

Evaluation of Strawberry Fruit Quality (*Fragaria* × *ananassa* Duch.) and its Response to Nutrient Solutions

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ABSTRACT

Objective: To evaluate the effect of different nutrient solutions on the fruit quality of artificially pollinated strawberries grown under shade-house conditions in the Guasave Valley, Sinaloa.

Design/methodology/approach: A Randomized Complete Block Design (RCBD) was established with four treatments and six replicates. The evaluated treatments were as follows: T1=Nutrient Solution 1 (NS1)=Steiner solution; T2=Nutrient Solution 2 (NS2)=commercial solution Vidamin-NPK 20-30-10 COMPO EXPERT[®]; T3=Nutrient Solution 3 (NS3)=commercial solution Foliamin K 15-5-30 COMPO EXPERT[®]; and T4=Nutrient Solution 4 (NS4)=tap water without additional nutrients. Fruit physical characteristics (weight and equatorial diameter) and physicochemical characteristics (°Brix, pH, and internal and external color) were evaluated as response variables.

Results: A significant difference ($p \leq 0.05$) was observed for the physical variables, with fruits treated with NS2 and NS3 exhibiting the greatest weight (39.8 g and 36.1 g, respectively). Regarding the physicochemical characteristics, both pH and color (L, a*, C*, and H*) showed significant differences ($p \leq 0.05$). Fruits grown with NS2 exhibited a lower pH (3.3) than those under the other treatments, whose pH ranged from 3.53 to 3.6.

Findings/conclusions: Concerning internal and external color, fruits fertilized with NS1 and NS2 showed greater red color saturation (a*). Overall, the results were favorable in terms of fruit quality. A limitation of this study is that it was conducted under specific shade-house conditions in a single region; nevertheless, nutrient solutions appear to constitute a viable alternative for improving strawberry fruit quality.

Keywords: Physicochemical characterization, internal color, external color, artificial pollination.

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INTRODUCTION

Strawberries (*Fragaria* × *ananassa* Duch.) (Rosaceae) account for an annual production of 641,000 tons (SIAP, 2023). The quality of these fruits depends on numerous factors, among which fertilization and horticultural practices are particularly relevant (Hernández-Martínez *et al.*, 2023). These factors affect both the composition of strawberry fruit and its physical properties, such as color and size. Fruit size, as well as its composition, are attributes that directly influence quality and consumer acceptability.

Fruit size is regulated under different standards (UNECE STANDARD FFV-35, 2017). However, parameters such as total soluble solids (TSS, °Brix), pH, titratable acidity, and total phenolic compounds must be analyzed to assess fruit suitability for processing (Bao *et al.*, 2018). To increase yield and improve quality, it is of utmost importance to understand the nutritional requirements of the crop, as well as their relationship with the environmental factors under which it is produced (Du *et al.*, 2024). The Steiner nutrient solution (1984) is commonly used as a reference because of its nutrient content, ionic balance, and rapid assimilation, which enhance plant performance by promoting growth and fruit production (Luna-Fletes *et al.*, 2021). However, considering the occurrence of certain types of abiotic stress during the crop growth cycle, such as extreme temperatures and water stress, which cause losses in both quality and yield, the use of biostimulants has also been increasingly implemented. When applied to crops, these compounds stimulate growth and development by influencing physiological processes (Ikan *et al.*, 2023) and biochemical processes, such as protein and chlorophyll biosynthesis and the accumulation of metabolites responsible for stimulating the formation of reproductive structures such as flowers and fruits (Rouphael and Colla, 2020). This, in turn, allows for improved nutrient absorption and greater tolerance to adverse climatic conditions (Batista *et al.*, 2015; Du Jardin, 2015; Veobides-Amador *et al.*, 2018; Drobek *et al.*, 2019). Based on the foregoing, the aim of the present study was to evaluate the effect of different nutrient solutions on the quality of artificially pollinated strawberry fruit under shade-house conditions in the Guasave Valley, Sinaloa, Mexico.

MATERIALS AND METHODS

Crop establishment

The study was conducted inside a double-section shade-house structure covered with anti-aphid mesh and equipped with a manually operated upper shade curtain, with a height of 4 m and an area of 74 m², without climate control. It was located at the experimental field of the Instituto Tecnológico Superior de Guasave, Ejido El Burriñoncito, municipality of Guasave, Sinaloa, Mexico [25° 31' 30" N latitude, 108° 22' 37" E longitude; altitude 19 m (INEGI, 2022)]. The plant material used consisted of the strawberry cultivar 'Frontera'. Seedlings were obtained from local growers in the municipality of Ahome, Sinaloa, Mexico. To establish the experiment, a hydroponic system was built using 4-inch hydraulic PVC pipes cut in a "U" shape and suspended 1 m above the ground, filled with a coconut-husk substrate composed of 50% dust and 50% fiber, and supported by ½-inch-diameter galvanized steel posts welded in a "T" shape and previously anchored into the soil. Each pipe section was 2 m long. Six sections were arranged in parallel per bench, for a total of four hydroponic benches. Six pipe sections were used per treatment, for a total of 24 experimental units arranged in a Randomized Complete Block Design (RCBD), with four treatments and three replicates. The evaluated treatments were: T1=Nutrient Solution 1 (NS1)=Steiner solution; T2=Nutrient Solution 2 (NS2)=commercial solution Vidamin-NPK 20-30-10 COMPO EXPERT[®]; T3=Nutrient Solution 3 (NS3)=commercial solution Foliamin K 15-5-30 COMPO EXPERT[®]; and T4=Nutrient Solution 4 (NS4)=tap water without additional nutrients. Irrigation was supplied through drip tape with a discharge

rate of 0.9 L h^{-1} per emitter and 10 cm spacing between emitters, connected to a $\frac{1}{4}$ hp centrifugal pump by means of a 16-mm blind hose and drip-tape starter valves. Irrigation was automated using a digital timer to provide five to eight irrigation events per day, depending on ambient temperature and evapotranspiration rate. The fertigation system was supplied by four 200-L containers, one for each nutrient solution, and each nutritional formula was applied independently in alternating turns. Transplanting was carried out on October 27, 2023, simultaneously in all experimental units. During the first days, irrigation consisted only of water from the supply canal, after which the different nutrient solutions were applied. Drainage was collected in trays, where volume, pH, and electrical conductivity were monitored twice a week from October 30, 2023, to February 26, 2024. For pest control, a schedule of repellent applications and preventive control molecules was implemented twice a week, together with sanitation pruning at the same frequency. During flowering, to favor pollination, programmed vibration motors were used daily for 3 hours from 11:00 to 13:00.

Evaluated variables

Physical characteristics

Physical variables such as fruit weight and equatorial diameter were evaluated once fruit maturity was reached, approximately 150 days after establishment. Diameter was measured at the widest part of the fruit using a digital caliper (AEGTVA[®]), whereas fruit weight was recorded using an OHAUS[®] analytical balance, model PX224 (Alvarado-Chávez *et al.*, 2020).

Physicochemical characteristics

The evaluated physicochemical characteristics were hydrogen potential (pH), total soluble solids ($^{\circ}$ Brix), and internal and external fruit color (CIELAB L^* , a^* , b^* , C^* , h^*), which were determined after each harvest. pH was measured with a HANNA Hi98130 pocket pH meter, and fruit $^{\circ}$ Brix was measured with a previously calibrated Cat Exttech Rf12 optical refractometer. The evaluation was performed from strawberry juice, in accordance with standard NMX-FF-062-SCFI-2002. Fruit color was measured using a colorimeter (CR-400 Chroma, Minolta, Osaka, Japan). Color parameters were recorded in the CIELAB color space, where L^* corresponds to lightness (0=black and 100=white), a^* ranges from positive to negative values, with red represented by positive values and green by negative values, and b^* determines yellow when values are positive and blue when they are negative. The h° value corresponds to hue angle expressed in degrees (0° =red, 90° =yellow, 180° =green, and 270° =blue), and C^* corresponds to chroma, where a higher value indicates greater color intensity.

Statistical analysis

Statistical analysis of the results was performed using one-way analysis of variance (ANOVA), and differences among treatments were determined by Tukey's test at a 95% confidence level. Data were processed using Minitab[®] 19.

RESULTS AND DISCUSSION

Physical variables

The statistical analysis revealed significant differences ($p \leq 0.05$) among the applied treatments. With regard to the evaluated physical variables, namely fruit weight and equatorial diameter, both exhibited statistically significant differences. The results obtained for fruit weight are presented in Figure 1, where NS2 and NS3 showed the highest values, with mean weights of 39.8 ± 1.5 g and 36.1 ± 2.15 g, respectively. Fruits fertilized with NS1 exhibited an average weight of 32.77 ± 1.72 g, whereas the control treatment (NS4) showed the lowest values, with 25.67 ± 1.65 g. Fruit weight is a highly relevant variable for quality assessment, as it is closely associated with crop yield performance. The fruit weight observed in the present study exceeded the ranges reported by Mixquititla-Casbis *et al.* (2020), who recorded values from 6.13 to 12.64 g in the San Andreas cultivar. However, our findings are consistent with those reported by Simkova *et al.* (2023) for the Lycia cultivar, in which fruit masses of up to 40.95 g were achieved, suggesting that the phenotypic response of fruit weight is strongly dependent on genotype and nutritional management.

Regarding equatorial diameter, significant differences ($p \leq 0.05$) were also detected among treatments (Figure 2). Fruits fertilized with NS3 exhibited the greatest diameter, with an average of 4.59 ± 0.22 cm, which was statistically different ($p \leq 0.05$) from the other treatments. NS1 and NS2 recorded average values of 3.47 ± 0.69 cm and 3.52 ± 0.37 cm, respectively, whereas the lowest value was observed in fruits treated with NS4 (3.91 ± 0.12 cm). Equatorial diameter is a parameter commonly used to classify strawberries according to different quality grades (NMX-FF-062-SCFI-2002). In a study conducted by Simkova *et al.* (2023), diameters ranging from 2.13 cm to 4.22 cm were reported for the Lycia and Clery strawberry cultivars, which are similar to those found in the present study.

Physicochemical variables

Total soluble solids represent the amount of sugars dissolved in the fruit and are directly associated with sweetness. The data obtained for this parameter are presented

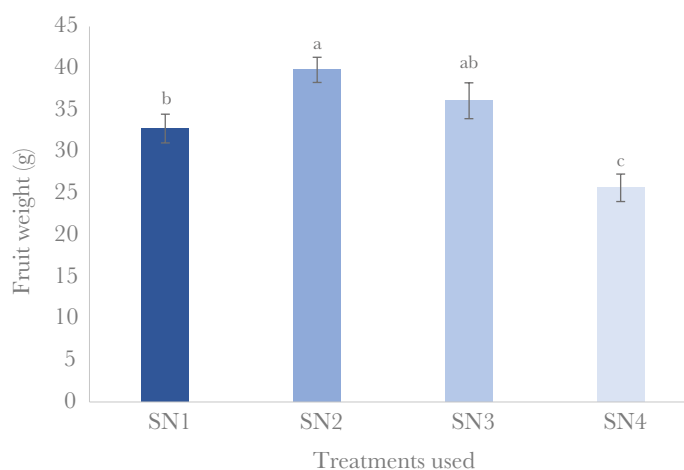


Figure 1. Average weight of strawberry fruits grown under shade-house conditions and fertilized with different nutrient solutions. Different letters above the bars indicate significant differences ($p \leq 0.05$).

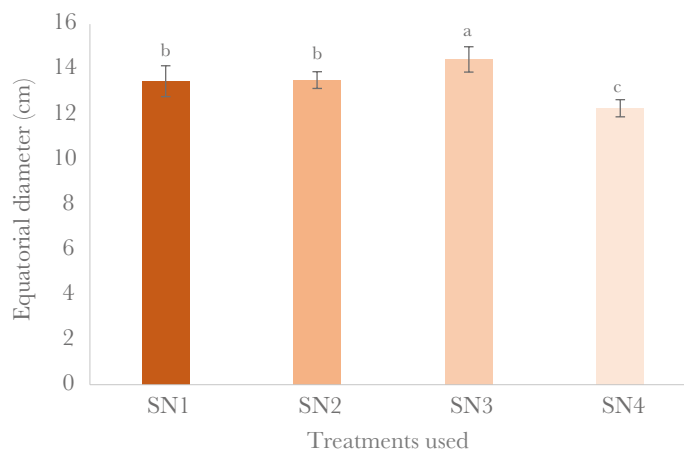


Figure 2. Average equatorial diameter of strawberry fruits grown under shade-house conditions and fertilized with different nutrient solutions. Different letters above the bars indicate significant differences ($p \leq 0.05$).

in Figure 3, where no significant differences ($p \geq 0.05$) were observed among treatments. Values ranged from 4.5 ± 0.4 to 4.9 ± 0.1 °Brix across all analyzed samples. In a study conducted on strawberry fruits of the Alba cultivar, Ceccanti *et al.* (2024) reported total soluble solids (TSS) values ranging from 7.2 to 8.4 °Brix. This parametric variation may be attributed to intrinsic factors, such as genotype and maturity stage, as well as to extrinsic factors associated with agronomic management.

Figure 4 shows the pH values obtained for strawberries grown with different nutrient solutions, revealing significant differences ($p \leq 0.05$) among treatments. Fruits grown with NS2 exhibited a lower pH (3.30 ± 0.1) than those cultivated with the other nutrient solutions, whose values ranged from 3.53 ± 0.15 to 3.60 ± 0.2 . pH values ranging from 3.46 to 3.48 have been reported for strawberries of the Rociera cultivar (Rabasco-Vílchez *et al.*, 2024).

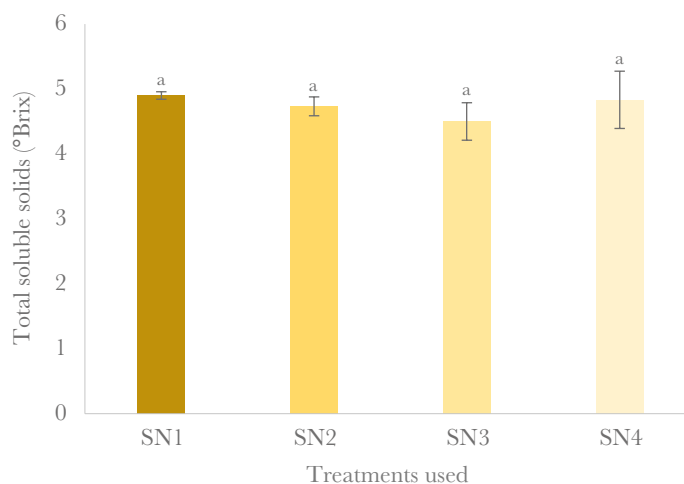


Figure 3. Average total soluble solids (°Brix) of strawberry fruits grown under shade-house conditions and fertilized with different nutrient solutions. Different letters above the bars indicate significant differences ($p \leq 0.05$).

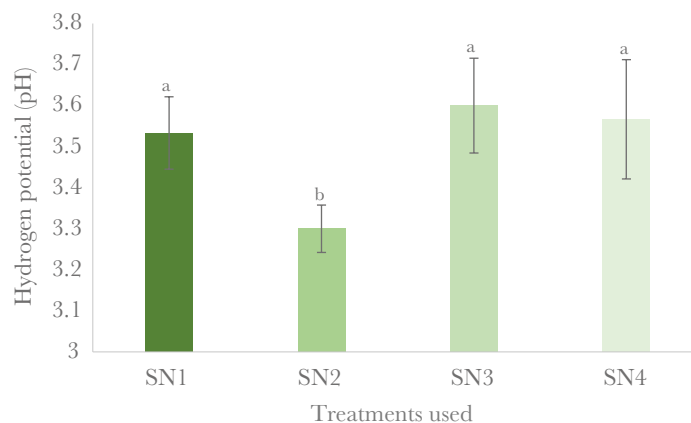


Figure 4. Average hydrogen potential (pH) of strawberry fruits grown under shade-house conditions and fertilized with different nutrient solutions. Different letters above the bars indicate significant differences ($p \leq 0.05$).

The external appearance and color of fruits are critical determinants in consumer purchase decisions; therefore, their physicochemical characterization is of considerable importance. The results presented in Table 1 show that most of the evaluated chromatic coordinates (L^* , a^* , C^* , and h^*) exhibited significant differences ($p \leq 0.05$) among treatments, with the exception of parameter b^* ($p > 0.05$), which remained stable within a range of 19.38 ± 0.86 to 21.54 ± 1.08 . Regarding lightness (L^*), fruits fertilized with NS3 (38.12 ± 1.01) and NS4 (37.24 ± 0.46) showed the highest values, whereas NS1 (34.37 ± 0.59) and NS2 (35.24 ± 0.47) produced darker fruits. The a^* coordinate, which reflects red color saturation and constitutes a fundamental quality parameter in strawberry, varied significantly from 29.92 ± 0.47 (NS3) to 33.54 ± 0.53 (NS1). Finally, the variables derived from the color space, namely chroma (C^*) and hue angle (h^*), revealed that treatment NS1 exhibited the highest color saturation (39.60 ± 0.62), while the highest hue values were recorded in fruits fertilized with nutrient solutions NS3 and NS4 (0.62 ± 0.02).

Internal color, or pulp color, is of even greater importance during fruit processing, as it contributes to maintaining uniform coloration in derived products. As shown in Table 2, the parameters evaluated for this trait were also L^* , a^* , b^* , C^* , and h^* . In this case, significant differences ($p \leq 0.05$) were observed for all parameters. Regarding L^* , the highest mean value was recorded in fruits grown with NS3 (48.84 ± 1.36), whereas the lowest was observed in NS4 (41.20 ± 0.66). In contrast, the a^* parameter exhibited an inverse trend

Table 1. Mean values and standard deviation of external color (L^* , a^* , b^* , C^* , h^*) in strawberry fruits.*.

Treatments	Variable				
	L^*	a^*	b^*	C^*	h^*
NS 1	34.37 ± 0.59^b	33.54 ± 0.53^a	21.03 ± 0.49	39.60 ± 0.62^a	0.56 ± 0.01^b
NS 2	35.24 ± 0.47^b	31.35 ± 1.07^{ab}	19.38 ± 0.86	36.87 ± 1.30^b	0.55 ± 0.01^b
NS 3	38.12 ± 1.01^a	29.92 ± 0.47^b	21.36 ± 1.21	36.82 ± 0.96^b	0.62 ± 0.02^a
NS 4	37.24 ± 0.46^a	30.26 ± 0.60^b	21.54 ± 1.08	37.17 ± 1.05^b	0.62 ± 0.02^a

^{abc} Different literal indicates significant difference ($p \leq 0.05$).

Table 2. Mean values and standard deviation of internal color (L*, a*, b*, C*, h*) in strawberry fruits.*

Treatments	Variable				
	L*	a*	b*	C*	h*
NS 1	44.29±0.50 ^b	33.91±0.50 ^{ab}	35.14±0.91 ^a	48.84±0.99 ^a	0.80±0.01 ^b
NS 2	42.60±0.70 ^{bc}	32.87±0.61 ^b	32.58±0.83 ^b	46.31±0.77 ^b	0.78±0.01 ^c
NS 3	48.84±1.36 ^a	28.48±1.15 ^c	35.48±0.77 ^a	45.56±1.00 ^b	0.90±0.02 ^a
NS 4	41.20±0.66 ^c	34.07±0.53 ^a	32.63±1.13 ^b	47.19±1.12 ^{ab}	0.76±0.01 ^c

^{abc} Different literal indicates significant difference ($p \leq 0.05$).

relative to L*, with the highest value recorded in treatment NS4 (34.07 ± 0.53) and the lowest in NS3 (28.48 ± 1.15). As for C*, the behavior differed, since the highest value for this parameter was observed in NS1, with a mean of 39.60 ± 0.62 , which was statistically different ($p \leq 0.05$) from all other treatments.

Fruit color can be attributed to multiple factors, including maturity stage, agronomic conditions, genotype, and cultivar, among others. Kilic *et al.* (2021) conducted a study evaluating the effect of chemical and organic fertilizers on the quality of strawberry fruits (*Fragaria* × *ananassa* Duch.) and reported that L* ranged from 24.76 to 33.40, a* from 34.72 to 41.26, b* from 18.57 to 25.80, and C* from 39.64 to 47.94. These values are comparable to those obtained in the present study. In another investigation, Cao *et al.* (2023) reported L* values ranging from 36 to 38, a* values between 44 and 46, and b* values from 32 to 36 in strawberry fruits subjected to different pollination types. Likewise, these values are consistent with those observed in the present research.

CONCLUSIONS

The application of different fertilization schemes based on nutrient solutions significantly affected the quality profile of strawberry fruits, improving not only their shape and size, but also their physicochemical and color attributes. The data showed that fruits fertilized with NS2 and NS3 exhibited superior weight and equatorial diameter, both of which are key indicators of commercial performance. Regarding fruit pH, a tendency toward greater acidity was observed in one of the evaluated treatments (NS2). In terms of color, treatment NS1 recorded the highest saturation of red hues in both the external surface and the pulp, suggesting a positive correlation between this formulation and anthocyanin concentration, thereby reinforcing the aesthetic and nutritional quality of the product.

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