



RESEARCH ARTICLE

Integrated effects of biostimulants and mulching on vegetative growth and biomass of strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn and Camarosa

Manjot Kaur* & Krishan Kumar Singh*

Department of Horticulture, Faculty of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda 151 302, Punjab, India

*Correspondence email - Manjotkaur2418@gmail.com; forekrishna@gmail.com

Received: 02 June 2026; Accepted: 27 July 2026; Available online: Version 1.0: 28 September 2026

Cite this article: Manjot K, Krishan KS. Integrated effects of biostimulants and mulching on vegetative growth and biomass of strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn and Camarosa. Plant Science Today. 2026;13(sp5):01–09. <https://doi.org/10.14719/pst.15805>

Abstract

Strawberry (*Fragaria × ananassa* Duch.) is a valuable fruit crop whose development is heavily controlled by cultivar selection and crop management strategies. The current study assessed the interactive impacts of biostimulants and mulching on the vegetative growth and biomass production of two cultivars of strawberry grown in the field. The experiment included a split-split-plot experiment involving two cultivars (V_1 -Winter Dawn and V_2 -Camarosa), two mulches (M_1 -paddy straw and M_2 -black polythene sheet) and seven biostimulants treatments (T_1 -humic acid 0.1 %, T_2 -humic acid 0.2 %, T_3 -salicylic acid 0.5 mM, T_4 -salicylic acid 1.0 mM, T_5 -salicylic acid 1.5 mM, T_6 -salicylic acid 2.0 mM and T_7 -control) and was carried out at the Fruit Research Farm, Guru Kashi University, Talwandi Sabo, Punjab from 2024–25 and 2025–26. The plant height, plant spread, leaf area, number of leaves and fresh and dry weights of shoots and roots were determined. Significant differences among cultivars, mulches, biostimulants and interactions thereof were noted for all the recorded traits. The V_1 significantly larger plant height (19.03 cm), number of leaves (29.50) and fresh shoot weight (54.05 g), fresh root weight (19.74 g), dry weights of shoots (15.63 g) and roots (3.55 g), while V_2 showed significantly larger plant spread (27.26 cm) and leaf area (62.10 cm²). In terms of mulch, M_2 was superior for V_1 , while V_2 was superior for M_2 . The T_2 alone was the best biostimulant for all the recorded parameters and its combination with M_2 mulch gave the best results regarding growth characteristics. Thus, it can be concluded that cultivar-specific mulch along with T_2 is an effective means of enhancing vegetative growth and biomass in strawberries grown in Punjab agro-climatic conditions.

Keywords: humic acid; paddy straw; polythene mulch; salicylic acid; strawberry

Introduction

Strawberry (*Fragaria × ananassa* Duch.) is one of the most commercially significant and extensively cultivated berry crops in the world due to its distinctive taste, appealing colour, nutritional value and substantial market demand (1). It is a high value, short-duration crop, which responds swiftly to improved agronomic methods and input management. Strawberry output in India and other subtropical and tropical countries has expanded considerably in recent years (2). Growers prefer cultivars such as Winter Dawn and Camarosa because of their adaptability, productivity and fruit quality. Strawberry production is of economic significance, but they are especially susceptible to environmental conditions, soil fertility and management practices that directly influence plant growth, productivity and fruit quality (3). Sustaining optimal plant development and fruit quality under fluctuating environmental and edaphic conditions is a primary challenge in strawberry farming. Strawberry roots are shallow and the plants are highly sensitive to the amount of moisture and nutrition in the soil and to conditions in the rhizosphere. In this regard, the use of biostimulants and mulching to enhance plant performance, soil health and sustainable production is increasingly gaining prominence in current horticulture methods. Humic acid and salicylic acid are a broad-

spectrum of biostimulants, which are recognised as promising agents due to their diverse roles in plant growth control and stress alleviation (4,1).

Humic acid is a naturally occurring organic biostimulant produced by the breakdown of plant and animal wastes. It boosts soil fertility by improving nutrient availability, root development and nutrient uptake, which promotes plant growth and biomass accumulation (5). Humic acid's chelating characteristics allow for better absorption of critical macro- and micronutrients, resulting in increased plant vigour and productivity. Humic acid has been shown in strawberry to improve vegetative growth, biomass output and fruit quality while also increasing plant tolerance to environmental challenges such as drought and salt through improved root formation and water consumption (6, 7). These qualities make humic acid a suitable biostimulant for long-term strawberry production.

Salicylic acid is one of the major phenolic plant growth regulators that serve as signaling molecules in the growth and stress response of plants. It helps regulate the physiology related to growth and improves the performance of the plant under both favourable and stress conditions. The use of exogenous salicylic acid has been known to improve the growth, chlorophyll content, yield and quality

of fruits of strawberries along with their tolerance to abiotic stresses. Due to its many positive effects, salicylic acid has attracted a lot of attention as an excellent biostimulant for strawberries (8,9).

The independent effects of humic acid and salicylic acid on plant growth and productivity are well known. However, combination of these substances provides synergistic strategy to enhance crop performance. The association of these biostimulants may improve absorption of nutrients, physiological efficiency and stress tolerance, leading in increased output and quality of fruits. However, the efficacy of these treatments may be dependent on environmental circumstances, crop type and farming techniques (10).

The application of mulching is another critical aspect in contemporary strawberry production. An essential role in optimising microclimate and crop performance is the use of mulch. Mulching is the application of organic or in-organic materials to the surface of soil to conserve moisture, moderate temperature, reduce weed development and improve soil fertility. Mulching is especially essential in strawberry production, since this crop is very sensitive to variation of soil moisture and to competition by weeds (11). The availability, biodegradability and probable enhancement in soil organic matter content of organic mulches such as paddy straw sometimes led to its usage in strawberry growing. Mulching with paddy straw enhances conservation of soil moisture reduction of evaporation losses as well as improves soil structure over time. It also promotes good microbial activity for nitrogen cycling and soil health. Organic mulches also help insulate against temperature extremes, therefore preserving plant roots and encouraging development (12).

In commercial strawberry cultivation, inorganic mulches such as polyethylene sheets are widely utilised. Plastic mulching is an excellent way to conserve soil moisture, reduce weeds and keep soil temperature optimal. It reduces fluctuation of soil moisture and avoids soil direct contact with fruits, therefore creating a suitable microenvironment for plant development and avoiding fruit rot, improving cleanliness and quality (13). Plastic mulches have proven effective in improving early output and fruit size and uniformity in strawberry. The type of mulching material used has a very essential role on plant development, productivity and fruit quality. Organic mulches are helpful for the long-term health of the soil. Plastic mulches are useful for moisture retention and weed control. Hence, there is a need to evaluate the comparative efficiency of various mulching materials for the advancement of strawberry farming practices (14).

Crop performance is ultimately very reliant on specific varieties and agronomic techniques. The strawberry varieties Winter Dawn and Camarosa vary in growing habit, potential output, fruit quality and adaptation to the environment. Camarosa has great yields, extremely big fruit size and firmness and is suited for long distance transport and for processing. Winter Dawn is adapted to subtropical environment. It has early bearing, ideal for off-season production (15,16).

Although the individual effects of humic acid, salicylic acid and mulching on strawberry growth have reported, limited information is available regarding their interactive effects on vegetative growth and biomass accumulation in contrasting strawberry cultivars under subtropical field conditions. Therefore, the present study was conducted to evaluate the influence of humic acid and salicylic acid treatment with various mulching materials i.e. paddy straw and polythene mulch on growth, yield and quality of

strawberry cultivars Winter Dawn and Camarosa. It was hypothesised that combining humic acid with suitable mulching practices would enhance vegetative growth and biomass more effectively than individual treatments. The present study aimed to evaluate the interactive effects of humic acid, salicylic acid, paddy straw mulch and black polythene mulch on the vegetative growth and biomass accumulation of strawberry cultivars Winter Dawn and Camarosa. The present research is intended to assist in the development of better strawberry growing methods for farmers especially in places with comparable agro-climatic conditions.

Materials and Methods

Site selection and climate conditions

The present study was conducted at the Fruit Research Farm, Department of Horticulture, Guru Kashi University, Talwandi Sabo, Punjab, during the October–March growing seasons of 2024–25 and 2025–26. The experimental site was located at Talwandi Sabo, Bathinda-District, Punjab, India, situated in the plains away from the Shivalik hills. It lay at 29.96° N latitude and 75.12° E longitude, with an altitude of 213 m above mean sea level. The Bathinda region received about 408 mm annual rainfall across approximately 20 rainy days with an erratic distribution. The average temperature reached 4 to 32 °C in October–March. The experimental soil was sandy loam having the pH of 7.63, EC 0.32 dSm⁻¹, organic carbon 0.47 %, available nitrogen 266 kg ha⁻¹, available phosphorus 15.2 kg ha⁻¹, available potassium 285 kg ha⁻¹ and water-holding capacity of 44.5 %.

Planting material

Strawberry cultivars Winter Dawn (V₁) and Camarosa (V₂) runners were procured from Subash Nursery, Maharashtra. Healthy, uniform and disease-free runner's plants, approximately 4–6 weeks old with 3–4 fully expanded leaves were selected for the experiment. The runners were planted at spacing 30×30cm on prepared 15–20 cm raised beds of width 80cm. The planting of crops was done during the last week of October and harvest was taken place from January to March every year. Standard practices were followed, including fertilisation, irrigation, plant protection and mulching with paddy straw (M₁) and black polythene sheet (M₂), to more accurately evaluate the impacts of different treatments. Strawberries were also planted with the initial recommended fertiliser dosage for increased productivity and quality (package of practices, PAU). Humic and salicylic acids were applied as foliar sprays at various concentrations using a hand-operated knapsack sprayer. Black polyethylene mulch (25 µm thickness) was applied on raised beds prior to transplanting and planting pits were created with desired distance. After transplanting, paddy straw mulch was spread around the plant to an average thickness of 5–7 cm (Table 1 and 2).

Observations recorded

In the experiment, two years data obtained, analysed and pooled. The following parameters were monitored: plant height, plant spread, leaf area, number of leaves, fresh weight (Shoot and root weight) and dry weight (Shoot and root weight). These parameters were estimated from five tagged plants. The plant height was recorded in centimetre from the soil level to the tip of the plant. The plant spread was measured the north–south (NS) and east–west (EW) directions at right angles to each other and average (5 tagged plants) were work out. The leaf area was measured using the Li-COR 3100 leaf area meter and represented in square centimetres

Table 1. Experimental treatments

Treatment Level	Details
Main treatment	Cultivars
	V ₁ -Winter Dawn
	V ₂ -Camarosa
Sub treatment	Mulching
	M ₁ -Paddy straw
	M ₂ -Black polythene sheet(25 micron)
Sub-sub treatment	Biostimulants
	T ₁ -Humic acid 0.1 %
	T ₂ -Humic acid 0.2 %
	T ₃ -Salicylic acid 0.5 mM
	T ₄ -Salicylic acid 1.0 mM
	T ₅ -Salicylic acid 1.5 mM
	T ₆ -Salicylic acid 2.0 mM
	T ₇ -Control

Table 2. Details of layout

Particulars	Details
Experimental design	Split-split-plot design
Main treatments	2
Sub treatments	2
Sub-sub treatments	7
Number of replications	3
Total number of plots	28 × 3 = 84 plots
Cultivar of strawberry	2 (Winter Dawn and Camarosa)

Number of leaves per plant was counted for each treatment. Fresh and dry weight (root and shoot weight) was measured from tagged plants for each treatment after completion of harvesting, plants were uprooted and cleaned properly. The cleaned roots and shoots were wiped with tissue paper and weighed with the use of a digital balance to get the fresh (root and shoot weight) weight. They were then dried in oven at 65–70 °C and the weight was recorded as dried (root and shoot weight) weight and it represented in grams (g).

Statistical analysis

Appropriate variance analysis was done on the outcomes of each experiment and data received from field surveys was pooled before being analysed using OPSTAT program (Statistical Software Package for Agricultural Researchers) Developed by Prof. O.P. Sheoran (CCS Haryana Agricultural University, Hisar, India) (17).The

crucial difference at the 5 % level of significance was determined to equalise the mean of the various treatments.

Results and Discussion

Plant height (cm)

The findings in the Table 3 (pooled data) and Fig. 1, indicated that the Plant height was significantly influenced ($p \leq 0.05$) by cultivar, mulching treatment, biostimulant application and their interactions during study years, 2024–25 and 2025–26. In main treatments, V₁cultivar showed maximum value with 19.03 cm and minimum value represented by V₂cultivar 17.77 cm. V₁ had the tallest plants when compared to V₂ cultivar, indicating that it is better adapted to the environmental conditions. The slight superiority in the growth of V₁ to V₂ might be explained by certain differences between the two cultivars in vegetative vigour and efficiency in the use of resources (15). In sub treatments, M₂ mulch (18.78) increased the plant height as compared to M₁ (18.01 cm). The M₂ mulch was associated with taller plants than M₁ mulch. The M₂ most probably provided favourable soil moisture and temperature conditions for the growth of the plants (13, 14). In case of, Biostimulants treatments, humic acid 0.2 % (T₂) had the highest value with 22.79 cm followed by humic acid 0.1 % (T₁) (21.05 cm), salicylic acid 2.0 mM (T₆) (20.37 cm). Amongst salicylic acid treatments, T₆ was superior to other concentrations demonstrating favourable response at higher dosages. In all development phases, the least plant height was seen in the control (T₇). Increased growth can be linked to better roots and nutrients absorption due to humic acid treatments which probably provided favourable conditions for proper growth. These findings corroborate previous reports highlighting the synergistic benefits of humic acid and black polythene mulch in promoting strawberry growth (18, 19, 20).

Plant spread (cm)

There were significant differences in the plant spread (Table 3 and Fig. 1) due to cultivar, mulches, biostimulants and interactions among them ($p < 0.05$) in pooled data of both years study. In main treatments, V₂(27.26 cm) showed significantly higher plant spread than V₁(25.38 cm). This indicated that V₂ had better canopy development and vegetative vigour. With respect to the different

Table 3. Effect of cultivars, mulching and biostimulants on vegetative growth and biomass parameters

Treatment	Plant height (cm)	Plant spread (cm)	Leaf area (cm ²)	No. of leaves (No.)	Fresh weight (shoot weight)	Fresh weight (root weight)	Dry weight (shoot weight)	Dry weight (root weight)
Varieties								
V ₁	19.03 ^a	25.38 ^b	58.53 ^b	29.50 ^a	54.05 ^a	19.74 ^a	15.63 ^a	3.55 ^a
V ₂	17.77 ^b	27.26 ^a	62.10 ^a	27.08 ^b	51.47 ^b	17.86 ^b	13.79 ^b	2.83 ^b
SE(d)	0.0332	0.1032	0.0315	0.0559	0.0367	0.0379	0.0133	0.0186
CD (5 %)	0.1428	0.4439	0.1355	0.2404	0.1578	0.1629	0.057	0.0798
Mulching								
M ₁	18.01 ^b	26.93 ^a	61.63 ^a	27.37 ^b	51.67 ^b	18.17 ^b	14.02 ^b	2.94 ^b
M ₂	18.78 ^a	25.71 ^b	58.99 ^b	29.22 ^a	53.84 ^a	19.43 ^a	15.41 ^a	3.44 ^a
SE(d)	0.0119	0.0779	0.0593	0.0471	0.0338	0.0375	0.0299	0.0116
CD (5 %)	0.0331	0.2164	0.1647	0.1308	0.094	0.1042	0.0831	0.0322
Treatment								
T ₁	21.05 ^b	28.04 ^b	63.63 ^b	31.17 ^b	53.94 ^e	17.20 ^e	14.53 ^e	2.95 ^e
T ₂	22.79 ^a	29.15 ^a	64.52 ^a	32.56 ^a	58.94 ^a	23.74 ^a	18.26 ^a	4.03 ^a
T ₃	16.43 ^f	24.74 ^e	56.97 ^f	26.23 ^f	53.06 ^f	16.76 ^f	13.28 ^f	2.73 ^f
T ₄	17.58 ^e	25.86 ^d	59.53 ^e	27.36 ^e	55.16 ^d	18.77 ^d	15.15 ^d	3.19 ^d
T ₅	18.98 ^d	27.10 ^c	60.83 ^d	29.22 ^d	56.89 ^c	19.98 ^c	16.32 ^c	3.49 ^c
T ₆	20.37 ^c	28.94 ^a	61.83 ^c	30.12 ^c	57.85 ^b	21.19 ^b	17.06 ^b	3.80 ^b
T ₇	11.57 ^g	20.41 ^f	54.88 ^g	21.38 ^g	33.47 ^g	13.97 ^g	8.41 ^g	2.13 ^g
SE(d)	0.1518	0.1262	0.1585	0.0918	0.0873	0.054	0.0526	0.0419
CD (5 %)	0.3051	0.3386	0.3186	0.1845	0.1756	0.1085	0.1058	0.0843

V₁: Winter dawn variety; V₂: Camarosa variety; M₁: paddy straw mulching; M₂: black polythene sheet mulching; T₁: humic acid 0.1%; T₂: humic acid 0.2%; T₃: salicylic acid 0.5 mM; T₄: salicylic acid 1.0 mM; T₅: salicylic acid 1.5 mM; T₆: salicylic acid 2.0 mM; T₇: control.

mulches, the M_1 mulched (26.93 cm) plants had significantly wider plant spread than M_2 mulch (25.71 cm). This might have been due to moisture conservation and provision of a conducive microenvironment for continuous vegetative growth, which has been observed earlier (21, 22). As far as the different biostimulants are concerned, the highest plant spread was observed in foliar spraying of T_2 with values (29.15 cm), followed by T_6 with values (28.94 cm), while the T_7 gave the lowest values with 20.41 cm. The higher response of humic acid might have been because of the increased root proliferation, nutrient absorption and metabolic activities resulting in greater lateral spread of canopies. This is supported by the findings of (9, 23).

Leaf area (cm²)

The leaf area was significantly influenced by cultivar, mulching, biostimulants and their interactions in two years of the experiment ($p < 0.05$) (Table 3 and Fig. 1). In terms of cultivars, V_2 (62.10 cm²) showed significantly high leaf area as compared to V_1 with 58.53 cm², thus, depicting better vegetative vigour and canopy development. In the mulching treatments, the M_1 mulch (61.63 cm²) caused the highest leaf area as compared to M_2 (58.99 cm²), implying that due to moisture conservation and moderation in soil temperature, favourable conditions were created for continuous leaf area expansion, in agreement with the observations (21, 24). Foliar spray of T_2 caused the maximum leaf area with 64.52 cm², while the T_1 caused second-highest leaf area with 63.63 cm², whereas the lowest leaf areas were recorded under T_7 (54.88 cm²) condition. This could be due to better biostimulant effect of humic acid, enhancing nutrient uptake, root development and cell division, resulting in leaf initiation and expansion (25, 26). The above results are also in conformity with the observations of previous findings (9).

Number of leaves

Number of leaves was highly influenced by cultivar, mulch, biostimulant treatments and their interaction during the experiment period ($p < 0.05$) (Table 3 and Fig. 1). Regarding the cultivar effect, the highest number of leaves was recorded with V_1 cultivar (29.50) while V_2 showed (27.08), which indicates superior vegetative vigour and higher leaves production capacity compared to V_2 . For the mulch treatment, M_2 (29.22) showed the highest number of leaves and least

represented by M_1 (27.37), which can be associated with better soil moisture conservation and a favourable growth environment for continuous vegetative development, as reported by previous researchers (22, 27). Regarding the biostimulant treatments, foliar spray of T_2 (32.56) recorded the highest number of leaves, followed by T_1 (31.17) and T_7 (21.38) had the lowest. Higher number of leaves in humic acid could be due to the capability of the substance to improve nutrient uptake, root growth and cellular metabolism and, thus, the formation and development of leaves (25, 28). The results also conform to previous reports showing humic acid as an effective biostimulant for vegetative development and canopy formation in strawberry (9, 26).

Fresh weight (Shoot weight/g)

Table 3 (pooled data) and Fig. 1, indicate that the shoot fresh weight of strawberry plants was significantly influenced by various plant biostimulants, mulching treatments and cultivars ($p < 0.05$) throughout both the years of study (2024–25 and 2025–26). Among the main treatments, V_1 recorded a significantly higher shoot fresh weight (54.05 g) than V_2 (51.47 g). Strawberry cultivars may differ in terms of genetic vigour, canopy growth and assimilate production capability. In mulching treatments, M_2 mulch always had the highest shoot fresh weight above M_1 mulch in both years study. The mean mulch values of 53.84 g were obtained by M_2 mulch and lowest showed by M_1 mulch with 51.67 g. Higher fresh shoot weight was seen with M_2 mulch, which might be related to enhance nutrient availability and reduced weed competition, allowing for more resources to be allocated shooting growth. Furthermore, biostimulants, maximum shoot fresh weight was reported with T_2 with administration in both years among the various biostimulants. The T_2 had a mean fresh shoot weight of 58.94 g. The T_6 was closely followed with 57.85 g in the corresponding years. The lowest fresh shoot weight was recorded under T_7 treatment with mean values of 33.47 g, respectively. The effect of humic acid could have something to do with better utilisation of nutrients, physiological activity improvement and vegetative mass accumulation. Humic substances have biostimulating impact on plants due to their ability to stimulate nutrient uptake and growth processes regulation, leading to biomass formation. The same positive impacts of cultivar selection, humic acid, black polythene, on the growth and biomass

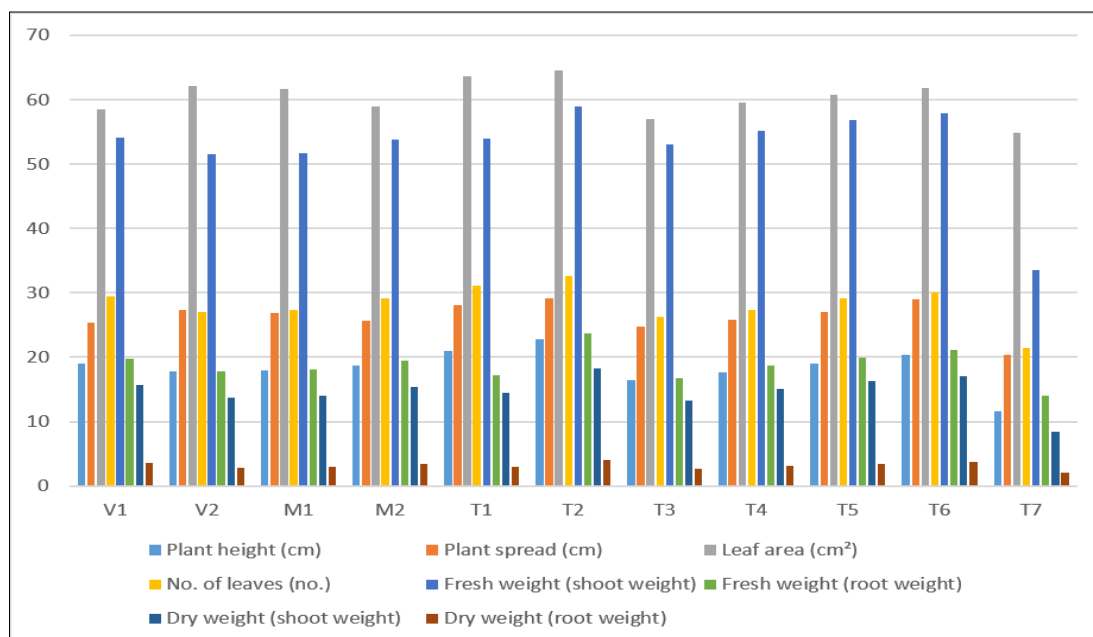


Fig. 1. Effect of cultivars, mulching and biostimulants on vegetative growth and biomass parameters of strawberry plants.

formation of strawberries have been described by previous researchers (23, 25, 26).

Fresh weight (Root weight/g)

There were also significant differences in fresh root weight due to cultivars, mulching, biostimulants and interactions among them ($p < 0.05$) (Table 3 and Fig. 1). The V_1 (19.74 g) had greater fresh root weight than V_2 (17.86 g), implying better root development and greater capacity for underground growth. Greater root biomass in V_1 might be attributed to specific features of cultivar root system and resource acquisition capability. As for mulches, the greatest fresh root weight was observed under M_2 mulch (19.43 g) and lowest in M_1 (18.17g), which can be explained by lower weed competition and better accessibility of soil nutrients, contributing to better root formation. In biostimulant treatments, T_2 (23.74 g) produced the greatest fresh root weight, followed by T_6 (21.19 g), while T_7 (13.97 g) treatment gave the lowest results. The positive impact of humic acid on root biomass might be related to stimulating root initiation, branching and elongation, increasing the ability of plants to explore soil and increase nutrient uptake. Humic substances are known to enhance root system development via auxin-like action and increased nutrient mobilisation (26, 28). Similar positive effects of humic acid treatment on growth of strawberries have been reported by previous researchers (9).

Dry weight (Shoot weight/g)

Dry shoot weight was significantly affected by cultivar, mulch, biostimulant application and their interactions ($p < 0.05$) (Table 3 and Fig. 1). Among the cultivars, V_1 (15.63 g) accumulated drier shoot biomass than V_2 (13.79 g), indicating that it has higher efficiency in dry matter production and biomass partitioning to aerial organs. The better performance of V_1 could be related to genetic potential of canopy formation and use of available resources. The use of M_2 mulch (15.41 g) improved the dry shoot weight against M_1 (14.02 g) mulching practices possibly by reducing fluctuations in the environment and improving resource availability during the growth period of the crop. In biostimulants, maximum dry shoot weight was recorded by T_2 (18.26 g) among biostimulants, followed by T_6 (17.06 g) while minimum biomass was recorded by T_7 (8.41 g) plants. The increased accumulation of dry shoots under humic acid application could be due to better assimilation of nutrients and increased formation of structural carbohydrates and hence a higher deposition of dry matter. The role of humic substances in improving the plant biomass accumulation and nutrient-use efficiency has been widely reported (26, 29).

Dry weight (Root weight/g)

The results reported in Table 3 and Fig. 1, revealed that there was a substantial difference in the root dry weight of strawberry plants owing to various cultivars, mulching, plant biostimulants treatments ($p < 0.05$) over the two years of study. In Cultivars, V_1 cultivar (3.55 g) recorded greatest mean root dry weight than V_2 (2.83 g). This indicates greater root system growth and effective biomass allocation to below-ground organs. In mulching treatments, M_2 mulch showed increased root dry weight as compared to M_1 mulch in pooled data of both years. With M_2 mulch, mean values of 3.44 g and M_1 recorded lowest value with 2.94 g respectively. Paddy straw mulch had somewhat lower values in both the years. The increased dry root weight under black polythene mulch might be attributed to better root-zone stability, reduced weed competition and increased availability of vital nutrients, all of which encouraged ongoing root

development. Furthermore, in biostimulants, T_2 (4.03 g) produced highest dry root weight, followed by T_6 (3.80 g) and lowest showed by T_7 (2.13 g). The increased dry root biomass under humic acid conditions might be related to increased root branching and structural dry matter deposition in root tissues. Humic substances promote root growth by altering cellular processes and increasing nutrient accessibility, resulting in greater root development (25, 28). These findings back with prior research showing that humic acid administration promotes plant biomass and root growth in strawberry (9).

Interaction of varieties, mulching and growth regulator on strawberry plants

The Table 4 and Fig. 2, 3 and 4 shows interaction impact of cultivars, mulching and various biostimulants treatments on vegetative growth parameters of strawberry plants. Two strawberry cultivars V_1 and V_2 variety were taken under two mulching treatments M_1 mulch and M_2 mulch. The treatments were different concentrations of humic acid and salicylic acid i.e., T_1 , T_2 -humic acid 0.2 %, salicylic acid 0.5 mM (T_3), salicylic acid 1.0 mM (T_4), salicylic acid 1.5 mM (T_5) and T_6 and T_7 .

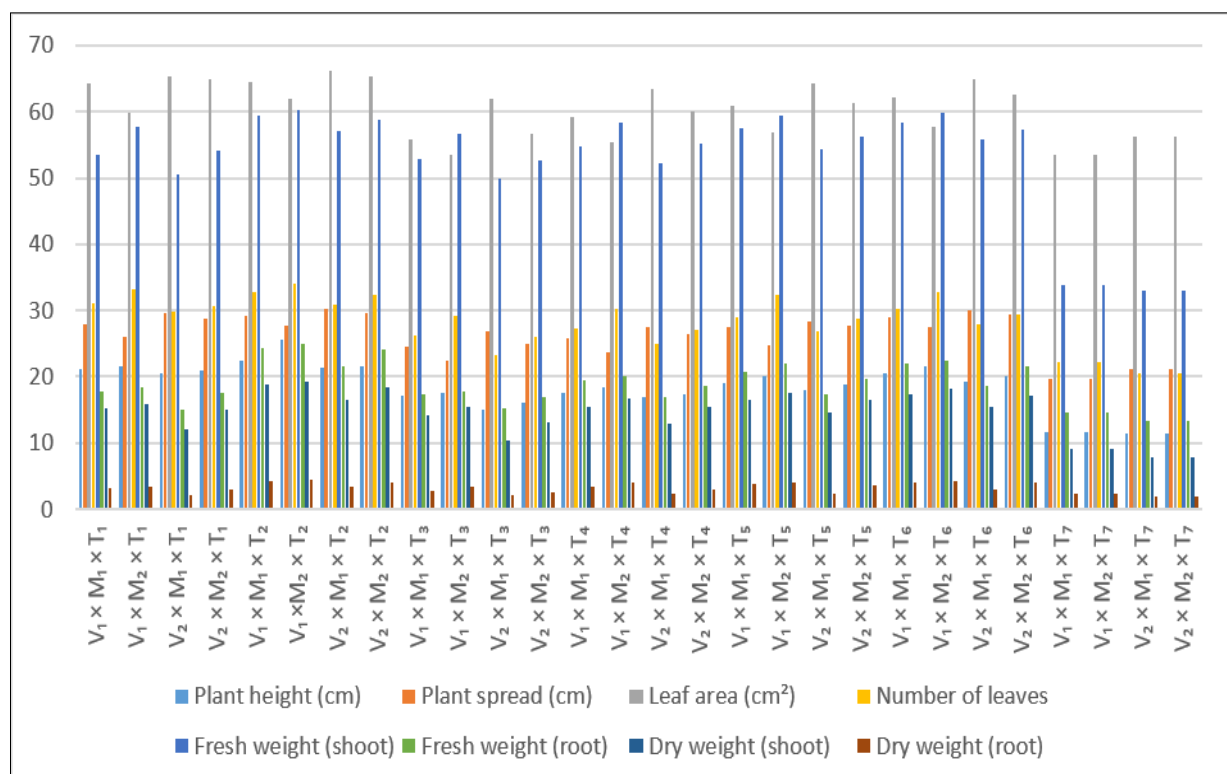
The greatest plant height (25.70 cm) was seen in $V_1 \times M_2 \times T_2$ with V_1 variety under M_2 mulch with T_2 over all the treatment combinations. This treatment was much better than all other combinations suggesting that the greater concentration of humic acid together with M_2 mulch dramatically improved vegetative growth. The minimal plant height (11.40 cm) was recorded in $V_2 \times M_1 \times T_7$ and $V_2 \times M_2 \times T_7$ (control treatments), suggesting inadequate development in absence of growth boosting chemicals. Maximum plant spread (30.15 cm) was observed in $V_2 \times M_1 \times T_2$ showing favourable response of V_2 variety to M_1 mulching with T_2 . The lowest plant spread (19.67 cm) was found in the control treatment of V_1 , at both the levels of mulching ($V_1 \times M_1 \times T_7$ and $V_1 \times M_2 \times T_7$) greater spread was seen with humic acid treatment which may be attributed to greater root growth and nutrient intake. Leaf area also differed considerably across treatments. The maximum leaf area (66.28 cm²) was seen in $V_2 \times M_1 \times T_2$ followed by $V_2 \times M_2 \times T_2$ and $V_2 \times M_1 \times T_1$. This suggests that the V_2 cultivar had wider leaves in the application of humic acid. The lowest leaf area (53.43 cm²) was seen in control treatment combinations. The increase in leaf area with the humic acid treatments may be ascribed to increased chlorophyll production and cell elongation. Maximum number of leaves per plant (34.08) was recorded in $V_1 \times M_2 \times T_2$ which again revealed the advantage of T_2 under M_2 mulching for V_1 variety. The lowest number of leaves (20.58) was found in control treatments of V_2 . The increase in leaf output in treated plants may be related to better physiological activity and nutrient availability. Maximum fresh shoot weight (60.28 g) was recorded in $V_1 \times M_2 \times T_2$, followed by $V_1 \times M_1 \times T_2$ and $V_1 \times M_2 \times T_6$. Similarly, the fresh root weight was similarly maximum (24.97 g) under $V_1 \times M_2 \times T_2$. The findings showed that 0.2 % humic acid considerably improved the buildup of biomass, particularly when paired with M_2 mulch. The untreated control plants had the lowest fresh shoot and root weights, indicating low plant vigour.

The buildup of dry materials showed a similar tendency. The maximum dry shoot weight (19.27 g) and dry root weight (4.40 g) was reported in $V_1 \times M_2 \times T_2$. The increase in dry matter production implies effective photosynthetic activity, nitrogen uptake and general plant growth and health under humic acid administration. Minimum dry shoot and root weights were recorded in the control

Table 4. Interaction of cultivars, mulches and biostimulants on vegetative growth and biomass parameters of strawberry plants

Varieties × Mulching × Treatment	Plant height (cm)	Plant spread (cm)	Leaf area (cm ²)	Number of leaves (No.)	Fresh weight (shoot weight)	Fresh weight (root weight)	Dry weight (shoot weight)	Dry weight (root weight)
V ₁ × M ₁ × T ₁	21.25 ^{cd}	27.85 ^g	64.33 ^c	31.07 ^d	53.40 ^m	17.80 ^m	15.15 ^k	3.25 ^{hi}
V ₁ × M ₂ × T ₁	21.60 ^c	26.05 ^j	59.90 ^h	33.15 ^b	57.67 ^e	18.33 ^l	15.85 ⁱ	3.42 ^{gh}
V ₂ × M ₁ × T ₁	20.45 ^{ef}	29.60 ^{bc}	65.38 ^b	29.72 ^f	50.62 ^p	15.10 ^q	12.15 ^o	2.17 ^{no}
V ₂ × M ₂ × T ₁	20.90 ^{de}	28.67 ^{ef}	64.88 ^{bc}	30.73 ^d	54.07 ^l	17.58 ^{mn}	14.97 ^k	2.97 ^{jk}
V ₁ × M ₁ × T ₂	22.45 ^b	29.15 ^{cde}	64.52 ^c	32.85 ^b	59.52 ^b	24.33 ^b	18.83 ^b	4.18 ^{bc}
V ₁ × M ₂ × T ₂	25.70 ^a	27.73 ^g	61.98 ^e	34.08 ^a	60.28 ^a	24.97 ^a	19.27 ^a	4.40 ^a
V ₂ × M ₁ × T ₂	21.35 ^{cd}	30.15 ^a	66.28 ^a	30.90 ^d	57.17 ^f	21.55 ^f	16.43 ^h	3.50 ^{fg}
V ₂ × M ₂ × T ₂	21.67 ^c	29.55 ^{bc}	65.30 ^b	32.42 ^c	58.78 ^c	24.10 ^c	18.50 ^c	4.03 ^{cd}
V ₁ × M ₁ × T ₃	17.15 ^{kl}	24.50 ^l	55.80 ^{lm}	26.27 ^m	52.77 ⁿ	17.25 ^o	14.12 ^m	2.87 ^k
V ₁ × M ₂ × T ₃	17.52 ^{kl}	22.52 ⁿ	53.55 ⁿ	29.27 ^{gh}	56.77 ^g	17.75 ^m	15.53 ^j	3.33 ^{gh}
V ₂ × M ₁ × T ₃	15.07 ⁿ	26.90 ^{hi}	61.92 ^{ef}	23.33 ^o	49.95 ^q	15.22 ^q	10.30 ^p	2.07 ^{op}
V ₂ × M ₂ × T ₃	16.00 ^m	25.05 ^k	56.62 ^k	26.05 ^m	52.75 ⁿ	16.83 ^p	13.15 ⁿ	2.65 ⁱ
V ₁ × M ₁ × T ₄	17.62 ^{jk}	25.90 ^j	59.13 ⁱ	27.28 ^k	54.80 ^k	19.40 ^j	15.40 ^j	3.35 ^{gh}
V ₁ × M ₂ × T ₄	18.40 ^{hi}	23.70 ^m	55.50 ^m	30.28 ^e	58.32 ^d	20.13 ^h	16.80 ^g	4.03 ^{bcd}
V ₂ × M ₁ × T ₄	16.92 ^l	27.43 ^{gh}	63.37 ^d	24.90 ⁿ	52.27 ^o	16.98 ^p	13.02 ⁿ	2.32 ^{mn}
V ₂ × M ₂ × T ₄	17.40 ^{kl}	26.40 ^{ij}	60.10 ^h	26.98 ^{kl}	55.27 ^j	18.57 ^k	15.40 ^j	3.08 ^{ij}
V ₁ × M ₁ × T ₅	19.15 ^g	27.43 ^{gh}	60.98 ^g	29.02 ^{hi}	57.60 ^e	20.68 ^g	16.58 ^h	3.73 ^e
V ₁ × M ₂ × T ₅	20.00 ^f	24.80 ^{kl}	56.80 ^k	32.27 ^c	59.45 ^b	22.08 ^e	17.55 ^e	4.13 ^{bcd}
V ₂ × M ₁ × T ₅	17.95 ^{ij}	28.40 ^f	64.25 ^c	26.85 ^l	54.27 ^l	17.45 ^{no}	14.67 ^l	2.45 ^m
V ₂ × M ₂ × T ₅	18.82 ^{gh}	27.77 ^g	61.28 ^{fg}	28.73 ⁱ	56.23 ^h	19.72 ⁱ	16.48 ^h	3.63 ^{ef}
V ₁ × M ₁ × T ₆	20.45 ^{ef}	28.95 ^{de}	62.20 ^e	30.27 ^e	58.30 ^d	22.03 ^e	17.45 ^e	4.02 ^{cd}
V ₁ × M ₂ × T ₆	21.60 ^c	27.40 ^{gh}	57.80 ^j	32.85 ^b	59.93 ^a	22.52 ^d	18.27 ^d	4.22 ^b
V ₂ × M ₁ × T ₆	19.23 ^g	29.97 ^{ab}	64.83 ^{bc}	27.88 ^j	55.83 ⁱ	18.68 ^k	15.42 ^j	3.02 ^{jk}
V ₂ × M ₂ × T ₆	20.20 ^f	29.48 ^{bcd}	62.50 ^e	29.48 ^{fg}	57.35 ^{ef}	21.53 ^f	17.1 ^f	3.97 ^d
V ₁ × M ₁ × T ₇	11.73 ^o	19.67 ^p	53.43 ⁿ	22.18 ^p	33.93 ^r	14.55 ^r	9.03 ^q	2.35 ^m
V ₁ × M ₂ × T ₇	11.73 ^o	19.67 ^p	53.43 ⁿ	22.18 ^p	33.93 ^r	14.55 ^r	9.03 ^q	2.35 ^m
V ₂ × M ₁ × T ₇	11.40 ^o	21.15 ^o	56.33 ^{kl}	20.58 ^q	33.00 ^s	13.38 ^s	7.78 ^r	1.92 ^p
V ₂ × M ₂ × T ₇	11.40 ^o	21.15 ^o	56.33 ^{kl}	20.58 ^q	33.00 ^s	13.38 ^s	7.78 ^r	1.92 ^p
Varieties × Mulching × Treatments (CD(5 %))	0.6103	0.5076	0.6372	0.3691	0.3512	0.217	0.2116	0.1685

V₁: Winter Dawn variety; V₂: Camarosa variety; M₁: paddy straw mulching; M₂: black polythene sheet mulching; T₁: humic acid 0.1%; T₂: humic acid 0.2%; T₃: salicylic acid 0.5 mM; T₄: salicylic acid 1.0 mM; T₅: salicylic acid 1.5 mM; T₆: salicylic acid 2.0 mM; T₇: control.

**Fig. 2.** Interaction of cultivars, mulching and biostimulants on vegetative growth and biomass of strawberry plants.

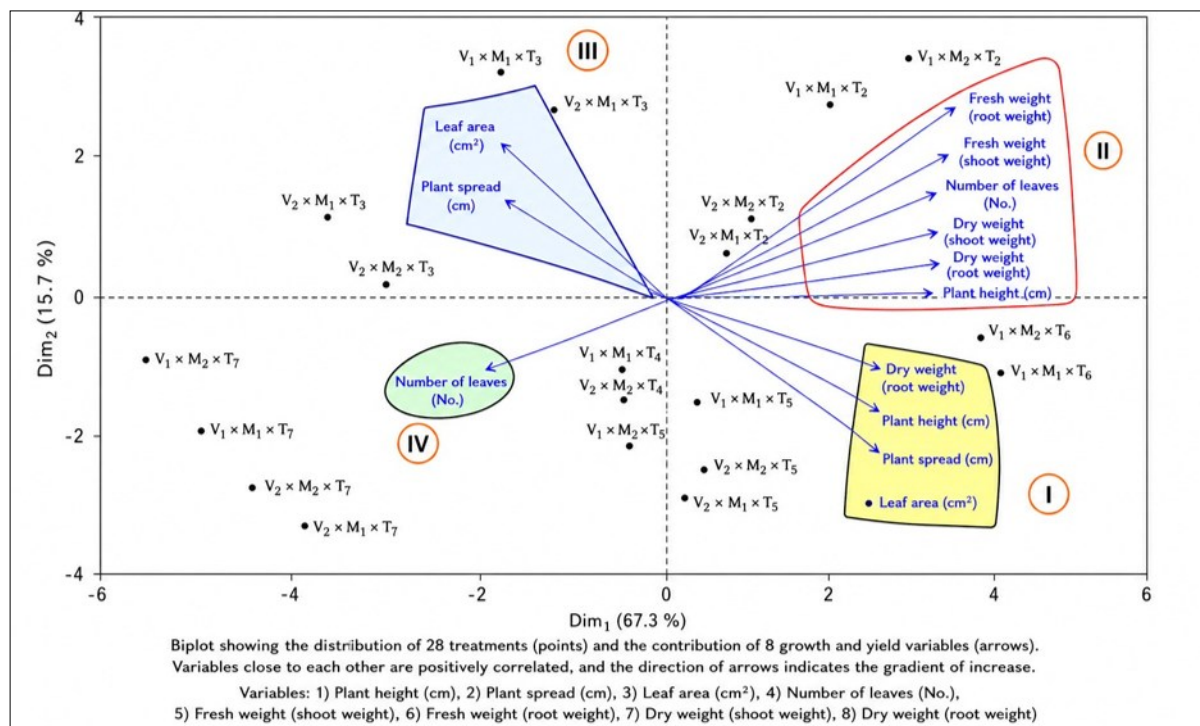


Fig. 3. Principal component analysis (PCA) of vegetative growth and biomass of strawberry plants.

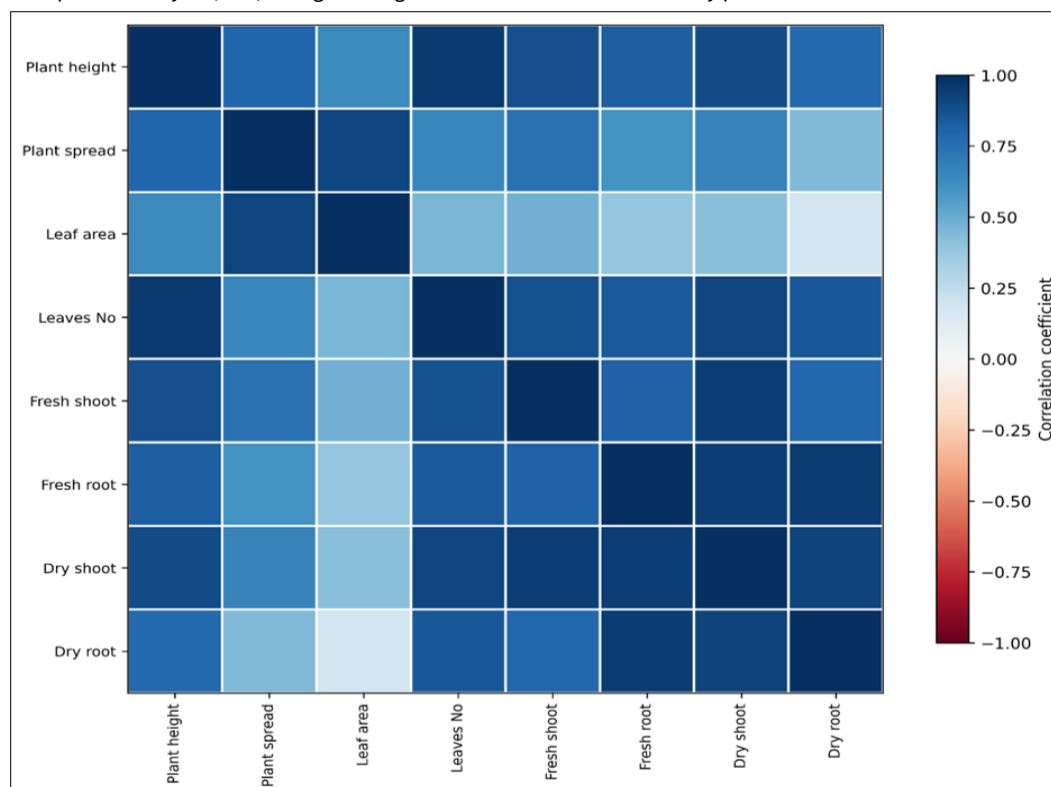


Fig. 4. Correlation heat map of vegetative growth and Biomass of strawberry plants.

treatments indicating the positive function of growth regulators and mulch. Overall, the findings clearly indicated that the T_2 concentration was the most effective treatment for increasing vegetative development properties of strawberry plants. In average, M_2 mulch performed better than M_1 mulch probably owing to greater moisture retention, weed control and soil temperature regulation. Between the cultivars, V_1 was better in most of the growth indices especially when paired with M_2 mulch and T_2 .

The crucial difference (CD) values at 5 % level revealed that the differences across treatment combinations were statistically significant for all the parameters assessed. It can be concluded that

the interaction of variety, mulching and growth regulator treatments had a strong effect on strawberry vegetative development. The combination $V_1 \times M_2 \times T_2$ emerged as optimal treatment combination for obtaining.

Conclusion

The present research clearly showed that the combined impact of biostimulants and mulching techniques are highly significant for enhancement of growth and biomass features of strawberry in field situations. Among all the treatments, humic acid 0.2 % (T_2) was the most effective treatment for boosting all vegetative growth parameters. This shows the great impact of humic acid in improving

soil properties, nutrient availability and plant health, resulting in improved plant performance. Black polythene (M_2) mulch was more effective in enhancing across most growth parameters than paddy straw mulch (M_1). This demonstrates its beneficial influence in improving the soil structure and microbial activity over time. Therefore, each kind of mulching material has its merits based on individual production goals and environmental circumstances. Winter Dawn (V_1) was better than Camarosa (V_2) for most of the growth and biomass traits of the cultivars. This suggests that V_1 is better adapted to the current agro-climatic conditions of the experiment location, with enhanced vegetative vigour and resource use efficiency. However, V_2 showed acceptable results notably in plant spread and leaf area in various treatments indicating its probable suitability under enhanced management techniques. The study indicated that coupled application of T_2 and optimised mulching techniques, particularly M_2 mulch, greatly improved the strawberry plant growth and biomass yield. The combined effect of biostimulants and mulching not only improves plant performance but also boosts more efficient resource use and sustainable crop output. Further studies should evaluate the long-term effects of these treatments on fruit yield, quality, soil health and economic returns under different agro-climatic conditions.

Acknowledgements

The authors sincerely thank the Vice-Chancellor, Guru Kashi University, Talwandi Sabo, Punjab, India for providing necessary facilities to carry out this research work

Authors' contributions

MK designed the study, conducted the experiment, analysed the data and wrote the manuscript. KKS provided substantial guidance, necessary laboratory facilities, experimental support and contributed to the preparation of the manuscript. Both authors reviewed and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Azizah F, Kumar A, Nazmul KM, Chy MAH, Chy MH. From field to market: advances, varieties of strawberry and its prospects in Bangladesh. *GRS J Multidiscip Res Stud*. 2025;2(12):3–10.
2. Zia UH, Hassan I, Khan MA, Jilani G. Effect of salicylic acid application on growth, production, fungal decay and overall quality of strawberry. *Plant Prot*. 2024;8(4):729–39. <https://doi.org/10.33804/pp.008.04.5460>
3. Bhobhria V, Selvan SS, Patel KK, Kantwa RC, Kumar R, Raj P, et al. From fields to markets: the rise of strawberry farming in Abohar, Punjab, India. *Asian Res J Agric*. 2025;18(2):30–9. <https://doi.org/10.9734/arja/2025/v18i2677>
4. Garza-Alonso CA, Olivares-Sáenz E, González-Morales S, Cabrera-De la Fuente M, Juárez-Maldonado A, González-Fuentes JA, et al. Strawberry biostimulation: from mechanisms of action to plant growth and fruit quality. *Plants*. 2022;11(24):3463. <https://doi.org/10.3390/plants11243463>
5. Nabi F, Sarfaraz A, Kama R, Kanwal R, Li H. Structure-based function of humic acid in abiotic stress alleviation in plants: a review. *Plants*. 2025;14(13):1916. <https://doi.org/10.3390/plants14131916>
6. Singh R, Sharma RR, Kumar S, Gupta RK, Patil RT. Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (*Fragaria × ananassa* Duch.). *Bioresour Technol*. 2008;99(17):8507–11. <https://doi.org/10.1016/j.biortech.2008.03.034>
7. Boutahiri S, Benrkia R, Tembeni B, Idowu OE, Olatunji OJ. Effect of biostimulants on the chemical profile of food crops under normal and abiotic stress conditions. *Curr Plant Biol*. 2024;40:100410. <https://doi.org/10.1016/j.cpb.2024.100410>
8. Fang X, Xie Y, Yuan Y, Long Q, Zhang L, Abid G, et al. The role of salicylic acid in plant defense responses against biotic stresses. *Plant Horm*. 2025;1(1):100003. <https://doi.org/10.48130/ph-0025-0003>
9. Zydlik Z, Zydlik P. The effect of a preparation containing humic acids on the growth, yield and quality of strawberry fruits (*Fragaria × ananassa* (Duchesne ex Weston) Duchesne ex Rozier). *Agronomy*. 2023;13(7):1872. <https://doi.org/10.3390/agronomy13071872>
10. Kiremit MS, Arslan H, Bakirova A, Abdulrasaq SA. Synergistic effects of humic and salicylic acids on water productivity, physiology and antioxidant defense in salt-stressed lettuce. *J Plant Nutr Soil Sci*. 2026;26(1):1–22. <https://doi.org/10.1007/s42729-026-03015-z>
11. Pinto JP, Cunha FF, Silva Adão A, Paula LB, Ribeiro MC, Costa Neto JR. Strawberry production with different mulches and wetted areas. *Horticulturae*. 2022;8(10):930. <https://doi.org/10.3390/horticulturae8100930>
12. Biswas AI, Singh R, Patil N, Betkekar AR, Adhikari S, Sinha A. Mulching interventions in strawberry: influence on soil temperature, moisture conservation and pest dynamics. *Int J Adv Biochem Res*. 2025;9(4):646–52. <https://doi.org/10.33545/26174693.2025.v9.i4h.4169>
13. Taparuskienė L, Miseckaitė O. Effect of mulch on soil moisture depletion and strawberry yield in sub-humid area. *Pol J Environ Stud*. 2014;23(2):475–82.
14. Medina Y, Gosselin A, Desjardins Y, Gauthier L, Harnois R, Khanizadeh S. Effect of plastic mulches on yield and fruit quality of strawberry plants grown under high tunnels. *Acta Hortic*. 2011;893:1327–32. <https://doi.org/10.17660/ActaHortic.2011.893.156>
15. Khound A, Sarmah UJ, Neog M, Sharmah D. Winter Dawn strawberry cultivar: suitable for commercial cultivation in Assam. *J Krishi Vigyan*. 2021;9(2):251–4. <https://doi.org/10.5958/2349-4433.2021.00046.5>
16. Roussos PA, Triantafyllidis A, Kepolas E, Peppas P, Piou A, Zoti M, et al. Effects of integrated and organic management on strawberry (cv. Camarosa) plant growth, nutrition, fruit yield, quality, nutraceutical characteristics and soil fertility status. *Horticulturae*. 2022;8(2):184. <https://doi.org/10.3390/horticulturae8020184>
17. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. Statistical software package for agricultural research workers. In: Recent advances in information theory, statistics and computer applications. Hisar (India): Department of Mathematics Statistics, CCS Haryana Agricultural University; 1998. p. 139–43.
18. Ullah I, Sajid M, Shah ST, Khan S, Iqbal Z, ul Hassan E, et al. Influence of humic acid on growth and yield of strawberry cv. Chandler. *Pure Appl Biol*. 2017;6(4):1171–6. <https://doi.org/10.19045/bspab.2017.600125>
19. Pílanal N, Kaplan M. Investigation of effects on nutrient uptake of humic acid applications of different forms to strawberry plant. *J Plant Nutr*. 2003;26(4):835–43. <https://doi.org/10.1081/PLN-120018568>
20. Anushi, Tripathi VK. Influence of biostimulants and organic mulch on physiological, biochemical and yield attributes of strawberry (*Fragaria × ananassa* Duch.) cv. Katrain Sweet. *Plant Sci Today*. 2025;12(3):1–9. <https://doi.org/10.14719/pst.5994>
21. Semwal A, Singh S, Nautiyal P, Pandey S. Effect of mulching on growth, yield and economics of strawberry (*Fragaria × ananassa*) under subtropical conditions of Uttarakhand. *Int J Agric Environ Biotechnol*.

- 2022;15(4):819–25. <https://doi.org/10.30954/0974-1712.04.2022.5>
22. Supreetha GB, Singh NP, Sharma S. Influence of mulching on fruit development and quality attributes of strawberry. *Indian J Hortic.* 2022;79(2):221–8. <https://doi.org/10.5958/0974-0112.2022.00030.5>
 23. Aghaeifard F, Babalar M, Fallahi E, Ahmadi A. Influence of humic acid and salicylic acid on yield, fruit quality and leaf mineral elements of strawberry (*Fragaria × ananassa* Duch.) cv. Camarosa. *J Plant Nutr.* 2016;39(13):1821–9. <https://doi.org/10.1080/01904167.2015.1088023>
 24. Maurya S, Srivastav A, Vishwakarma UB, Maurya P. Evaluation of the effect of different mulches on vegetative growth and yield of strawberry cv. Winter Dawn. *Int J Adv Biochem Res.* 2026;10(3 Suppl):964–6. <https://doi.org/10.33545/26174693.2026.v10.i3Sl.8031>
 25. Canellas LP, Olivares FL, Aguiar NO, Jones DL, Nebbioso A, Mazzei P, et al. Humic and fulvic acids as biostimulants in horticulture. *Sci Hortic.* 2015;196:15–27. <https://doi.org/10.1016/j.scienta.2015.09.013>
 26. Rouphael Y, Colla G. Toward a sustainable agriculture through plant biostimulants: from experimental data to practical applications. *Front Plant Sci.* 2020;11:40. <https://doi.org/10.3389/fpls.2020.00040>
 27. Singh S, Singh NP, Sharda R, Sangwan AK. Response of irrigation, fertigation and mulching on plant growth and fruit yield of strawberry. *Indian J Hortic.* 2019;76(2):233–40. <https://doi.org/10.5958/0974-0112.2019.00036.7>
 28. Nardi S, Pizzeghello D, Schiavon M, Ertani A. Plant biostimulants: physiological responses induced by humic substances. *Agronomy.* 2021;11(7):1474. <https://doi.org/10.3389/fpls.2020.01203>
 29. du Jardin P. Plant biostimulants: definition, concept, main categories and regulation. *Sci Hortic.* 2015;196:3–14. <https://doi.org/10.1016/j.scienta.2015.09.021>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.