Response of Strawberry to Growth, Productivity, and Marketability to Foliar Application of Potassium Silicates and Aqueous Hibiscus Extract

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Abstract

The experiment was conducted in an agricultural field in Babil Governorate during the 2024 growing season to study the effect of potassium silicate at concentrations of A0, A1,A2 and aqueous hibiscus (Hibiscus sabdariffa L.) extract at concentrations of C0, C1, C2 on growth characteristics, productivity, and marketability of strawberry fruits of the Rubygem cultivar after 10 days of storage at 2°C and relative humidity of 80–85%. The objective was to evaluate the potential of these treatments in enhancing postharvest fruit quality by improving nutritional content and reducing losses.

The results demonstrated the significance of these treatments in minimizing postharvest losses and enhancing the quality of strawberries prepared for marketing, thereby contributing to increased economic returns for farmers. Foliar application of A2 significantly increased leaf area (235.5 cm^2), number of crowns (5.77 crowns•plant^{-1}), yield per plant (332.5 g•plant^{-1}), total yield per plastic house (353.2 kg•plastic house^{-1}), and total soluble solids (TSS) percentage (8.10%). It also significantly reduced the percentage of post-storage decay to 5.93% compared to the control, which recorded the lowest values for these traits.

Application C2 also resulted in a significant improvement in some studied traits: leaf area (173.4 cm^2), number of crowns (5.28 crowns•plant^{-1}), yield per plant (313.0 g•plant^{-1}), yield per plastic house (344.6 kg•plastic house^{-1}), and TSS percentage (8.08%). Decay percentage post-storage decreased to 6.32% compared to the control.

The interaction treatment A_2 C_1 (5.00 ml•L^{-1} potassium silicate + 5 g•L^{-1} hibiscus extract) significantly increased leaf area (244.3 cm^2), while the interaction A_2 C_2 (5.00 ml•L^{-1} potassium silicate + 10 g•L^{-1} hibiscus extract) resulted in significant increases in number of crowns (6.36 crowns•plant^{-1}), yield per plant (341.5 g•plant^{-1}), yield per plastic house (370.3 kg•plastic house^{-1}), and TSS percentage, outperforming other treatment combinations.

Introduction - :

Strawberry (Fragaria × ananassa Duch.) is a perennial small-fruit crop of significant economic importance and wide global distribution. It belongs to the order Rosales, subfamily Rosoideae, and the family Rosaceae [3]. The species is believed to have originated in North America, though it is now cultivated extensively in Europe, Asia, Africa, and the Americas [3]. Certain cultivars of strawberry have the ability to grow in tropical regions and up to 70°N latitude, with the crop being most widely cultivated between latitudes 51° and 55° [16.[

Globally, the total cultivated area of strawberries is estimated at approximately 389,665 hectares, with a total production of 9,175,384 tons. China leads the world in both cultivated area and fruit production, followed by the United States, with an annual

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production of 1,211,090 tons from 19,919 hectares [7]. In Iraq, however, there are no official statistics available regarding strawberry cultivation area or production.

Potassium silicate serves as a primary source of both silicon and potassium—two essential nutrients required for plant growth. Potassium plays a vital role in plant development and productivity, making it a critical component for plant health [19]. Although silicon is one of the most abundant elements in soil, its supplementation has been shown to enhance plant tolerance to abiotic stresses and activate antioxidant defense mechanisms [6]. Silicon deposition in plant stems and leaves strengthens tissue resilience to mechanical damage, acting as a physical barrier against pests and pathogens [13]. Furthermore, its incorporation into the cell wall increases hemicellulose and lignin content, thereby enhancing rigidity [12.[

Hibiscus (Hibiscus sabdariffa L.), known locally as "Karkadeh," is a crop of both medicinal and industrial importance. It is commonly used as a cooling beverage, rich in vitamin C and bioactive compounds that help lower blood pressure. Its red pigments are widely used as natural food colorants, and its seeds contain approximately 20–25% oil suitable for human consumption, in addition to 25–35% protein content [17]. Hibiscus extract is considered a valuable source of vitamins, minerals, amino acids, and bioactive compounds [2]. It is known to stimulate vital physiological processes such as photosynthesis, respiration, chlorophyll formation, cell division, tissue development, and the regulation of plant hormones [14]. The extract contains ascorbic acid—a potent antioxidant—as well as polyphenols and flavonoids that provide antioxidant protection. It also includes potassium, which serves as an enzymatic activator, and magnesium, which is essential for ribosome stability and constitutes the central atom in chlorophyll molecules [9.[

Strawberry fruits are classified as soft fruits, and they are particularly susceptible to mechanical damage during marketing and storage due to loss of firmness. This softening increases the risk of fungal infections. The primary reason for this loss of firmness is the breakdown of cell walls and dissolution of the middle lamella, with pectin degradation being a key control point in this process [18.[

While several previous studies have addressed the impact of foliar spraying on strawberry plant growth, there has been limited focus on its effect on fruit quality during storage and under marketing conditions. Given the delicate and juicy nature of strawberry fruits, which leads to a rapid loss of firmness postharvest, this study aims to assess the impact of foliar application of potassium silicate and aqueous hibiscus extract on improving fruit quality, storability, and marketability.

Materials and Methods

Experimental Design and Implementation:

The study was conducted as a factorial experiment using a Complete Randomized Block Design (CRBD) during the 2023–2024 growing season, with two factors: potassium silicate (Factor A) applied at concentrations of 0, 2.50, and 5.00 $ml \cdot L^{-1}$, and aqueous hibiscus extract (Factor C) at concentrations of 0, 5, and 10 $g \cdot L^{-1}$.on strawberry plants of the Rubygem cultivar The experiment consisted of three replications (3 × 3), resulting in a total of 27 experimental units with 5 plants per experimental unit. Strawberry seedlings were transplanted on October 28, 2023. The first foliar spray was applied on December 20,

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2023, followed by subsequent applications every 10 days. Spraying was performed early in the morning to the point of runoff, with the addition of a surfactant to reduce surface tension.

Data were analyzed statistically using GENSTAT software, and treatment means were compared using the Least Significant Difference (LSD) test at a 0.05 probability level

Table 1. Physical and chemical properties of the field soil before planting

Values	Unit	Parameter
2.6	ds/m	Electrical conductivity
7.3	----	(pH)
10.2	$g\cdot kg^{-1}$	Organic matter
13.8	$mg\cdot kg^{-1}$	Available nitrogen
5.6	$mg\cdot kg^{-1}$	Available potassium
167	$mg\cdot kg^{-1}$	Available phosphorus
1.13	$g\cdot cm^{-3}$	Bulk density
600	$g\cdot kg^{-1}$ soil	Sand
245	$g\cdot kg^{-1}$ soil	Silt
155	$g\cdot kg^{-1}$ soil	Clay
Sandy loam		Soil texture

Soil analysis was conducted in the Soil Laboratory of the Babil Agriculture Directorate.

Table 2. Chemical composition of potassium silicate

Proportions	Component
%35	Potassium silicate
%12	Potassium oxide

Table 3. Temperature and humidity inside the plastic house

% Humidity	Temperature (°C)	Date
47	16.2	2022/12/16
38	25.7	2022/12/28
28	33.7	2023/1/11
27	33.4	2023/1/21
26	31.5	2023/1/26
28	34.1	2023/2/7

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Preparation of the Extract

Hibiscus Extract

The extract was prepared by soaking hibiscus (karkadeh) flowers in water for 12 hours, then filtering the solution and using it for foliar application.

Leaf Area (cm^2:(

• The surface area of selected plant leaves from each experimental unit was measured using the punching method. Ten known-area discs were taken from five plants, air-dried, then oven-dried at 68°C until constant weight. Leaf area was calculated using the formula described by [23:[

Leaf Area (cm^2)=(Leaf disc area×Dry weight of whole leavesDry weight of discs)÷Number of dried leaves×Total number of leaves\text{Leaf Area (cm^2)} = \left(\frac{\text{Leaf disc area} × \text{Dry weight of whole leaves}}{\text{Dry weight of discs}} \right) ÷ \text{Number of dried leaves} × \text{Total number of leaves}Leaf Area (cm^2)=(Dry weight of discsLeaf disc area×Dry weight of whole leaves)÷Number of dried leaves×Total number of leaves

• Number of Crowns:

Crown numbers were recorded at the end of the growing season per experimental unit, and averages were calculated per plant.

• Yield per Plant (g•plant^{-1}:(

Determined by dividing the total cumulative yield of each unit by the number of plants.

• Total Yield per Plastic House (kg•house^{-1}:(

Cumulative yields were calculated from the first harvest to the final harvest, and total yield per plastic house was estimated using:

Total Yield (kg)=Average Yield per Plant (kg)×Number of Plants per House\text{Total Yield (kg)} = \text{Average Yield per Plant (kg)} × \text{Number of Plants per House}Total Yield (kg)=Average Yield per Plant (kg)×Number of Plants per House

Storage Trial:

Fruits from all field treatments were stored under controlled conditions using a completely randomized design (CRD). From each treatment, 250 g of uniform fruits were placed in perforated plastic containers and stored at 2°Cand a relative humidity of 80–85% for 10 days containers on March 15, 2024 . Data were analyzed using GENSTAT, and means were compared using LSD at a 0.05 significance level .

Storage Trial Parameters:

• Percentage of Weight Loss (Decay:(

Fruits were considered decayed if they showed water-soaked lesions or microbial infection. The percentage of decay was calculated as:

\text{Decay (%) } = \left(\frac{\text{Number of decayed fruits}}{\text{Total number of fruits}} \right) × 100

• Total Soluble Solids (T.S.S:(%

TSS was measured using a handheld refractometer. Juice was extracted from five randomly selected fruits from each experimental unit.

Results and Discussion

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The data presented in Table 1 indicate that foliar application of potassium silicate and aqueous hibiscus extract had a significant effect on several growth and yield parameters of strawberry plants.

Regarding the main effect of potassium silicate (Factor A), treatment A_2 (5.00 ml•L^{-1}) resulted in a significant increase in leaf area, number of crowns, yield per plant, and total yield per plastic house, with recorded values of 235.5 cm², 5.77 crowns•plant^{-1}, 332.5 g•plant^{-1}, and 353.2 kg•plastic house^{-1}, respectively, compared to the control treatment.

Similarly, the aqueous hibiscus extract (Factor C) showed a significant effect under treatment C_2 (10 g•L^{-1}), which led to improvements in the same parameters: leaf area (173.4 cm²), number of crowns (5.28 crowns•plant^{-1}), yield per plant (313.0 g•plant^{-1}), and total yield per plastic house (344.6 kg•plastic house^{-1}.(

In terms of interaction effects between the two factors, the combination A_2 C_1 (5.00 ml•L^{-1} potassium silicate + 5 g•L^{-1} hibiscus extract) recorded the highest leaf area (244.3 cm²). The interaction A_2 C_2 (5.00 ml•L^{-1} potassium silicate + 10 g•L^{-1} hibiscus extract) produced the best results in number of crowns (6.36 crowns•plant^{-1}), yield per plant (341.5 g•plant^{-1}), and total yield per plastic house (370.3 kg•plastic house^{-1}), outperforming all other treatment combinations.

Table 1. Effect of foliar application of potassium silicate and aqueous hibiscus extract on leaf area, number of crowns, yield per plant, and total yield per plastic house in strawberry

Treatment	Leaf Area (cm²)	Crowns (no./plant)	Yield per Plant (g)	Yield per Plastic House (kg)
A0	109.9	4.14	266.6	308.6
A1	139.3	5.08	302.8	328.1
A2	235.5	5.77	332.5	353.2
L.S D A	16.30	0.159	9.33	6.41
c0	149.3	4.79	288.8	317.9
c1	162.0	4.93	300.1	327.2
c2	173.4	5.28	313.0	344.6
LSDc	16.30	0.159	9.33	6.41
A0c0	92.9	4.03	268.1	302.7
A0c1	108.3	4.09	248.8	302.3
A0c2	128.4	4.29	282.8	320.7
A1c0	121.7	4.85	275.9	310.4
A1c1	133.5	5.21	317.9	331.0
A2c2	162.8	5.19	314.6	343.0
A2c0	233.3	5.48	322.4	340.8
A2c1	244.3	5.48	333.5	348.4
A2c2	229.0	6.36	341.5	370.3
LSD Ac	28.23	0.27	16.16	11.10

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The results presented in Table 2 indicate that foliar application of potassium silicate and hibiscus aqueous extract significantly affected most postharvest quality traits of strawberry fruits.

With respect to potassium silicate (Factor A), treatment A_2 (5.00 ml•L^{-1}) resulted in the highest total soluble solids (T.S.S), reaching 8.10%, and the lowest decay percentage after 10 days of cold storage (5.93%), compared to the control treatment .

Similarly, the application of hibiscus extract (Factor C) at 10 g•L^{-1} (C_2) showed a statistically significant increase in T.S.S (8.08%) and a reduction in fruit decay percentage (6.32%) relative to the control.

Regarding the interaction effects, the A_2 C_2 treatment (5.00 ml•L^{-1} potassium silicate + 10 g•L^{-1} hibiscus extract) exhibited the most favorable results, achieving the highest T.S.S value (8.33%) and the lowest decay rate after storage (5.12%) when compared to all other combinations.

Table 2. Effect of foliar application of potassium silicate and aqueous hibiscus extract on total soluble solids (T.S.S %) and postharvest decay percentage of strawberry fruits

Treatment	TSS %	**Percentage of Weight Loss**
A0	7.78	8.04
A1	7.73	6.88
A2	8.10	5.93
LSD A	0.12	0.24
c0	7.62	7.88
c1	7.91	6.65
c2	8.08	6.32
LSD C	0.12	0.24
A0c0	7.70	10.38
A0c1	7.71	7.03
A0c2	7.94	6.71
A1c0	7.35	6.86
A1c1	7.88	6.65
A2c2	7.97	7.12
A2c0	7.82	6.41
A2c1	8.14	6.27
A2c2	8.33	5.12
LSD Ac	0.21	0.42

Discussion

The increase in vegetative growth indicators due to foliar spraying with potassium silicate may be attributed to the fact that silicon increases the size of chloroplasts and the number of grana, which increases their chlorophyll content, thus leading to an increase in the products of photosynthesis (8). It also regulates the absorption of nutrients and the transport of nutrients across cell membranes when deposited in the cell walls (20), in addition to its role in regulating sugar metabolism and hormonal balance (11). The

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nutrient solution also contains a high level of potassium, an element that plays an important role in various vital processes in the plant, as it is considered one of the essential nutrients needed by the plant to complete its life cycle and directly affects photosynthesis in the plant (22) and the regulation of metabolism (5). It also activates more than 60 enzymes and is directly involved in protein synthesis (19). Moreover, it helps in the transport of nutrients from leaves to roots and improves nutrient absorption (21), which led to strong vegetative and floral growth that was reflected in the yield indicators. This agrees with (15) that the increase in growth indicators due to the interaction treatments between the studied factors may be due to the effect of each factor individually in increasing these indicators, and thus these interactions collectively followed the same behavior. These factors, whether individually or in combination, contributed to improving the nutritional status of the plant, which was reflected in its growth and development and created a state of nutritional balance for the plant, resulting in an increase in the quantitative yield of the plant. This agrees with (24.(

As for the aqueous extract of hibiscus, it also recorded an increase in some traits compared to the non-sprayed treatment. This may be attributed to the important nutrients contained in this extract, which are directly or indirectly involved in important vital processes inside the plant, significantly contributing to the plant's growth and development.

The reason may also be that hibiscus extract is considered one of the important sources of vitamins, minerals, compounds, and amino acids, and it stimulates functional processes within plants such as photosynthesis, respiration, chlorophyll formation, cell division, tissue growth, and the regulation and activation of plant hormones (1), and this agrees with (4.(

Conclusions

.1
Foliar application of potassium silicate at 5.00 ml•L⁻ ¹ and hibiscus aqueous extract at 10 g•L⁻ ¹, individually and in combination, significantly improved most of the studied traits in strawberry plants.

.2 Storing strawberry fruits for 10 days at 2°C with 80–85% relative humidity following foliar application with potassium silicate and hibiscus extract had a positive impact on fruit quality indicators, reducing postharvest losses and enhancing marketability.

Recommendations

.1
Foliar spraying of strawberry plants with 5.00 ml•L⁻ ¹ potassium silicate and 10 g•L⁻ ¹ plant extracts is recommended to enhance vegetative growth and increase yield.

.2 It is advisable to promote the use of plant-based extracts, as they are safe, environmentally friendly, and easy to apply.

.3 Implementing pre-cooling of strawberry fruits before storage is essential, as it positively affects postharvest quality and helps maintain fruit characteristics during storage

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