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Yield and quality promotion of strawberries through chitosan and potassium combined spray under fluctuating sub-tropical winter

Khadiza Akter KOLY[1], Joydeb GOMASTA[1], Kifyat KABIR[2], Sharmila Rani MALLICK[1], Hasina SULTANA[1], Emrul KAYESH[1] (✉)

[1] Department of Horticulture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh
[2] College of Agricultural Sciences, International University of Business Agriculture and Technology, Dhaka 1230, Bangladesh

✉ Corresponding author: ekayeshhrt@bsmrau.edu.bd

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ABSTRACT

Production of quality strawberries with high nutritive and bioactive properties has faced challenges in the tropics and sub-tropics due to the short and unstable winter conditions. Hence, this study has assessed the vegetative and reproductive behaviors and fruit bioactive properties of strawberry upon the application of chitosan (Cht) and potassium (K) at six varied formulations viz., Cht at 0.6 g/L + K at 2.5 g/L, Cht at 0.8 g/L + K at 2.5 g/L, Cht at 1.0 g/L + K at 2.5 g/L, Cht at 0.6 g/L + K at 5.0 g/L, Cht at 0.8 g/L + K at 5.0 g/L and Cht at 1.0 g/L + K at 5.0 g/L along with control (no spray of Cht or K) following a randomized complete block design with three replications. Results exhibited that Cht at 0.8 g/L + K at 5.0 g/L treatment caused superior vegetative performances and a significantly greater number of flowers (20.67/plant) and fruits (18.00/plant) corresponding to the maximum yield (322.50 g/plant) over other treatments. Among the fruit bioactive compounds, total flavonoid content (21.87 mg/100 g FW) and total soluble solids (10.07%) were estimated maximum at Cht at 1.0 g/L + K at 2.5 g/L, while total anthocyanin (105.82 mg/100 g FW) and vitamin C (58.54 mg/100 g FW) contents were led by Cht at 1.0 g/L + K at 5.0 g/L treatment compared to control. Thus, regulated chitosan and potassium application can improve the yield and nutritive properties of strawberries under heat-stressed sub-tropical field conditions.

Keywords: strawberry (*Fragaria* × *annanasa*), foliar feeding, vegetative growth, berry yield, bioactive compounds, temperature stress

INTRODUCTION

In the last few decades, there has been a substantial increase in the consumption of freshly harvested strawberries, blueberries, and brambles packed with beneficial bioactive constituents, resulting in scientifically proven health advantages. Emerging insights emphasize the significant role of these naturally sourced compounds in enhancing human health (Sun-Waterhouse, 2011; Giampieri et al., 2017). Among these, strawberries (*Fragaria* × *annanasa*) stand out as a globally popular and economically significant fruit, esteemed for their distinct flavor, vibrant color, and nutritional value. High contents of anthocyanins, carotenoids, vitamins, flavonoids, and phenolics of this crop boast remarkable antioxidant capacities (Hossain et al., 2016; Rahman et al., 2018, Gomasta et al., 2023a). The presence of phenolic compounds, such as anthocyanins and flavonoids, contributes to their anticancer and antioxidant activities (Zhang et al., 2008; Giampieri et al., 2017). While strawberries are valued for their health benefits, optimizing their cultivation for enhanced yield and quality presents challenges and opportunities for the growers. The use of agricultural inputs has gained interest as a means to improve growth, yield, and quality. However, concerns about environmental and health impacts due to excessive use of synthetic agrochemicals, particularly for fruits consumed fresh like strawberries, necessitate an eco-conscious approach that enhances both yield and quality (Rahman et al., 2018).

Chitosan, a natural polysaccharide derived from chitin, has gained attention for its potential to enhance strawberry production. With origins in sources like crab shells and fungi, chitosan is environmentally friendly and non-toxic (Kumaresapillai et al., 2011). It triggers natural plant defence responses and has been used to control pre- and post-harvest pathogenic diseases (El Ghaouth et al., 1991). Studies have reported chitosan's antimicrobial activities against phytopathogens (Rahman et al., 2014) and its effectiveness in enhancing anthocyanin content and storability (Malerba and Cerana, 2018). Chitosan is promising in promoting vegetative growth, yield, and biochemical contents in various plants (El-Miniawy et al., 2013; Mukta et al., 2017; Pirbalouti et al., 2017; Ramakrishna et al., 2017; Ray et al., 2023; Khanam et al., 2023). Conversely, potassium (K+) holds paramount importance in plant growth, comprising a significant portion of a plant's dry mass. Potassium's role extends to influencing fruit and vegetable quality, which directly impacts human health (Lester et al., 2010). For strawberries, potassium is crucial for protein, sugar production, and water regulation, contributing to resilience against diseases (Zörb et al., 2014). Potassium significantly influences the growth, yield, and quality of strawberries, affecting parameters like sugar content, vitamin C concentration, and fruit acidity (Lester et al., 2010). Its role in nutrient transport to fruits is vital; deficiency leads to reduced productivity and compromised quality. Again, in Bangladesh, strawberry cultivation is best suited during the winter months starting from October-November and continuing till February-March (Paul et al., 2017). But, short winter and relatively warm environments at the end of winter (Gomasta et al., 2023b) sometimes make it difficult to harvest good quality winter crops including strawberries during that time. Chitosan and potassium are some of the external elements which can solely ameliorate the deleterious effect of high-temperature stress in plants including strawberries (Górnik et al., 2008; Waraich et al., 2012).

However, while the individual effects of chitosan and potassium have been studied, their combined impact on strawberry cultivation remains underexplored. This study aims to bridge this research gap by investigating the synergistic effects of chitosan and potassium on strawberry growth, yield, and quality. To this end, the present experiment was conducted to evaluate the combined impact of potassium and chitosan spray on the vegetative and reproductive growth influencing the yield and functional properties of strawberries.

MATERIAL AND METHODS

Site details and planting material

The experiment was conducted in the research field of the Department of Horticulture, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur-1706, Bangladesh in pots from November 2022 to April 2023, while nutritional analyses were performed at the laboratory of the same department. The experimental field was situated in the Madhupur Tract (AEZ 28), characterized by shallow red-brown terrace soil from the Salna Series (Brammer, 1977). The study area was characterized by a tropical climate where winter was short, dry and scarce rainfall, and relatively warm at the end of the season (Apu et al., 2022). Prior to planting, robust strawberry cv. festival seedlings free from pests and pathogens were meticulously sourced from Adarsha Nursery located in Sreepur, Gazipur.

Experimental design and layout

The pot experiment was set in a randomized complete block design (RCBD) taking three replicates where five pots containing a single plant each were considered as a replication under each treatment. Treatments consisted of six different combination doses of chitosan and potassium besides control. All the pots with strawberry plants were placed 15 cm apart from each other for convenient intercultural operations.

Treatment preparation and application

In this experiment, a series of six combination doses of chitosan and potassium were applied as foliar spray along with a control group. The treatments were named as T_0: Control (no spray), T_1: Chitosan (Cht) at 0.6 g/L + K at 2.5 g/L, T_2: Cht at 0.8 g/L + K at 2.5 g/L, T_3: Cht at 1.0 g/L + K at 2.5 g/L, T_4: Cht at 0.6 g/L + K at 5 g/L, T_5: Cht at 0.8 g/L + K at 5 g/L, T_6: Cht at 1.0 g/L + K at 5 g/L. The process of preparing and applying potassium and chitosan was carried out through a series of steps. The powdered chitosan was obtained from the market and transformed into a solution. Initially, a mixture of 6 mL 0.1 N acetic acid was taken into a beaker and placed on a magnetic stirrer. Subsequently, a specific amount of chitosan corresponding to each treatment was added to the beaker. Following thorough mixing, deionized water was introduced, resulting in a comprehensive blending. This resulting solution was then combined with the appropriate volume of deionized water, and the pH level was adjusted to 6.3 using 0.1 N NaOH. The formulated solution was systematically applied at 15-day intervals subsequent to transplantation, in accordance with the designated treatment protocol. In the experimental field, potassium sulfate was employed at concentrations of both 2.5 g/L and 5 g/L, in alignment with the stipulated experimental framework.

Pot preparation and management

Plastic pots of dark brown in color and 42 cm × 36 cm in size were used to plant strawberries. Firstly, weeds were removed from the base soil. Secondly, the soil was exposed to sunlight for 4 days before the pots were prepared, ensuring that the soil would be free from pathogens. Each pot was filled with soil plus vermicompost and a cocodust mixture up to the brim at a 2:1 ratio. The space between each pot was 15 cm. Twenty-day-old healthy and disease-free seedlings were collected and transplanted on 23rd November 2022. All intercultural operations like weeding, insect-pest management, watering, etc. were practised as and when necessary.

Measurement of growth, yield and biochemical attributes

Vegetative growth of strawberry plants treated with chitosan and potassium spray was assessed by measuring plant height (cm), number of leaves/plant, leaf length (cm) and canopy diameter (cm). These measurements were recorded at transplanting and at the flowering stage as described by Gomasta et al. (2023a). Leaf chlorophyll content as SPAD values were measured by a portable chlorophyll meter (Model: SPAD-502Plus; Konica Minolta, Japan) at full blossom. Runners developed by the transplants were immediately removed upon being observed on any plant. Flowering started on January 10, 2023, and reproductive data (the number of flowers and fruits per plant) were noted regularly. The fruit was harvested when the color of the fruit changed from pink to red. Immediately after harvest, fruits were weighed (g) and sepals were removed and stored at −20 °C for biochemical analyses from fruit flesh. The stored as well as harvested fresh fruits were utilized for biochemical analyses. Total soluble solids (TSS) were assessed using a hand refractometer (Model: Atago NI, Japan). Titratable acidity determination was carried out following the method of Cardwell et al. (1991). The total phenolic content (TPC) from fresh strawberry samples was estimated using Folin–Ciocalteu procedure (Singleton et al., 1999), total flavonoid content was determined by aluminum chloride colorimertic method (Pourmorad et al., 2006), ascorbic acid (vitamin c) content was determined using titration method (Elgailani, 2017) and anthocyanin content was estimated spectrophotometrically according to the methods of Hughes and Smith (2007).

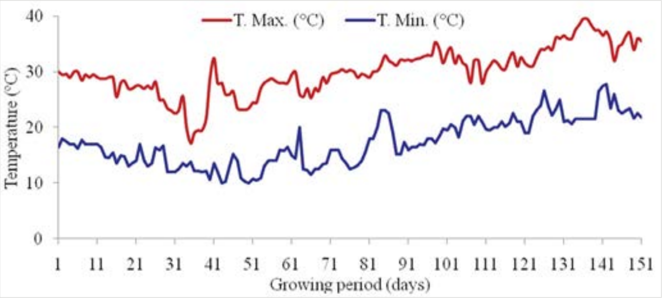
Statistical analysis

All the collected data were gathered, analyzed and presented as treatment means of three replications after performing a one-way analysis of variance (ANOVA) where treatment means were separated using Fisher's protected Least Significance Difference (LSD) test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Weather status

Remarkable fluctuations and differences between maximum and minimum temperatures were noticed during the experiment (Figure 1). Both high and low temperature indexes showed gradual decreases from 30.0 °C and 16.5 °C on 1st December 2022, to 19.0 °C and 10.0 °C in mid-January 2023. Thereafter, a steady temperature increase was noted until the end of the harvest in April 2023 up to a maximum of 38.5 °C. The daily maximum temperature was noted to have been below 30 °C up to the first week of February, and the maximum daily temperature increased from the second week of February 2023. It was also noticed that the difference in high and low temperatures never went below 12.0 °C. Temperature variations almost throughout the vegetative growth stage and reproductive phase were more than 15.0 °C (early January to mid-March) (Figure 1A).

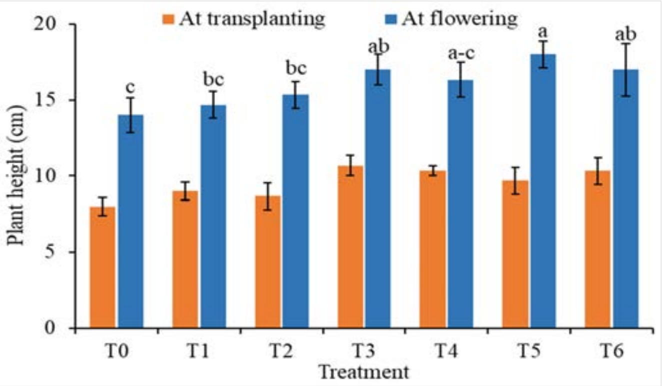


T. Max. and T. Min. indicate maximum and minimum temperature, respectively

Figure 1. Temperature readings of the experimental site during the growing period of strawberries (November 15, 2022, to April 15, 2023)

Plant height

The findings indicated a rapid surge in plant height during the initial 15-day growth period, which subsequently slowed down (Figure 2). On the day of transplantation, the tallest plants were recorded in the T_3 treatment (11 cm), while the control (T_0) had the lowest plant height (8 cm). Despite the variation in treatment, statistical significance was not evident. As plants reached the flowering stage, the T_5 treatment exhibited the tallest height (18 cm), statistically similar to those of the T_3 (17 cm), T_4 (16.33 cm), and T_6 (17 cm) treatments. The control group (T_0) at 14 cm, displayed the shortest height and was statistically inferior to all other treatments (Figure 2). These findings align with prior research. El-Miniawy et al. (2013) noted increased plant height with chitosan foliar application at 5 mg/l thrice. Similarly, Mukta et al. (2017) observed heightened plant height at 250 ppm chitosan application. Moreover, Bibi et al. (2016) found that applying 600 g (ONC) of potassium resulted in the tallest strawberry plants. Chitosan's positive impact on growth is due to improved water uptake, nutrient availability, osmotic pressure modulation, and reduced harmful radicals via enhanced antioxidants and enzymes (Guan et al., 2009). Potassium is known to contribute to enhanced nutrient adsorption, leading to greater plant height (Nehra et al., 2001).



T_0: Control (no spray), T_1: Chitosan (Cht) at 0.6 g/L + K at 2.5 g/L, T_2: Cht at 0.8 g/L + K at 2.5 g/L, T_3: Cht at 1.0 g/L + K at 2.5 g/L, T_4: Cht at 0.6 g/L + K at 5 g/L, T_5: Cht at 0.8 g/L + K at 5 g/L, T_6: Cht at 1.0 g/L + K at 5 g/L

Figure 2. Effect of potassium and chitosan on plant height at different days after transplanting of the strawberry plant

Number of leaves/plant

Leaf count per plant was recorded on both the day of transplantation and the day of flowering. On the transplantation day, the T_1 (5.00) and T_5 (5.00) treatments exhibited the highest number of leaves, whereas the lowest counts were seen in the T_2 (4.33) and T_6 (4.33) treatments. Similarly, when flowering occurred, T_5 (13.00) demonstrated the highest leaf count, while the lowest leaf count was observed in the T_0 treatment (8.33) (Table 1).

Table 1. Effect of chitosan and potassium on the number of leaves/plant and canopy area of strawberry

Treatment	Number of leaves/plant		Canopy spread (cm)	
	At transplanting	At flowering	At transplanting	At flowering
T_0	4.67 ± 0.33	8.33 ± 1.20^{c}	13.33 ± 0.6^{bc}	17.67 ± 0.88^{b}
T_1	5.00 ± 0.58	11.00 ± 0.58^{b}	14.83 ± 1.01^{b}	22.17 ± 0.73^{a}
T_2	4.33 ± 0.33	9.00 ± 1.15^{bc}	12.00 ± 0.76^{c}	22.83 ± 0.5^{a}
T_3	4.67 ± 0.33	12.33 ± 1.45^{a}	14.66 ± 1.04^{b}	22.00 ± 0.60^{a}
T_4	4.67 ± 0.67	12.00 ± 1.15^{ab}	14.830 ± 0.6^{b}	21.83 ± 1.01^{a}
T_5	5.00 ± 0.58	13.00 ± 1.53^{a}	14.66 ± 1.2^{b}	23.50 ± 1.59^{a}
T_6	4.33 ± 0.33	11.67 ± 0.88^{ab}	17.5 ± 0.33^{a}	21.67 ± 1.15^{a}
$LSD_{0.05}$	1.35	3.67	2.3021	2.3387
CV (%)	16.31	18.67	8.94	6.07
Level of significance	NS	*	**	**

Values are means ± the standard errors of three independent replications. Different letters within the column indicate statistically significant differences among the treatments according to LSD at $P \leq 0.05$. Here, T_0: Control (no spray), T_1: Chitosan (Cht) at 0.6 g/L + K at 2.5 g/L, T_2: Cht at 0.8 g/L + K at 2.5 g/L, T_3: Cht at 1.0 g/L + K at 2.5 g/L, T_4: Cht at 0.6 g/L + K at 5 g/L, T_5: Cht at 0.8 g/L + K at 5 g/L, T_6: Cht at 1.0 g/L + K at 5 g/L.

The findings correspond with earlier research. Rahman et al. (2018), Abdel-Mawgoud et al. (2010) and Mondal et al. (2012) reported an increase in the number of leaves per plant in strawberries and okra with elevated chitosan concentrations. Ray et al. (2023) also noted a superior number of leaves in onion after chitosan spray. Additionally, Bibi et al. (2016) found that potassium at 600 g (ONC) resulted in the highest leaf count. These outcomes underscore the role of chitosan concentration and potassium in influencing leaf count dynamics within strawberry plants.

Canopy area

The canopy size per plant exhibited notable variations among the different treatments, both at the time of transplanting and during flowering (Table 1). During transplanting, the largest canopy area was observed in T_6 (17.5 cm), while the smallest canopy was noted in T_2 (12 cm), which was statistically comparable to T_0 (13.33 cm). Upon flowering, the most substantial canopy area was seen in T_5 (23.50 cm), showing statistical resemblance to T_1 (22.17 cm), T_2 (22.83 cm), T_3 (22.00 cm), T_4 (21.83 cm) and T_6 (21.67 cm). Conversely, the smallest canopy area was recorded in T_0 (17.57 cm). Our findings are consistent with Mukta et al. (2017) and Rahman et al. (2018), demonstrating chitosan-induced increases in strawberry canopy spread. Similarly, Bibi et al. (2016) observed increased canopy size due to potassium application at 600 g. Although our chitosan and potassium combination differed from theirs, our results yielded similar outcomes, especially at lower dosages. This suggests the efficacy of this combination in influencing canopy size.

Chlorophyll content

The application of the potassium and chitosan combination influenced the chlorophyll content in strawberry leaves (Table 2). Treatment T_1 (SPAD value 57) and T_3 (SPAD value 57) demonstrated elevated levels of chlorophyll content. Nevertheless, the distinctions among the treatments did not achieve statistical significance. Our findings align with El-Miniawy et al. (2013), wherein varying concentrations of chitosan were utilized, yielding results somewhat similar to our own. In contrast, Tohidloo et al. (2018) observed relatively lower SPAD values in their research involving different potassium doses. This indicates that the combined application of potassium and chitosan leads to improved chlorophyll content compared to individual treatments.

Number of flowers/plant

The application of different treatments led to significant variations in the total number of flowers per strawberry plant (Table 2). The highest flower count was recorded in T_5 (20.67/plant), and this count was statistically similar to the flower counts in T_4 (18.33/plant) and T_6 (17.33/plant). In contrast, the control group exhibited the lowest number of flowers (8/plant), which was statistically comparable to the flower count in T_1 (10/plant). Our findings align with those of Bibi et al. (2016), who observed an increased number of flowers with different potassium doses. Furthermore, Abdel-Mawgoud et al. (2010) reported that chitosan positively influenced plant growth and development, resulting in an augmented number of flowers per plant. This concurrence in outcomes emphasizes the potential of both chitosan and potassium to enhance floral production in strawberry plants.

Number of fruits/plant

Fruit quantification took place between the 41st and 45th days following the initial plant placement. The response of strawberry plants in terms of fruit production was notably influenced by the administration of diverse treatments (Table 2). The result showed that T_5 (18.00/plant) displayed an increased fruit count, statistically resembling T_4 (16.33/plant) and T_6 (15.67/plant). Conversely, the control treatment yielded a diminished fruit count (7.67/plant), showing statistical similarity to T_1 (8.67/plant). Mukta et al. (2017) demonstrated variation in fruit numbers at different chitosan concentrations, where 500 ppm of chitosan resulted in a higher fruit count per plant. Similarly, Abdel-Mawgoud et al. (2010) noted that increased chitosan concentrations led to heightened fruit numbers per plant. Moreover, Bamouh et al. (2019) found that the application of potassium sulfate increased the number of fruits in strawberries. These findings collectively underscore the influence of chitosan and potassium on fruit quantity in strawberry plants.

Yield per plant

The recorded yields per plant showed significant differences across various treatments (Table 2). The treatment T_5 led to an increased yield per plant (322.5 g/plant), sharing statistical resemblance to T_4 and T_6. In contrast, the lowest yield per plant was observed in T_0

Table 2. Effect of potassium and chitosan on chlorophyll content, number of flowers and fruits and fruit yield per plant in strawberry

Treatment	Chlorophyll content	Number of flowers/plant	Number of fruits/plant	Yield per plant (g)
T_0	56 ± 1.47	8.00 ± 0.58^{d}	7.67 ± 0.33^{c}	139.3 ± 7.7^{e}
T_1	57 ± 0.92	10.00 ± 1.15^{d}	8.67 ± 0.33^{c}	157.9 ± 8.4^{de}
T_2	55 ± 1.20	13.67 ± 0.88^{c}	11.33 ± 0.33^{b}	210.8 ± 5.6^{cd}
T_3	57 ± 0.75	15.00 ± 1.53^{bc}	13.00 ± 1.53^{b}	242.4 ± 32.3^{bd}
T_4	55 ± 0.42	18.33 ± 0.88^{ab}	16.33 ± 0.33^{a}	311.6 ± 12.1^{a}
T_5	54 ± 1.22	20.67 ± 0.88^{a}	18.00 ± 0.58^{a}	322.5 ± 14.8^{a}
T_6	54 ± 1.43	17.33 ± 1.45^{ab}	15.67 ± 1.20^{a}	275.8 ± 28.7^{ab}
$LSD_{0.05}$	3.5077	3.3545	2.4756	57.521
CV (%)	3.54	12.81	10.74	13.63
Level of significance	NS	*	*	**

Values are means ± the standard errors of three independent replications. Different letters within the column indicate statistically significant differences among the treatments according to LSD at $P \leq 0.05$. Here, T_0: Control (no spray), T_1: Chitosan (Cht) at 0.6 g/L + K at 2.5 g/L, T_2: Cht at 0.8 g/L + K at 2.5 g/L, T_3: Cht at 1.0 g/L + K at 2.5 g/L, T_4: Cht at 0.6 g/L + K at 5 g/L, T_5: Cht at 0.8 g/L + K at 5 g/L, T_6: Cht at 1.0 g/L + K at 5 g/L.

(139.3 g/plant). Comparisons with prior studies underline the treatment-specific impact on yield. El-Miniawy et al. (2013) reported strawberry yields of 9-13 tons/ha with chitosan, while Bamouh et al. (2019) achieved 11 tons/ha with potassium application. Our results suggest that the combined chitosan-potassium treatment holds promise for enhancing yield. The observed synergy may stem from chitosan's stress response induction (El Ghaouth et al., 1991) and potassium's influence on physiological processes affecting growth and productivity (Bibi et al., 2016).

Total flavonoid content (TFC)

Differences were evident in the total flavonoid content among the treatment groups (Table 3). The treatment T_3 demonstrated the highest value of total flavonoid content at 21.87 mg QE/100g FW, followed by T_5 (16.18 mg QE/100g FW) and T_6 (15.23 mg QE/100g FW). The enhancement of total flavonoid content in strawberry plants treated with chitosan foliar spray was also examined by Rahman et al. (2018). This outcome suggests a potential synergistic effect between these two compounds at the specified concentrations. Potassium is known to influence various physiological processes, including plant metabolism, which could indirectly impact flavonoid production. Chitosan, a biopolymer derived from chitin, has been shown to induce stress responses and secondary metabolite synthesis in plants, possibly contributing to the observed increase in flavonoid content (Ray et al., 2023).

Total phenol content (TPC)

Variations in total phenolic content (TPC) were observed to be non-significant across the different treatments (Table 3). The maximum phenolic value (75.63 mg GAE/100 g FW) was obtained in the T_6 treatment, and the estimated minimum value was observed in the control treatment. Despite the disparities between the phenol contents associated with these treatments, statistical significance was not detected. Comparing our findings with Rahman et al. (2018) reveals a notable contrast in outcomes. Our study highlights the highest total phenolic content (TPC) when applying a combination of chitosan and potassium. In contrast, Rahman et al. achieved their peak TPC through chitosan treatment alone at 1000 ppm. Potassium's essential role in various

Table 3. Effect of chitosan and potassium spray on the contents of total flavonoid, total phenol and total anthocyanin in strawberry fruits

Treatment	Total flavonoid content (mg/100 g FW)	Total phenol content (mg/100 g FW)	Total anthocyanin content (mg/100 g FW)
T_0	13.49 ± 1.10^c	50.69 ± 2.26	83.50 ± 1.21^c
T_1	13.65 ± 0.41^c	58.02 ± 3.61	97.22 ± 0.24^{bc}
T_2	13.65 ± 1.64^c	65.06 ± 2.30	100.28 ± 1.17^a
T_3	21.87 ± 1.01^a	63.02 ± 3.22	101.91 ± 0.98^a
T_4	14.74 ± 0.77^{bc}	57.31 ± 4.75	99.10 ± 0.87^{bc}
T_5	16.18 ± 0.56^b	66.22 ± 3.71	102.45 ± 0.66^a
T_6	15.23 ± 0.53^b	75.63 ± 6.01	105.82 ± 0.33^a
$LSD_{0.05}$	13.06	16.71	9.9861
CV (%)	7.25	9.09	5.69
Level of significance	*	NS	*

Values are means ± the standard errors of three independent replications. Different letters within the column indicate statistically significant differences among the treatments according to LSD at $P \le 0.05$. Here, T_0: Control (no spray), T_1: Chitosan (Cht) at 0.6 g/L + K at 2.5 g/L, T_2: Cht at 0.8 g/L + K at 2.5 g/L, T_3: Cht at 1.0 g/L + K at 2.5 g/L, T_4: Cht at 0.6 g/L + K at 5 g/L, T_5: Cht at 0.8 g/L + K at 5 g/L, T_6: Cht at 1.0 g/L + K at 5 g/L.

physiological processes suggests its potential influence on quality parameters (Bibi et al., 2016), such as phenolic production pathways. Its presence at 2.5 g/L might have facilitated these pathways, ultimately boosting phenolic content. Chitosan's capacity to induce stress responses and secondary metabolite synthesis aligns with its role in promoting higher phenolic accumulation. The interaction between chitosan and potassium could have triggered specific metabolic reactions, resulting in increased phenolic synthesis.

Total anthocyanin content (TAC)

Total anthocyanin content exhibited diversity among distinct treatments. The highest level of anthocyanins was detected in T_6 (105.82 mg/100g FW) and bears statistical parity with the T_2, T_3 and T_5 treatments. In contrast, the control treatment (T_0) showcased the least amount of anthocyanin. Our findings stand in contrast to those of Rahman et al. (2018), who reported higher anthocyanin levels in response to chitosan application alone at a concentration of 500 ppm. However, it is essential to highlight that our study incorporated a combination of chitosan and potassium. This combination could plausibly trigger a synergistic interaction, leading to enhanced anthocyanin production. The introduction of potassium might have influenced metabolic pathways or cellular processes that contributed to the observed higher anthocyanin levels.

Total soluble solids (TSS)

Statistical variations were noted among the treatments in terms of total soluble solids (TSS) content in strawberry fruits (Table 4). The treatment T_3, which encompassed the combination of Chitosan (1.0 g/L) and Potassium (2.5 g/L), displayed the highest TSS reading (10.07%). These values were statistically akin to T_4, T_5, and T_6. Conversely, T_0 had the lowest TSS measurement (7.87%), a result that was statistically comparable to T_1 (8.00%). El-Miniawy et al. (2013) reported more or less similar Brix values to ours with the application of chitosan whereas Bamouh et al. (2019) found a slightly lower Brix value with the application of potassium. Our findings take on additional significance when considering the specific combination treatment of chitosan and potassium. This unique combination could account for the observed increase in TSS readings. Potassium is known to influence various physiological processes, including sugar translocation and accumulation within the fruit (Zörb et al., 2014). Chitosan, recognized for its role in inducing stress responses and enhancing secondary metabolite synthesis (Abdel-Mawgoud et al., 2010; Mondal et al., 2012; El-Miniawy et al., 2013; Mukta et al., 2017) might contribute to a favorable physiological state for sugar accumulation.

Titratable acidity (TA)

Titratable acidity showed diversity among the treatments. Treatment T_6 demonstrated the highest titratable acidity (0.68%), whereas the lowest readings (0.58%) were observed in both T_0 and T_4. Comparative analysis with prior studies reveals the complexity of treatment effects on fruit acidity. El-Miniawy et al. (2013) reported slightly lower titratable acidity through chitosan application alone, indicating the intricate nature of chitosan's influence on fruit acid levels. Conversely, Bamouh et al. (2019) found higher TA with potassium application, highlighting the context-specific impact of treatments on acidity dynamics. Our findings suggest that the interaction between chitosan and potassium could have contributed to altered physiological processes associated with organic acid accumulation. Chitosan's known role in stress response induction (El Ghaouth et al., 1991) and secondary metabolite synthesis (Rahman et al., 2018) might have influenced organic acid content. Meanwhile, potassium's role in cellular pH regulation could have further modulated acid accumulation dynamics (Lester et al., 2010).

Vitamin C content

Differences in vitamin C (ascorbic acid) content were notably evident across various treatments (Table 4). Treatment T_6 resulted in the highest Vitamin C value in fruit (58.54 mg/100g). This result is statistically akin to the values observed in the rest of the chitosan and potassium combination treatments. In contrast, the

Table 4. Effect of potassium and chitosan on total soluble solids, titratable acidity and vitamin C content in strawberry

Treatment	Total soluble solids (%)	Titratable acidity (%)	Vitamin C (mg/100 g FW)
T_0	7.87 ± 0.15^{c}	0.58 ± 0.017	43.67 ± 1.22^{b}
T_1	8.00 ± 0.42^{c}	0.64 ± 0.025	52.81 ± 0.49^{a}
T_2	8.70 ± 0.92^{bc}	0.60 ± 0.018	54.85 ± 1.14^{a}
T_3	10.07 ± 0.18^{a}	0.59 ± 0.017	55.94 ± 1.29^{a}
T_4	9.17 ± 0.29^{abc}	0.58 ± 0.012	54.06 ± 0.24^{a}
T_5	8.77 ± 0.44^{abc}	0.59 ± 0.015	56.30 ± 0.98^{a}
T_6	9.70 ± 0.17^{ab}	0.68 ± 0.026	58.54 ± 0.37^{a}
$LSD_{0.05}$	1.3053	0.02	6.6574
CV (%)	8.25	5.76	6.96
Level of significance	*	NS	*

Values are means ± the standard errors of three independent replications. Different letters within the column indicate statistically significant differences among the treatments according to LSD at $P \leq 0.05$. Here, T_0: Control (no spray), T_1: Chitosan (Cht) at 0.6 g/L + K at 2.5 g/L, T_2: Cht at 0.8 g/L + K at 2.5 g/L, T_3: Cht at 1.0 g/L + K at 2.5 g/L, T_4: Cht at 0.6 g/L + K at 5 g/L, T_5: Cht at 0.8 g/L + K at 5 g/L, T_6: Cht at 1.0 g/L + K at 5 g/L.

control plants (T_0) exhibited the lowest Vitamin C value (43.67 mg/100g). These findings are in concordance with the results of El-Miniawy et al. (2013), who focused solely on chitosan application and reported similar outcomes during the second season. Conversely, the study of Tohidloo et al. (2018) revealed lower vitamin C content with the application of potassium. The potential antagonistic effect of potassium on vitamin C synthesis might be counteracted by the co-application of chitosan, as suggested by our results. Preciado-Rangel et al. (2020) also noted similar ascorbic acid contents in strawberries with the use of potassium in soilless cultivation.

CONCLUSIONS

The utilization of naturally occurring chitosan biopolymer and potassium has been practised to enhance the yield and quality of strawberries with further advantages to human health and the environment. The present investigation exhibited that combinations of shrimp shell chitosan and potassium enhanced the growth dynamics of strawberries. Strikingly, the administration of a blended spray of chitosan (0.8 and 1.0 g/L) and potassium (2.5 and 5.0 g/L) resulted in the highest counts of flowers, fruits, flavonoids, anthocyanins, ascorbic acid, soluble solids, and titratable acidity, while further achieving an impressive yield per plant. This study contributes valuable insights into sustainable agricultural practices, shedding light on tailored strategies for enhanced strawberry cultivation and nutritional value.

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REFERENCES

Abdel-Mawgoud, A. M. R., Tantawy, A. S., El-Nemr, M. A., Sassine, Y. N. (2010) Growth and yield responses of strawberry plants to chitosan application. European Journal of Scientific Research, 39 (1), 170-177.

Apu, S. C., Biswas, M. S., Bhuiyan, M. A. B., Gomasta, J., Easmin, S., Kayesh, E. (2022) Effect of Organic Amendments and Arbuscular Mycorrhizal Fungi on Plant Growth, Yield and Quality of Strawberry. Annals of Bangladesh Agriculture, 26 (2), 71-82. DOI: https://doi.org/10.3329/aba.v26i2.67867

Bamouh, A., Bouras, H., Nakro, A. (2019) Effect of foliar potassium fertilization on yield and fruit quality of strawberry, raspberry and blueberry. Acta Horticulturae, 1265, 255-262. DOI: https://doi.org/10.17660/ActaHortic.2019.1265.36

Bibi, S., Rhaman, I., Ijaz, F., Afzal, A., Khan, M., Khan, R. (2016) The Effect of Potassium on Growth and Yield of Strawberry (Fragaria Ananassa (Duchesne ex Weston) Duchesne ex Rozier). Pakistan Journal of Botany, 48 (4), 1407-1413.

Brammer, H., Brinkman, R. (1977) Surface-water gley soils in Bangladesh: environment, landforms and soil morphology. Geoderma, 17 (2), 91-109. DOI: https://doi.org/10.1016/0016-7061(77)90042-8

Cardwell, T. J., Cattrall, R. W., Cross, G. J., O'Connell, G. R., Petty, J. D., Scollary, G. R. (1991) Determination of titratable acidity of wines and total acidity of vinegars by discontinuous flow analysis using photometric end-point detection. Analyst, 116 (10), 1051-1054. DOI: https://doi.org/10.1039/AN9911601051

El Ghaouth, A., Arul, J., Ponnampalam, R., Boulet, M. (1991) Chitosan coating effect on storability and quality of fresh strawberries. Journal of Food Science, 56 (6), 1618-1620. DOI: https://doi.org/10.1111/j.1365-2621.1991.tb08655.x

Elgailani, I. E. H., Elkareem, M. A. M. G., Noh, E., Adam, O., Alghamdi, A. (2017) Comparison of two methods for the determination of vitamin C (ascorbic acid) in some fruits. American Journal of Chemistry, 2 (1), 1-7. DOI: https://doi.org/10.20448/812.2.1.1.7

El-Miniawy, S. M., Ragab, M. E., Youssef, S. M., Metwally, A. A. (2013). Response of strawberry plants to foliar spraying of chitosan. Research Journal of Agriculture and Biological Sciences, 9 (6), 366-372.

Giampieri, F., Forbes-Hernandez, T. Y., Gasparrini, M., Afrin, S., Cianciosi, D., Reboredo-Rodriguez, P., ... Battino, M. (2017) The healthy effects of strawberry bioactive compounds on molecular pathways related to chronic diseases. Annals of the New York Academy of Sciences, 1398 (1), 62-71. DOI: https://doi.org/10.1111/nyas.13373

Gomasta, J., Hassan, J., Sultana, H., Ozaki, Y., Alamri, S. A., Alfagham, A. T., AL-Humaid, L. A. (2023b) Tomato response evaluation through fertilization and PGRs application under temperature differentiation in late winter. bioRxiv, 2023-08. DOI: https://doi.org/10.1101/2023.08.04.552040

Gomasta, J., Islam, M. R., Rahman, M. A., Islam, M., Mondal, P., Hassan, J., Kayesh, E. (2023a) Watermoss mulching stimulates the productivity and physiochemical properties of strawberry in the tropical ecosystem of southern Bangladesh. Pertanika Journal of Tropical Agricultural Science, 46 (4), 1293-1308. DOI: https://doi.org/10.47836/pjtas.46.4.14

Górnik, K., Grzesik, M., Romanowska-Duda, B. (2008) The effect of chitosan on rooting of grapevine cuttings and on subsequent plant growth under drought and temperature stress. Journal of Fruit and Ornamental Plant Research, 16, 333-343.

Guan, Y. J., Hu, J., Wang, X. J., Shao, C. X. (2009) Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress. Journal of Zhejiang University Science B, 10, 427-433. DOI: https://doi.org/10.1631/jzus.B0820373

Hossain, A., Begum, P., Zannat, M. S., Rahman, M. H., Ahsan, M., Islam, S. N. (2016) Nutrient composition of strawberry genotypes cultivated in a horticulture farm. Food Chemistry, 199, 648-652. DOI: https://doi.org/10.1016/j.foodchem.2015.12.056

Hughes, N. M., Smith, W. K. (2007) Attenuation of incident light in Galax urceolata (Diapensiaceae): concerted influence of adaxial and abaxial anthocyanic layers on photoprotection. American Journal of Botany, 94 (5), 784-790. DOI: https://doi.org/10.3732/ajb.94.5.784

Khanam, S., Gomasta, J., Rahman, M. M., Amin, M. R., Mallick, S. R., Kayesh, E. (2023) Chitosan and probiotic bacteria promotion of yield, post-harvest qualities, antioxidant attributes and shelf life of broccoli heads. Agriculture and Natural Resources, 57 (4), 709-20. DOI: https://doi.org/10.34044/j.anres.2023.57.4.15

Kumaresapillai, N., Basha, R. A., Sathish, R. (2011) Production and evaluation of chitosan from Aspergillus niger MTCC strains. Iranian journal of pharmaceutical research: IJPR, 10 (3), 553.

Lester, G. E., Jifon, J. L., Makus, D. J. (2010) Impact of potassium nutrition on food quality of fruits and vegetables: A condensed and concise review of the literature. Better Crops, 94 (1), 18-21.

Malerba, M., Cerana, R. (2018) Recent advances of chitosan applications in plants. Polymers, 10 (2), 118. DOI: https://doi.org/10.3390/polym10020118

Mondal, M. M., Malek, M. A., Puteh, A. B., Ismail, M. R., Ashrafuzzaman, M., Naher, L. (2012) Effect of foliar application of chitosan on growth and yield in okra. Australian Journal of Crop Science, 6 (5), 918-921.

Mukta, J. A., Rahman, M., Sabir, A. A., Gupta, D. R., Surovy, M. Z., Rahman, M., Islam, M. T. (2017) Chitosan and plant probiotics application enhance growth and yield of strawberry. Biocatalysis and Agricultural Biotechnology, 11, 9-18. DOI: https://doi.org/10.1016/j.bcab.2017.05.005

Nehra, A. S., Hooda, I. S., Singh, K. P. (2001) Effect of integrated nutrient management on growth and yield of wheat (*Triticum aestivum*). Indian Journal of Agronomy, 46 (1), 112-117.

Paul, C., Gomasta, J., Hossain, M. M. (2017) Effects of planting dates and variety on growth and yield of strawberry. International Journal of Horticulture, Agriculture and Food Science, 1 (4), 1-12. DOI: https://doi.org/10.22161/ijhaf.1.4.1

Pirbalouti, A. G., Malekpoor, F., Salimi, A., Golparvar, A. (2017) Exogenous application of chitosan on biochemical and physiological characteristics, phenolic content and antioxidant activity of two species of basil (*Ocimum ciliatum* and *Ocimum basilicum*) under reduced irrigation. Scientia Horticulturae, 217, 114-122. DOI: https://doi.org/10.1016/j.scienta.2017.01.031

Pourmorad, F., Hosseinimehr, S. J., Shahabimajd, N. (2006) Antioxidant activity, phenol and flavonoid contents of some selected Iranian medicinal plants. African Journal of Biotechnology, 5 (11), 1142-1145.

Preciado-Rangel, P., Troyo-Diéguez, E., Valdez-Aguilar, L. A., García-Hernández, J. L., Luna-Ortega, J. G. (2020) Interactive effects of the potassium and nitrogen relationship on yield and quality of strawberry grown under soilless conditions. Plants, 9 (4), 441. DOI: https://doi.org/10.3390/plants9040441

Rahman, M. H., Shovan, L. R., Hjeljord, L. G., Aam, B. B., Eijsink, V. G., Sørlie, M., Tronsmo, A. (2014) Inhibition of fungal plant pathogens by synergistic action of chito-oligosaccharides and commercially available fungicides. PLoS One, 9 (4), e93192. DOI: https://doi.org/10.1371/journal.pone.0093192

Rahman, M., Mukta, J. A., Sabir, A. A., Gupta, D. R., Mohi-Ud-Din, M., Hasanuzzaman, M., ... Islam, M. T. (2018) Chitosan biopolymer promotes yield and stimulates accumulation of antioxidants in strawberry fruit. PLoS One, 13 (9), e0203769. DOI: https://doi.org/10.1371/journal.pone.0203769

Ramakrishna, R., Sarkar, D., Manduri, A., Iyer, S. G., Shetty, K. (2017) Improving phenolic bioactive-linked anti-hyperglycemic functions of dark germinated barley sprouts (*Hordeum vulgare* L.) using seed elicitation strategy. Journal of Food Science and Technology, 54, 3666-3678. DOI: https://doi.org/10.1007/s13197-017-2828-9

Ray, T., Gomasta, J., Hassan, J., Hossain, M. S., Kayesh, E. (2023) Foliar application of chitosan and plant probiotic bacteria influencing the growth, productivity and bulb storage life of onion. Australian Journal of Crop Science, 17 (10), 776-788. DOI: https://doi.org/10.21475/ajcs.23.17.10.p3888

Singleton, V. L., Orthofer, R., Lamuela-Raventós, R. M. (1999) Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. In Methods in enzymology (Vol. 299, pp. 152-178). Academic press. DOI: https://doi.org/10.1016/S0076-6879(99)99017-1

Sun-Waterhouse, D. (2011) The development of fruit-based functional foods targeting the health and wellness market: a review. International Journal of Food Science & Technology, 46(5), 899-920. DOI: https://doi.org/10.1111/j.1365-2621.2010.02499.x

Tohidloo, G., Souri, M. K., Eskandarpour, S. (2018) Growth and fruit biochemical characteristics of three strawberry genotypes under different potassium concentrations of nutrient solution. Open Agriculture, 3 (1), 356-362. DOI: https://doi.org/10.1515/opag-2018-0039

Waraich, E. A., Ahmad, R., Halim, A., Aziz, T. (2012) Alleviation of temperature stress by nutrient management in crop plants: a review. Journal of Soil Science and Plant Nutrition, 12 (2), 221-244. DOI: https://doi.org/10.4067/S0718-95162012000200003

Zhang, Y., Seeram, N. P., Lee, R., Feng, L., Heber, D. (2008) Isolation and identification of strawberry phenolics with antioxidant and human cancer cell antiproliferative properties. Journal of Agricultural and Food Chemistry, 56, 670-675. DOI: https://doi.org/10.1021/jf071989c

Zörb, C., Senbayram, M., Peiter, E. (2014) Potassium in agriculture-status and perspectives. Journal of Plant Physiology, 171 (9), 656-669. DOI: https://doi.org/10.1016/j.jplph.2013.08.008