, lowering evaporative losses, and inhibiting weed growth, mulching techniques help to lower the frequency of berry-related diseases. enhancing production and water use efficiency as well as fertiliser uptake (Islam *et al.*, 2022). Various studies on impact of plant growth regulators on growth, yield and quality has stated that strawberry is highly responsive to the application of plant growth regulators (Kumar *et al.*, 2012). Naphthalene acetic acid is a synthetic auxin affecting a number of physiological processes, including respiration rate photosynthesis and producing high quality fruits (Bhople *et al.*, 2020). On the other hand, Gibberellic acid (GA_3) encourages cell division and elongation thus increasing stalk length, fruit size, number of flowers and yield (Katel *et al.*, 2006). A properly managed strawberry farm has potential to produces 300 quintals per hectare of berries. While, only 100 - 200 quintals per hectare strawberry fruit is obtained. It is the ongoing challenge for strawberry growers, as it results in reduction of net profit. Protected cultivation of strawberries in polyhouse can help to produce maximum strawberry production per hectare (Farhangi *et al.*, 2023; Oh and Lu, 2023). Thus, aim of the study is to increase profit of farmers by deploying the use of growth regulators, mulching and protected cultivation techniques in strawberry.

Materials and Methods

The experimental research of various growth, physical and quality attributes was initiated in November at Polyhouse of Vegetable research farm, Khalsa College, Amritsar, Punjab, India, during the year 2022-2023. Quality attributes were determined using the Horticulture laboratory of Department of Agriculture. 'Camarosa' cultivar of strawberry was utilized for the study, planting material was procured from Solan, Himachal Pradesh, India. Mulching with black, transparent and silver-black polyethylene mulch was performed after two weeks of transplanting. Naphthalene acetic acid (NAA) and Gibberellic acid (GA_3) were sprayed after 4 weeks of transplanting in two different concentrations of 25, 50 ppm and 50, 75 ppm, respectively. A total of thirteen treatments were applied with three replications each in Randomized Block Design. Treatment details are as follow:

Treatments Detail

Treatments	Detail
T_1	NAA 25ppm + Black mulch
T_2	NAA 50ppm + Black mulch
T_3	NAA 25ppm + White mulch
T_4	NAA 50ppm + White mulch
T_5	NAA 25ppm + Silver-black mulch
T_6	NAA 50ppm + Silver-black mulch
T_7	GA_3 50ppm + Black mulch
T_8	GA_3 75ppm + Black mulch
T_9	GA_3 50ppm + White mulch
T_{10}	GA_3 75ppm + White mulch
T_{11}	GA_3 50ppm + Silver-black mulch
T_{12}	GA_3 75ppm + Silver-black mulch
T_{13}	Water spray (Control)

Agro-morphological attributes

Plant height (cm) was measured using the centimetre scale from the tagged plants and number leaves per plants were also counted from the same plants. Leaf area (cm^2) was recorded using the graph paper method. Days taken to first flowering was calculated from the date of transplanting. Number of flowers and runners were counted manually from the five tagged plants and average was taken as final reading.

Yield related and Yield attributes

Fruits on the tagged plants were calculated and average was taken as number of fruits per plants. Similarly, fruit weight (g) and yield (g) was recorded using digital weighing balance. While, fruit length and fruit breadth were noted by using Digital Vernier Caliper's and average value was expressed in millimeter (mm).

Quality attributes

Fruit juice was extracted and strained using a muslin cloth after harvesting five fruits per replication per treatment separately. This fruit juice was then analysed in laboratory for various biochemical attributes. Total soluble solids (%) was recorded with the help of digital refractometer. The values of TSS were corrected at 20^0C with the help of a temperature correction chart as per AOAC (2002) and expressed as TSS (%). Titratable acidity (%) was determined by titrating the juice against standard alkali solution (0.1N NaOH).

Juice pH was measured by dipping the electrode of pH meter inside juice (150 ml) for few seconds, and stabilized pH reading was recorded. Before every observation, the bulb of the pH meter was washed with double-distilled water to eliminate the residual effect. Total sugars, reducing and non-reducing sugars were estimated by the method proposed in AOAC (1990). Ascorbic acid content (mg/100g FW) was determined at marketable red ripe fruit stage by "2,6 dichlorophenol-indophenol visual titration method" as described by Ranganna (1995). Anthocyanin is the major pigment found in strawberry was estimated by method given by Ranganna (1995) was used for the determination of anthocyanin content in strawberry fruits. Tissue of 5g was homogenized in 10ml of 0.1% HCI in methanol. Extract prepared was put for 20 hrs at room temperature and the absorbance was noted at 530 nm and expressed as mg/100g FW. Total phenols (mg/100g FW) were analysed using the modified method of Swain and Hills (1959) Folin Cocalteu (FC) reagent was used for determining total phenols. 0.5ml juice of strawberry was diluted with 10 ml distilled water and 0.1ml sample was taken from the diluted solution. To this 0.1 ml diluted

Table 1: Influence of various mulching and growth regulators on agro-morphological attributes.

Treatments	Plant height(cm)	Number of leaves plant^{-1}	Leaf area(cm^2)	Days to first flowering	Number of flowers plant^{-1}	Number of runners plant^{-1}
T_1	$17.46^{hi}\pm0.13$	$18.66^{ef}\pm0.07$	$21.46^{b}\pm0.07$	$57.13^{gh}\pm0.37$	$14.80^{f}\pm0.42$	$1.06^{e}\pm0.06$
T_2	$18.06^{gh}\pm0.14$	$19.13^{e}\pm0.18$	$22.86^{a}\pm0.18$	$58.13^{fg}\pm0.41$	$13.26^{g}\pm0.07$	$1.26^{e}\pm0.07$
T_3	$17.06^{i}\pm0.13$	$18.00^{f}\pm0.31$	$21.93^{b}\pm0.37$	$61.93^{cd}\pm0.24$	$12.73^{gh}\pm0.35$	$1.20^{e}\pm0.12$
T_4	$17.06^{i}\pm0.35$	$18.06^{f}\pm0.13$	$21.46^{b}\pm0.48$	$63.13^{bc}\pm0.37$	$12.33^{g}\pm0.29$	$1.33^{de}\pm0.13$
T_5	$18.40^{fg}\pm0.12$	$20.93^{d}\pm0.37$	$21.86^{b}\pm0.27$	$55.93^{hi}\pm0.47$	$14.73^{f}\pm0.29$	$2.46^{c}\pm0.13$
T_6	$18.73^{f}\pm0.07$	$21.33^{d}\pm0.07$	$22.80^{a}\pm0.31$	$55.73^{i}\pm0.44$	$15.20^{f}\pm0.23$	$2.47^{c}\pm0.18$
T_7	$29.13^{c}\pm0.24$	$22.13^{c}\pm0.37$	$19.80^{def}\pm0.31$	$58.80^{e}\pm0.40$	$21.13^{b}\pm0.18$	$2.40^{c}\pm0.20$
T_8	$31.26^{b}\pm0.29$	$23.06^{b}\pm0.13$	$20.06^{cd}\pm0.13$	$61.66^{d}\pm1.16$	$22.04^{a}\pm0.20$	$2.53^{bc}\pm0.18$
T_9	$26.06^{e}\pm0.14$	$20.80^{d}\pm0.35$	$19.20^{f}\pm0.23$	$62.93^{bcd}\pm0.44$	$18.06^{e}\pm0.35$	$1.73^{d}\pm0.29$
T_{10}	$27.26^{d}\pm0.29$	$20.86^{d}\pm0.48$	$19.33^{ef}\pm0.29$	$63.53^{b}\pm0.24$	$17.46^{e}\pm0.07$	$1.46^{de}\pm0.06$
T_{11}	$28.60^{c}\pm0.20$	$22.93^{b}\pm0.27$	$19.93^{cde}\pm0.35$	$58.06^{fg}\pm0.37$	$19.08^{d}\pm0.42$	$2.93^{ab}\pm0.07$
T_{12}	$32.06^{a}\pm0.24$	$24.20^{a}\pm0.42$	$20.46^{c}\pm0.52$	$59.02^{ef}\pm0.31$	$19.66^{c}\pm0.29$	$3.06^{a}\pm0.07$
T_{13}	$14.40^{j}\pm0.20$	$15.13^{g}\pm0.18$	$18.06^{g}\pm0.24$	$73.06^{a}\pm0.24$	$10.73^{i}\pm0.29$	0.00^{f}
Mean ± S. E	22.73±0.02	20.40±0.15	20.71±0.22	60.77±0.19	16.24±0.19	1.84 ± 0.03
C.D$_{(p\leq0.05)}$	0.63	1.14	0.64	2.99	0.63	0.23

solution, 1.5 ml freshly prepared FC reagent (10 ml FC: 90 ml distilled water) and 4 ml saturated Na_2CO_3 was added and final volume was made to 10 ml with distilled water. The mixture was placed for 30 minutes in dark and absorbance was recorded at 738 nm using spectrophotometer. The content of total phenols expressed in mg/100g FW.

Statistical analysis

Means were separated using LSD test. Differences were considered significant at the level $p \leq 0.05$ using statistical analysis system software R studio (4.3.0).

Results and Discussion

Influence of various mulching and growth regulators on agro-morphological attributes

The analysis of variation (ANOVA) for various agro-morphological attributes of strawberry influenced by various mulches and growth regulators is represented in Table 1. depicts significant variation among different treatments for multiple traits. Maximum plant height per plant (32.06 cm) was reported with the use of GA_3 75 ppm + Silver-black mulch (T_{12}). This was immediately followed by treatment of GA_3 75 ppm + Black mulch (T_8) with the plant height of 31.26 cm. While, minimum plant height per plant (14.40 cm) was observed under control. Maximum number of leaves per plant (24.20) and number of runners (3.06) were also observed under treatment of GA_3 75 ppm + Silver-black mulch (T_{12}). Whereas, minimum number of leaves (15.13) and no runners were reported. This might be due to maintenance of optimum soil temperature, giving better environment for plant to grow (Singh *et al.,* 2019). Moreover, gibberellins' capacity to promote cell division and growth in the epidermis and parenchyma also helped the plants to achieve more plant height, number of leaves and runners per plant (Bist *et al.,* 2018). These results were similar with Kaur and Mirza (2018), Rathod *et al.,* (2020), Jat *et al.,* (2022) and Kumar *et al.,* (2022) in strawberry. Whilst, highest number of flowers per plant (22.04) were noted with the use of GA_3 75 ppm + Black mulch (T_8). It could be due to the application of GA_3, which accelerated the formation of differentiated inflorescence and encouraged flowering, and mulching, which produced ideal soil moisture and temperature conditions, hence fostering plant growth and development (Thakur *et al.,* 1991). The results are in line with Al-madhagi *et al.,* (2012) and Kumar *et al.,* (2017) in strawberry.

On the other hand, treatment of strawberry plants with NAA 50 ppm + Silver-black mulch (T_6) was the earliest to flower (55.73 days after transplanting) and recorded maximum leaf area (22.80 cm^2) among various treatments. This could be because of the mulching treatment, which reduced the number of weeds in the root zone and created an ideal moisture level, nutrient availability, and favourable soil temperature which resulted in more leaf area and early flowering. Moreover, auxin in particular NAA, stimulates florigen, which moves from the petiole to the growing tip and transforms the vegetative bud into a blooming bud. Fruit set, on the other hand, refers to the alteration in the ovary that results in the production of the fruit. Usually, NAA causes pollination and fertilisation, which results in these alterations (Kumar *et al.,* 2011). These findings are inclined with Kaur and Mirza (2018), Rathod *et al.,* (2020) and Kumar *et al.,* (2022) in strawberry.

Table 2: Influence of various mulches and growth regulators on yield and yield related attributes.

Treatments	Number of fruits plant^{-1}	Fruit weight (g)	Yield plant^{-1} (g)	Fruit length (mm)	Fruit breadth (mm)
T_1	$6.33^{de} \pm 0.06$	$12.02^{b} \pm 0.20$	$76.46^{g} \pm 1.04$	$25.20^{e} \pm 0.23$	$31.13^{c} \pm 0.74$
T_2	$6.53^{d} \pm 0.13$	$12.66^{ab} \pm 0.47$	$87.60^{e} \pm 0.46$	$26.53^{d} \pm 0.07$	$32.40^{ab} \pm 0.42$
T_3	$5.33^{f} \pm 0.13$	$8.73^{d} \pm 0.29$	$40.80^{i} \pm 0.83$	$25.20^{e} \pm 0.23$	$29.20^{d} \pm 0.31$
T_4	$5.80^{ef} \pm 0.23$	$8.06^{de} \pm 0.24$	$39.66^{i} \pm 0.58$	$24.93^{e} \pm 0.47$	$29.26^{d} \pm 0.07$
T_5	$6.26^{de} \pm 0.17$	$12.73^{ab} \pm 0.29$	$74.86^{g} \pm 1.32$	$27.13^{d} \pm 0.18$	$31.80^{bc} \pm 0.60$
T_6	$6.26^{de} \pm 0.07$	$13.40^{a} \pm 0.12$	$88.40^{e} \pm 1.55$	$27.06^{d} \pm 0.37$	$33.06^{a} \pm 0.18$
T_7	$11.40^{b} \pm 0.20$	$9.80^{c} \pm 0.20$	$106.13^{c} \pm 1.75$	$30.26^{ab} \pm 0.52$	$23.80^{fg} \pm 0.40$
T_8	$12.53^{a} \pm 0.18$	$10.20^{c} \pm 0.23$	$120.53^{a} \pm 1.09$	$31.33^{a} \pm 0.58$	$25.13^{e} \pm 0.33$
T_9	$9.02^{c} \pm 0.40$	$7.86^{e} \pm 0.18$	$71.13^{h} \pm 0.87$	$29.26^{bc} \pm 0.52$	$23.20^{gh} \pm 0.35$
T_{10}	$9.33^{c} \pm 0.37$	$8.66^{d} \pm 0.07$	$80.13^{f} \pm 0.79$	$28.86^{c} \pm 0.29$	$23.06^{gh} \pm 0.47$
T_{11}	$11.06^{b} \pm 0.24$	$10.02^{c} \pm 0.42$	$92.40^{d} \pm 1.27$	$30.80^{a} \pm 1.01$	$24.20^{efg} \pm 0.50$
T_{12}	$12.33^{a} \pm 0.27$	$9.86^{c} \pm 0.27$	$117.13^{b} \pm 0.88$	$31.46^{a} \pm 0.65$	$24.73^{ef} \pm 0.07$
T_{13}	$4.46^{g} \pm 0.13$	$5.80^{f} \pm 0.20$	$22.73^{j} \pm 1.16$	$23.93^{f} \pm 0.13$	$22.40^{h} \pm 0.12$
Mean ± S. E	8.20 ± 0.06	9.98 ± 0.07	78.30 ± 0.20	27.84 ± 0.21	27.18 ± 0.03
C.D$_{(p\leq0.05)}$	0.64	0.85	6.21	1.29	1.21

Influence of various mulches and growth regulators on yield and yield related attributes

A significant variation was observed among various physical and yield related attributes of strawberry during the analysis of variation (ANOVA), Table 2. clearly depicts that various mulches and growth regulators improved the physical and yield attributes of strawberry. Highest number of fruits per plant (12.53) were observed with application of treatment GA_3 75 ppm + Black mulch (T_8) which was at par with GA_3 75 ppm + Silver-black mulch (T_{12}). It's possible that the favourable soil temperature and moisture conditions, which enhanced the plant's photosynthetic rate, are to blame for this notable increase of fruits per plant under mulching Mann *et al.*, (2017). Furthermore, a higher delivery of nutrients and photosynthates to the plants may be the cause of the increase in fruit production following GA_3 treatment (Kumar and Tripathi 2009). The present findings are in conformity with results of Kaur and Mirza (2018) and Kumar *et al.*, (2022) in strawberry.

Whereas, highest fruit weight (13.40 g) was noted with use of NAA 50 ppm + Silver-black mulch (T_6). It could be the result of the treatment's enhancement of the water and nutrient uptake, which raised the photosynthetic rate and produced the highest fruit weight (Nor *et al.*, 2014). In the case of strawberries, our conclusion is consistent with the findings of Palei *et al.*, (2016), Kaur and Mirza (2018), Singh *et al.*, (2019), and Kumar *et al.*, (2022). While, maximum fruit yield per plant (120.53 g) reported with treatment of GA_3 75 ppm + Black mulch (T_8) which was immediately followed by use of GA_3 75 ppm + Silver-black mulch (T_{12}). These results can be probably due to improve in the root system microclimate, plant canopy, decreased weed competition, and moisture conservation all of which lead to more fruits per plant and ultimately high fruit yield, are the causes of this notable increase in fruit yield per plant (Kumar *et al.*, 2017). Furthermore, the greater capacity of GA_3 treated plants to photosynthesise may have encouraged and enhanced the build-up of dry matter, leading to a higher fruit output per plant and increase in yield (Kaur and Mirza 2018). The present results findings are in conformity the findings of Mann *et al.*, (2017), Rathod *et al.*, (2020) and Kumar *et al.*, (2022) in strawberry. Maximum length of berry (31.46 mm) was reported with the application of GA_3 75 ppm + Silver-black mulch (T_{12}) which stood at par with treatment of GA_3 75 ppm + Black mulch (T_8).

Whereas, maximum fruit width (33.06 mm) was noted under treatment of plants with NAA 50 ppm + Silver-black mulch (T_6), this do not differ significantly with NAA 50 ppm + Black mulch (T_2). While, minimum fruit length (23.93 mm) and fruit width (22.40 mm) was noted under control. This might be due to the improvement in the water uptake by mulching, which increased the photosynthetic rate promoting fruit growth (Kumar *et al.*, 2022). Moreover, increase in berry size (length and width) with growth regulator treatments may be due to greater supply of nutrients and photosynthates to the berries (Kumar and Tripathi 2009). Similar findings were made by Rana (2001), Kumar *et al.*, (2017) and Kumar *et al.*, (2022) in strawberry.

Influence of various mulches and growth regulators on quality attributes of strawberry

Analysis of variation (ANOVA) as shown in Table 3. highlighted that significant increase in TSS (%), juice

Table 3: Influence of various mulches and growth regulators on quality attributes of strawberry.

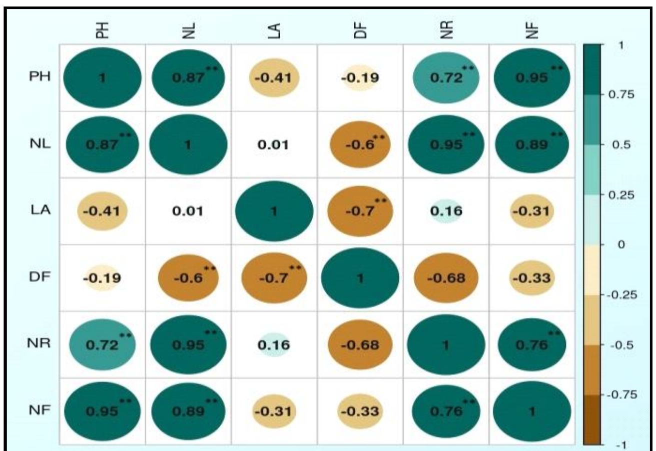
TR	TSS (%)	TA	Juice pH	TS	RS	NRS	AA	AC	TP
T_1	$8.06^{ab}\pm0.06$	$0.82^{e}\pm0.03$	$4.53^{bcd}\pm0.13$	$7.35^{a}\pm0.08$	$4.40^{ab}\pm0.08$	$2.74^{ab}\pm0.12$	$53.53^{a}\pm0.29$	$41.46^{d}\pm0.48$	$23.86^{b}\pm0.37$
T_2	$8.33^{a}\pm0.08$	$0.81^{e}\pm0.01$	$4.80^{abc}\pm0.12$	$7.47^{a}\pm0.02$	$4.46^{a}\pm0.04$	$2.79^{a}\pm0.02$	$53.80^{a}\pm0.43$	$41.26^{d}\pm0.24$	$23.93^{b}\pm0.13$
T_3	$6.86^{ef}\pm0.17$	$0.86^{cd}\pm0.01$	$3.86^{gh}\pm0.18$	$6.74^{d}\pm0.08$	$4.26^{bcd}\pm0.16$	$2.30^{cd}\pm0.12$	$49.66^{f}\pm0.29$	$39.13^{g}\pm0.27$	$21.80^{d}\pm0.31$
T_4	$7.73^{bc}\pm0.24$	$0.88^{c}\pm0.02$	$4.06^{fg}\pm0.06$	$6.73^{d}\pm0.15$	$4.21^{bcd}\pm0.04$	$2.33^{cd}\pm0.15$	$49.80^{f}\pm0.23$	$39.60^{g}\pm0.31$	$21.86^{d}\pm0.18$
T_5	$8.20^{ab}\pm0.11$	$0.83^{de}\pm0.01$	$4.86^{ab}\pm0.07$	$7.06^{bc}\pm0.02$	$4.27^{abcd}\pm0.02$	$2.73^{ab}\pm0.19$	$52.06^{c}\pm0.24$	$40.53^{ef}\pm0.18$	$22.80^{c}\pm0.41$
T_6	$7.93^{ab}\pm0.13$	$0.82^{e}\pm0.06$	$5.13^{a}\pm0.06$	$7.28^{ab}\pm0.06$	$4.31^{abc}\pm0.05$	$2.75^{ab}\pm0.03$	$53.40^{a}\pm0.31$	$40.40^{f}\pm0.42$	$22.20^{cd}\pm0.42$
T_7	$7.40^{cd}\pm0.12$	$0.88^{c}\pm0.03$	$4.33^{def}\pm0.06$	$7.07^{bc}\pm0.08$	$4.37^{abc}\pm0.02$	$2.50^{bc}\pm0.09$	$51.40^{cde}\pm0.31$	$44.53^{b}\pm0.18$	$25.06^{a}\pm0.27$
T_8	$7.20^{de}\pm0.23$	$0.88^{c}\pm0.01$	$4.46^{cde}\pm0.24$	$7.06^{bc}\pm0.09$	$4.36^{abc}\pm0.05$	$2.51^{bc}\pm0.13$	$51.73^{cd}\pm0.23$	$45.60^{a}\pm0.20$	$25.33^{a}\pm0.07$
T_9	$6.53^{fg}\pm0.24$	$0.91^{b}\pm0.02$	$4.13^{efg}\pm0.17$	$6.88^{cd}\pm0.15$	$4.19^{cd}\pm0.03$	$2.49^{bc}\pm0.15$	$51.73^{cd}\pm0.24$	$41.13^{de}\pm0.29$	$21.93^{d}\pm0.35$
T_{10}	$7.13^{de}\pm0.07$	$0.92^{ab}\pm0.07$	$3.93^{gh}\pm0.26$	$6.76^{d}\pm0.03$	$4.20^{bcd}\pm0.08$	$2.37^{cd}\pm0.09$	$51.13^{de}\pm0.18$	$40.42^{f}\pm0.31$	$22.00^{cd}\pm0.31$
T_{11}	$7.73^{bc}\pm0.07$	$0.88^{c}\pm0.02$	$4.46^{cde}\pm0.24$	$7.03^{c}\pm0.04$	$4.36^{abc}\pm0.05$	$2.48^{bc}\pm0.04$	$52.20^{ab}\pm0.17$	$43.20^{c}\pm0.20$	$24.86^{a}\pm0.18$
T_{12}	$7.26^{cde}\pm0.29$	$0.86^{cd}\pm0.01$	$4.66^{bcd}\pm0.10$	$6.88^{cd}\pm0.04$	$4.22^{bcd}\pm0.05$	$2.46^{bcd}\pm0.05$	$50.66^{e}\pm0.23$	$45.73^{a}\pm0.07$	$25.46^{a}\pm0.18$
T_{13}	$6.26^{g}\pm0.18$	$0.95^{a}\pm0.02$	$3.66^{h}\pm0.06$	$6.42^{e}\pm0.02$	$4.07^{d}\pm0.02$	$2.17^{d}\pm0.01$	$48.06^{g}\pm0.24$	$36.60^{h}\pm0.42$	$20.80^{e}\pm0.23$
Mean ± S. E	7.43±0.05	0.87 ± 0.03	4.37 ± 0.16	6.98 ±0.03	4.28 ±0.01	2.51 ±0.04	51.63 ±0.08	41.50 ±0.17	23.22 ±0.02
C.D ($p \le 0.05$)	0.38	0.03	0.27	0.22	0.32	0.21	1.19	1.29	0.85

TR: Treatments; TA: Titratable acidity (%); TS: Total sugars (%); RS: Reducing sugars (%); NRS: Non reducing sugars (%); AA: Ascorbic acid (mg/100g FW); AC: Anthocyanin content (mg/100g FW); TP: Total phenols (mg/100g FW)

pH, various sugars, ascorbic acid content, anthocyanin content and total phenols content was reported with application of various mulches and growth regulators. Maximum fruit juice TSS (8.33 %) was observed with the application of NAA 50 ppm + Black mulch (T_2). Minimum levels of titratable acidity (0.81 %) were also observed under the same treatment which was at par with treatment (T_1). While, minimum fruit juice TSS (6.26 %) and maximum titratable acidity (0.95 %) was observed in control (T_{13}). Maximum juice pH (5.13) was noted with the use of NAA 50 ppm + Silver-black mulch. This change in fruit TSS and acidity might be due to weed free environment, higher moisture conservation and maximum nutrient uptake under black polythene mulch treatment (Mathad and Jholgiker 2005). By raising the concentration of volatile chemicals and accelerating the hydrolysis of starchy compounds, the application of NAA to strawberry plants may have increased the level of TSS which ultimately increased juice pH and reduction in acidity of fruit (Krishnamoorthy 1981). These findings align with the research conducted on strawberries by Igbal *et al.*, (2009), Sujatha *et al.*, (2018), Palei *et al.*, (2016), Kaur and Mirza (2018), and Rathod *et al.*, (2020).

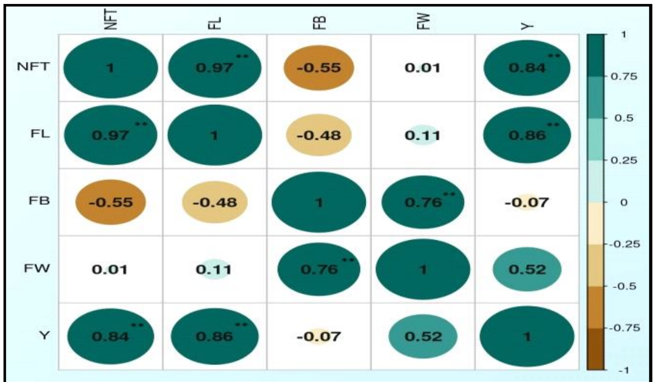
Moreover, highest total sugars (7.47 %), reducing sugars (4.46 %) and non-reducing sugars (2.79 %) were recorded in fruits of plants treated with NAA 50 ppm + Black mulch (T_2). Furthermore, highest levels of ascorbic acid content (53.80 mg/100g FW) were also noted under the treatment of NAA 50 ppm + Black mulch (T_2). The increased overall sugar content in strawberry fruits could potentially be attributed to increased enzymatic activity, including α-amylase and invertase, which are activated by NAA treatment (Singh *et al.*, 2017 and Singh *et al.*, 2025). Furthermore, the enzyme saccharose phosphate synthase has a role in controlling sugar buildup in many fruit species, including strawberries. Fruit from plants cultivated on black mulch is therefore more sweet and of higher quality as a result (Hubbard *et al.*, 1991). The present findings are in conformity with the findings of Palei *et al*., (2016), Mann *et al.*, (2017), Kaur and Mirza (2018) and Rathod *et al.*, (2020) in strawberry.

Whilst, lowest ascorbic acid content (48.06 mg/100g FW) was noted under control. This could be because mulching promoted healthy vegetative development and a higher rate of photosynthetic activity (Kumar *et al.*,



* Significant at $p \le 0.05$, ** Significant at $p \le 0.01$.
Note: *PH*- Plant height, *NL*- Number of leaves plant^{-1}, *LA*- Leaf area, *DF*- Days to first flowering, *NR*- Number of runners plant^{-1} and *NF*- Number of flowers plant^{-1}.

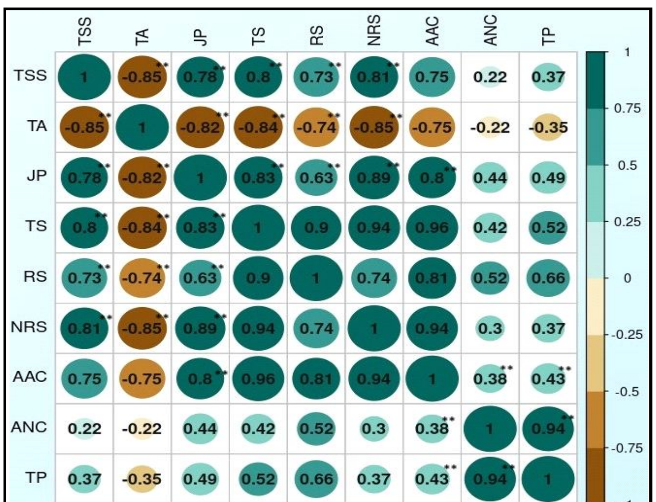
Fig. 1: Correlogram showing correlation coefficient between various agro-morphological attributes of strawberry.



***** Significant at $p \leq 0.05$, ****** Significant at $p \leq 0.01$.
Note: *NFT*- Number of fruits plant-1, *FL*-Fruit length, *FB*- Fruit breadth, *FW*- Fruit weight, and *Y*- Yield plant^{-1}.

Fig. 2: Correlogram showing correlation coefficient between various yield and yield related attributes of strawberry.

2022). Furthermore, the increased ascorbic acid content of strawberry fruits may be due to the rise in metabolites that activate the precursor of ascorbic acid content production in plants that received NAA (Singh *et al.*, 2017). The findings of Igbal *et al.*, (2009), Mann *et al.*, (2017), Kaur and Mirza (2018), Khunte *et al.*, (2019) and Rathod *et al.*, (2020) in strawberry also corroborate with present outcome. Whereas, maximum anthocyanin content (45.73 mg/100g FW) and total phenols content (25.46 mg/100g FW) was noted with the use of GA_3 75 ppm + Silver-black mulch (T_{12}). While, minimum anthocyanin content (36.60 mg/100g FW) and total phenols content (20.80 mg/100g FW) was observed under control (T_{13}). According to Pandey *et al.*, (2016), it could be the result of altered soil temperature regime and



***** Significant at $p \leq 0.05$, ****** Significant at $p \leq 0.01$.
Note: *TSS*- Total soluble solids, *TA*- Titratable acidity, *JP*- Juice pH, *TS*- Total sugars,*RS*- Reducing sugars, *NRS*- Non-reducing sugars,*AAC*- Ascorbic acid content, *ANC*- Anthocyanin content and*TP*- Total phenols.

Fig. 3: Correlogram showing correlation coefficient between various biochemical attributes of strawberry.

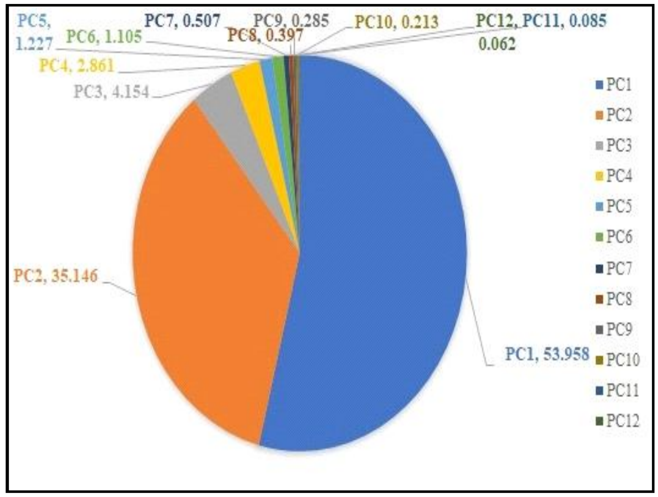


Fig. 4: Eigen analysis of the correlation matrix (PC, percentage contribution).

increased reflection light. Additionally, PGRs may have regulated the improved photosynthetic efficiency as well as the translocation of nutrients and other metabolites to the developing fruits, all of which had an impact on fruit quality (Pandey *et al.*, 2019 and Singh *et al.*, 2025). These findings of Wang and Millner (2009), Shiukhy *et al.*, (2015) and (Thakur *et al.*, 2017) in strawberry also corroborate with the present outcome.

Correlation coefficient for various attributes influenced by various treatments

Correlation coefficient between various agro-morphological attributes of strawberry

The data with regard to Pearson's correlation coefficient between various agro-morphological attributes is presented in the form of correlogram (Fig. 1.) depicts that a positively significant correlation of plant height was observed with number of leaves per plant (r= 0.87), number of flowers per plant (r= 0.95) and number of runners per plant (r= 0.72). Number of leaves per plant possessed high magnitude of positively significant

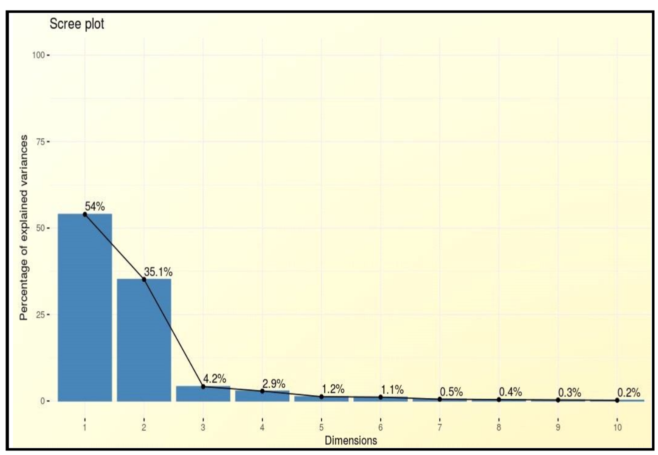


Fig. 5: Scree plot showing the variability described by various variable of strawberry.

correlation with number of flowers per plant (r= 0.89) and number of runners per plant (r= 0.95). While, low magnitude of negatively significant correlation of this trait was observed with days to flowering (r= -0.60). A significant negative correlation of leaf area was reported for days to flowering (r= -0.70). A positively significant correlation of number of flowers per plant was observed with number of runners (r= 0.76).

Correlation coefficient between various yield and yield related attributes of strawberry:

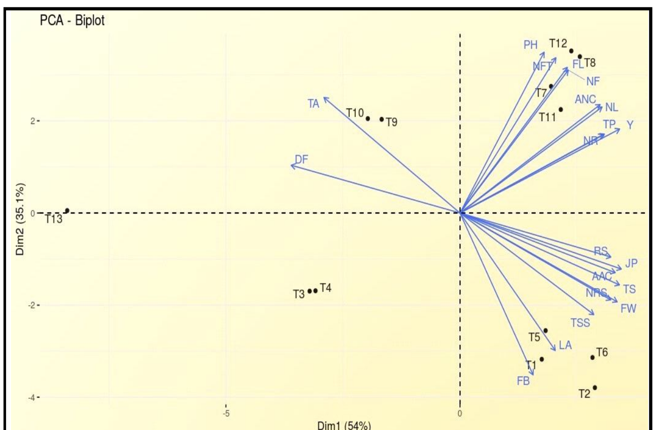
The data pertaining to Pearson's correlation coefficient between various yield and yield related attributes of strawberry in the form of correlogram is presented in Fig. 2. A significant positive correlation of number of fruits per plant was reported for fruit length (r= 0.97) and yield per plant (r= 0.84) showing its direct increase in yield of plant. Likewise, fruit breadth was observed in significant positive correlation for fruit weight (r= 0.76).

Correlation coefficient between various biochemical attributes of strawberry:

Correlogram representing Pearson's correlation coefficient between various biochemical attributes of strawberry (Fig. 3.) depicts that, total soluble solids (TSS) exhibited high degree of positive correlation with juice pH (r= 0.78), total sugars (r= 0.80), reducing sugars (r= 0.73) and non- reducing sugars (r= 0.81). Whereas, it showed negative significant correlation with titratable acidity (r= -0.85). In contrast to it titratable acidity showed low magnitude of negation correlation with juice pH (r= -0.82), total sugars (r= -0.84), reducing sugars (r= -0.74) and non-reducing sugars (r= -0.85). Moreover, juice pH was observed in strong positive correlation with total sugars (r= 0.83), reducing sugars (r= 0.63), non- reducing sugars (r= 0.89) and ascorbic acid content (r= 0.80). While, ascorbic acid content was found to be in positive correlation with anthocyanin content (r= 0.38) and total phenols (r= 0.43).

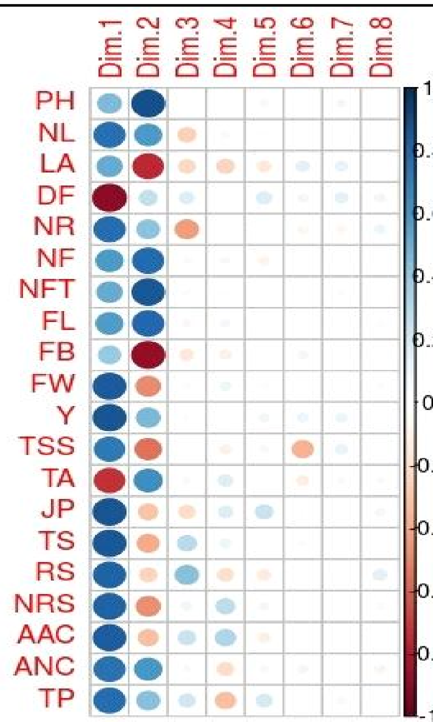
Principal component analysis for various attributes of strawberry as influenced by various treatments

In the present investigation, principal component analysis was performed for various agro-morphological, yield and biochemical attributes of strawberry as influenced by thirteen treatments. PCA could pick total of thirteen PCs (PC1 – PC13). Based on the eigen values, Kaiser's Method was applied to determine the ideal PC count. The PCs that contribute the most to explaining the variability in the treatments are those with eigenvalues ≥1. The first two of the thirteen PCs have more than one



Note: *PH*- Plant height, *NL*- Number of leaves plant^{-1}, *LA*- Leaf area, *DF*- Days to first flowering, *NR*- Number of runners plant^{-1}, *NF*- Number of flowers plant^{-1}, *NFT*- Number of fruits plant^{-}1, *FL*-Fruit length, *FB*- Fruit breadth, *FW*- Fruit weight, *Y*- Yield plant^{-1}, *TSS*- Total soluble solids, *TA*- Titratable acidity, *JP*- Juice pH, *TS*- Total sugars, *RS*- Reducing sugars, *NRS*- Non-reducing sugars, *AAC*- Ascorbic acid content, *ANC*- Anthocyanin content and *TP*- Total phenols.

Fig. 6: Biplot for the strawberry with various attributes and treatments (T1 – T13) along first two PCs or Dim (PC1 or Dim1, PC2 or Dim2).



Note: *PH*- Plant height, *NL*- Number of leaves plant^{-1}, *LA*- Leaf area, *DF*- Days to first flowering, *NR*- Number of runners plant^{-1}, *NF*- Number of flowers plant^{-1}, *NFT*- Number of fruits plant^{-}1, *FL*-Fruit length, *FB*- Fruit breadth, *FW*- Fruit weight, *Y*- Yield plant^{-1}, *TSS*- Total soluble solids, *TA*- Titratable acidity, *JP*- Juice pH, *TS*- Total sugars, *RS*- Reducing sugars, *NRS*- Non-reducing sugars, *AAC*- Ascorbic acid content, *ANC*- Anthocyanin content and *TP*- Total phenols.

Fig. 7: Heatmap of the attributes contributed to principal components.

eigen value (Fig. 4.) indicating towards the significant variations (89.10%) which can be explained by using these first two PCs only.

Graphical representation of the scree plot:

From PC1 to PC10 (Fig. 5.) shared 99.9% of total variability among thirteen treatments applied to strawberry. Out of which PC1 contributed 54% and PC2 exhibited 35.1% variability among them. So, it can be considered that these two PCs are evident to validate majority of variability among different treatments for various attributes.

Loading vectors for the principal components:

Loading matrix for the PC1 showed that it had positive values for PH (0.138), NL (0.233), LA (0.156), NR (0.235), NF (0.178), NFT (0.157), FL (0.176), FB (0.12), FW (0.258), Y (0.262), TSS (0.22), JP (0.265), TS (0.262), RS (0.248), NRS (0.247), AAC (0.255), ANC (0.23) and TP (0.237). However, it exhibited negative values with DF (-0.277) and TA (-0.223). As a result, it can be considered that first principal component is vital to achieve better results.

Biplot analysis:

The biplot analysis determined the correlation between various attributes and the associated treatments related to PC1 and PC2 speculating 89.1% variability in the obtained values. These PCs were used to visualise the two-dimensional cartesian plane as four coordinates in order to determine which primary characters in the observations were associated with certain treatments (Fig. 6.).

In coordinate-1 of biplot, T_8 and T_{12} stayed at away distance from the centre, while T_7 and T_{11} were closest to the centre. This coordinate-1, was found to be associated with the various attributes in clusters of PH, NFT, FL, NF, ANC, NL, TP, NR and Y traits. In coordinate-2, treatment T_9 was closest to the centre followed by T_{10}. Moreover, Treatment T_{13} was projected far away from the centre and closest to coordinate-3. These treatments exhibited relationship with only two attributes (TA and DF). However, both PC1 and PC2 were positive in coordinate-1 and 2. Furthermore, Coordinate-3 of biplot, clustered treatment T_3 and T_4 intact to each other but no attributes were found to be associated with them. Attributes like RS, JP, AAC, TS, NRS, FW, TSS, LA and FB were projected on coordinate-4 of biplot, treatment T_5 was closest to centre followed by T_1. Whereas, treatments T_6 and T_2, were far away from the centre.

Percentage contribution of attributes towards PC:

Among various PCs, attributes contributed majorly towards PC1 and PC2 (Fig. 7.). Agro-morphological attributes like PH, DF and NF contributed more to PC2, while traits like NL, LA and NR were associated PC1. Moreover, yield and yield related parameters like NFT and FL contributed PC2. However, other yield and yield related attributes like FB, FW and Y contributed PC1. Among biochemical attributes, all traits except TA contributed PC1. Consequently, it is advised to give these characteristics more weight while choosing treatments.

Conclusion

Protected cultivation of strawberry along with different mulches and growth regulators is successful in enhancing overall growth of plants, fruits, yield and fruit quality. GA_3 75 ppm + Silver-black polyethylene mulch was the stand out treatment followed by GA_3 75 ppm + Black polyethylene mulch from the investigation. PCA also reflected towards the close association of such treatments in improvement of strawberry farming under protected conditions.

Authors' contribution

Arshdeep Singh (Conduct of field/lab experiment, data collection, Data analysis and interpretation and Manuscript preparation), Maninderjit Singh (Conceptualization, designing of research work and Manuscript preparation).

Declaration: Authors declare that they do not have any conflict of interest.

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