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INFLUENCE OF NUTRIENT REGIMES ON YIELD AND QUALITY OF STRAWBERRY (*FRIGARIA×ANANASSA*) UNDER EBB AND FLOW SYSTEM OF HYDROPONICS

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ABSTRACT

To study the influence of different nutrient concentration of Hoagland solution (50, 80, 130 and 200 %) on yield and quality of strawberry cv Sweet Sensation under ebb and flow system of hydroponics, an experiment was conducted at Soilless Agriculture Demonstration Unit, NSP, University of Agricultural Sciences, GKVK, Bengaluru. The results reveal that Treatment T_3 (26.85 days) was first to flower with highest number of flowers (19.36), highest number of fruits (16.57), highest fruit set percentage (85.41 %), longest fruit (32.64 mm), highest fruit weight (13.41 g), highest fruit volume (17.90 cm^3), highest per plant yield (222.44 g), highest TSS (9.46 °Brix), highest TSS: Acid ratio (11.57) and highest total sugar content (8.73). However, 50 per cent Hoagland or 200 per cent Hoagland produced lowest yield and quality. Strawberry grown under ebb and flow system with 130 per cent of Hoagland solution produced optimum yield and quality compared to other treatments. Hence this treatment can be used for production of strawberry under ebb and flow system for maximum yield and better quality.
Keywords **:** Strawberry, Ebb and Flow, Soilless culture, Hoagland Solution .

Introduction

Soil is the most readily available growing medium for plants, providing vital support, nutrients, water, and air necessary for healthy plant development. However, cultivating plants in soil presents numerous challenges. By 2050, it is estimated that nearly half of the world's arable land will no longer be suitable for agriculture, primarily due to the impacts of climate change (Annon, 2017). To meet the food demands of a rapidly increasing global population, agricultural production will need to rise by 110 per cent (Gashgari *et al.*, 2018). Additional challenges associated with soil-based farming include the presence of harmful pathogens, unsuitable pH levels, compaction, poor drainage, and erosion. Furthermore, traditional open-field farming demands significant amounts of space, labour, and water resources. In densely populated urban areas, fertile land may be limited or unavailable due to geographical and topographical constraints (Sharma *et al.*, 2022). These challenges emphasize the urgency of developing alternative methods for food production that are cost-effective, resource-efficient, and capable of addressing rising global food demands.

Strawberry (*Fragaria × ananassa Duch.*), a hybrid species from the Rosaceae family, originated from the crossbreeding of *Fragaria chiloensis* (native to Chile) and *Fragaria virginiana* (native to North America) (Darrow, 1966). This crop has historical roots in France, which is regarded as the center of its origin (Liston *et al.*, 2014). Strawberries are among the most economically important and widely consumed fruit crops worldwide, highly valued for their exceptional flavor, vibrant color, and rich nutritional profile (Sturm *et al.*, 2003).

Global strawberry production currently stands at approximately 9.57 million metric tonnes annually. China is the largest producer, contributing 3.36 million tonnes, followed by the United States with 1.42 million tonnes. Together, these two countries account for half of the world's total production. In India, during 2021–22, strawberries were cultivated on 3,031 hectares, yielding 19,840 metric tonnes (Annon, 2023). Haryana leads India's production with 31.50%, followed by Maharashtra at 24.50%, and Jammu and Kashmir at 20.93%. Additionally, strawberry cultivation has recently expanded to specific regions of Karnataka, including Belagavi, Bengaluru Rural, Dharwad, and Shivamogga.

As global awareness of health and nutrition grows, strawberries are becoming increasingly popular due to their rich nutritional content. They are an excellent source of ascorbic acid, natural sugars, secondary metabolites, and antioxidants, which provide various health benefits (Pe-Rez *et al*., 1997; Kanupriya, 2002). A 100-gram serving of strawberries contains 89 grams of water, 0.07 grams of protein, 0.5 grams of fat, 8.4 grams of carbohydrates, and 59 milligrams of ascorbic acid (Galletta and Bringhurst, 1995). Strawberries are consumed both fresh and in processed forms, including ice cream, beverages, candies, and preserves such as jams and jellies, which make them available year-round (Galletta and Bringhurst, 1995).

Consuming strawberries offers numerous health advantages, including lowering cholesterol levels, improving vascular health, reducing inflammation, and combating oxidative stress-related diseases such as cancer (Giampieri *et al*., 2012; Hannum, 2004; Zhang *et al*., 2008). They are also rich in phenolic compounds, which act as powerful antioxidants and are linked to preventing cardiovascular diseases and cancer (Hakkinen and Torronen, 2000).

Growing strawberries hydroponically is a sustainable alternative to traditional cultivation. This method minimizes the use of water and pesticides while maximizing productivity. Hydroponically cultivated strawberries also cater to the growing demand for high-quality, nutrient-dense foods and can command premium prices due to their superior quality and health benefits. Keeping the above facts in mind the present investigation was carried out to examine the effect of nutrient concentration on yield and quality of strawberry grown under Ebb and flow system of hydroponics.

Materials and Methods

Site description and treatment details

Strawberry plants (cv. Sweet Sensation) of similar growth were procured from KF Bioplants Ltd. Pune. These plants were planted under Ebb and flow system of hydroponics in soilless medium. The experiment was carried out at temperature-controlled greenhouse of Soilless Agriculture Demonstration Unit, National Seed Project, University of Agricultural Sciences, GKVK, Bengaluru. Geographically it is located in Eastern Dry Zone (Zone-5) of Karnataka at latitude 13º5º N and 77º34º E with an altitude of 923.3 m above mean sea level.

The soilless substrates (*viz.,* coco peat, perlite etc.) and water-soluble plant nutrients were procured from Green Heaven, Rajiv Gandhinagar, Bengaluru. Four different nutrient concentrations were prepared namely, T_1: Hoagland solution (50 %), T_2: Hoagland solution (80 %), T_3: Hoagland solution (130 %), T_4: Hoagland solution (200 %). Following is the nutrient composition:

- Hoagland solution (50 %) (ppm): N-105.00, P-15.50, K-117.00, Ca-100.00, Mg-17.00, S-32.00, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04
- Hoagland solution (80 %) (ppm): N-168.00, P-24.80, K-187.20, Ca-160.00, Mg-27.20, S-51.20, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04
- Hoagland solution (130 %) (ppm): N-273.00, P-40.30, K-304.20, Ca-260.00, Mg-44.20, S-83.20, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04
- Hoagland solution (200 %) (ppm): N-420.00, P-62.00, K-468.00, Ca-400.00, Mg-68.00, S-128.00, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04

The temperature (23℃/17℃) and relative humidity inside the polyhouse was controlled by sensor-based technology.

Experimental Setup

For this experiment, strawberry plants (cv. Sweet Sensation) are grown using an ebb and flow hydroponics system, where each treatment receives a specific nutrient concentration. Each treatment is cultivated on separate ebb and flow tables, ensuring that the nutrient solutions applied to the plants remain independent for each group. To ensure accurate application of the different nutrient regimes, each ebb and flow table is provided with a dedicated nutrient reservoir. Strawberry plants are placed in individual pots filled with a mixture of soilless media; these pots allow the nutrient solution into the media during the flood cycle via capillary action. Each table had a drainage outlet to allow the nutrient solution to return to the dedicated reservoir after the flood cycle. The pH and electrical conductivity (EC) of each nutrient solution are regularly monitored to ensure the nutrient levels remain optimal for plant growth. Adjustments are made as necessary to maintain the target nutrient concentration in each reservoir.

Methodology

Days to first flowering was recorded as a total number of days taken from the date of planting to the date of appearance of the first flower bud. Fruit length of ten randomly selected fruits from each treatment was measured with the help of a vernier calliper and average fruit length was expressed in millimetre. Diameter of ten randomly selected fruits from each treatment was measured with the help of a digital vernier calliper and average fruit diameter was expressed in millimetres. Weight of 5 randomly selected fruits from each treatment in each replication was taken at each picking using the sensitive balance and average fruit weight was calculated, and expressed in gram.

The water displacement method was used for calculating fruit volume. To perform this measurement, a graduated cylinder is filled with a known volume of water, and the initial water level is recorded. The fruit is then gently submerged in the water, ensuring that it is completely underwater without causing splashing. The new water level is recorded, and the difference between the initial and final water levels gives the volume of fruit and expressed in cubic centimetre.

The healthy and not misshapen fruits were sorted and fruits weighed more than 10 gram per fruit considered as marketable. The per cent marketable yield is calculated using the following formula:

$$\text{Per cent marketable yield} = \frac{\text{Marketable yield per plant}}{\text{Yield per plant}} \times 100$$

Total soluble solids (TSS) of the berry juice were determined with the help of Erma Hand Refractometer (0-32°Brix). The Refractometer was calibrated with distilled water before use and then a few drops of fruit juice were placed on the prism and the reading was recorded. The results thus obtained were expressed in degree Brix of juice

Acidity was determined by titration method. 10 gram of fruit samples was macerated with distilled water, filtered through muslin cloth and made up to 10 ml with distilled water. 5 ml of this was titrated against standard NaOH using phenolphthalein as an indicator. The appearance of light pink colour was marked as the end point. The value was expressed in terms of malic acid as per cent titratable acidity.

Total sugar was estimated by following procedure. Twenty-five grams of fresh berry pulp was taken in a 250 mL volumetric flask and thoroughly homogenized in distilled water. To this, 10 mL of 45 per cent saturated lead acetate was added and the contents were shaken and filtered and kept for ten minutes. Thereafter, 10 mL of 22 per cent potassium oxalate was added to precipitate the excess of lead and the final volume was made to 250 mL with distilled water. The contents were again filtered and one hundred ml of the filtrate was taken in another 250 mL volumetric flask, it was hydrolysed by adding 5 mL of concentrated hydrochloric acid. The hydrolysis was carried out by keeping it overnight. The excess of acid was then neutralized by adding saturated sodium hydroxide and the final volume was made to 250 ml with distilled water. The hydrolysed aliquot was then taken in a burette and titrated against a boiling mixture of five ml solution each of Fehling A and Fehling B reagents using methylene blue as an indicator. The end point was indicated by the appearance of a brick red colour Rangana (1986). Total sugars were expressed in per cent on fresh berry weight basis by using the following formula:

$$\text{Total sugar (\%)} = \frac{(\text{Fehling factor} \times \text{Dilution} \times \text{Dilution})}{\text{Titre value} \times \text{Volume of aliquot} \times \text{Weight of sample taken}}$$

The remaining filtered stock solution was used for the determination of reducing sugars. Boiling solution mixture containing 5 mL each of Fehling A and Fehling B reagents was titrated against remaining unhydrolyzed, de-leaded and clarified pulp solution obtained from above total sugars solution using methylene blue as an indicator. The end point was indicated by the appearance of a brick red colour. The results were expressed as per cent on fresh berry weight basis as given below:

$$\text{Reducing sugar (\%)} = \frac{\text{Fehling factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight of sample}} \times 100$$

The statistical design used for the experiment was Completely Randomized Design (CRD) with five replications. The overall significance of difference among the treatments was tested, using critical differences (C.D.) at 5 per cent level of significance. The results were statistically analysed using OPSTAT.

Results and Discussion

Days taken for the first flowering

The number of days taken for the first flowering is an important indicator of the plant's readiness to transition from vegetative growth to the reproductive phase. The shortest time taken for first flowering (26.85 days) was observed in T_3 (Hoagland solution 130 %), followed by T_2 (Hoagland solution 80 %) at 30.17 days. The earlier flowering observed in these treatments suggests that nutrient concentrations between 80 per cent and 130 per cent of the standard Hoagland solution are optimal for promoting the timely onset of flowering. This is consistent with findings by Giri *et al*. (2024), who reported that adequate nutrient supply accelerates the transition to the reproductive phase by providing the necessary energy and resources for flower development. On the other hand, T_1 (Hoagland solution 50 %) took the longest time to initiate flowering (33.31 days). The delayed flowering in this treatment is likely due to nutrient deficiency, which can slow down the metabolic processes of plant and delay the transition to flowering. Telgote and Mishra (2024), observed that suboptimal nutrient concentrations can extend the vegetative phase and delay flowering, as the plant prioritizes vegetative growth over reproductive development under nutrient-limited conditions (Table 1).

Number of flowers

The number of flowers produced by a plant is directly related to its potential fruit yield. T_3 (Hoagland solution 130 %) produced the highest number of flowers (19.36), followed by T_4 (Hoagland solution 200 %) and T_2 (Hoagland solution 80 %) with 14.65 and 14.08 flowers, respectively. The higher flower production in T_3 suggests that this nutrient concentration provides the optimal balance of nutrients necessary for maximizing flower initiation and development. This finding aligns with Singh *et al.* (2019), who found that nutrient concentrations slightly above the standard Hoagland solution enhance flowering by ensuring that the plant has sufficient resources to support reproductive growth. In contrast, T_1 (Hoagland solution 50 %) produced the fewest flowers (13.32), indicating that nutrient deficiency limits the ability of plant to produce flowers. Roostaa and Hamidpour (2011) reported that suboptimal nutrient levels can reduce the number of flowers by restricting the availability of essential nutrients required for flower initiation and development (Table 1).

Number of fruits

The number of fruits is a crucial determinant of yield and productivity. T_3 (Hoagland solution 130 %) outperformed the other treatments, producing the highest number of fruits (16.57), followed by T_2 (Hoagland solution 80 %) with 11.43 fruits. The superior fruit production in these treatments indicates that nutrient concentrations within this range are optimal for supporting fruit set and development. Giri *et al*. (2024) noted that adequate nutrient supply during the flowering and fruiting stages is essential for maximizing fruit production, as it ensures that the plant has sufficient resources to support the development of multiple fruits. On contrary, T_1 (Hoagland solution 50 %) recorded the lowest fruit production, with an average of 9.04 fruits per plant, highlighting the negative impact of nutrient deficiency on fruit set. The reduced fruit number in this treatment may be due to inadequate nutrient availability, which can lead to poor flower development, reduced pollination efficiency, and lower fruit set. Shah *et al*. (2011) observed that nutrient-deficient conditions often result in lower fruit set and reduced yield due to the plant's inability to sustain reproductive growth under nutrient-limited conditions (Table 1).

Fruit set percentage

The fruit set percentage is a measure of the efficiency with which flowers are converted into fruits, reflecting the overall reproductive success of the plant. T_3 (Hoagland solution 130 %) recorded the highest fruit set percentage (85.41 %), followed by T_2 (Hoagland solution 80 %) with 81.30 per cent. The high fruit set in these treatments suggests that the nutrient concentrations provided an optimal environment for successful pollination, fertilization, and fruit development. This result is consistent with the findings of Magwaza *et al*. (2020), who reported that optimal nutrient concentrations enhance fruit set by ensuring that the plant has sufficient energy and resources to support the conversion of flowers into fruits. In contrast, T_1 (Hoagland solution 50 %) had the lowest fruit set percentage (67.89 %), indicating that nutrient deficiency negatively impacts the ability of plant to convert flowers into fruits. The lower fruit set in this treatment may be due to reduced flower quality, poor pollination efficiency, or early fruit drop, all of which can be exacerbated by inadequate nutrient availability. Hanic *et al*. (2012) suggested that nutrient-deficient conditions often lead to reduced fruit set due to the inability of plant to allocate sufficient resources towards reproductive processes (Table 1).

Table 1: Effect of various nutrient regimes on days to first flowering, number of flowers, number of fruits, fruit set percentage of strawberry cv. Sweet Sensation under Ebb and flow system of hydroponics

Treatments	Days to first flowering	Number of flowers	Number of fruits	Fruit set per cent (%)
T_1- Hogland solution (50 %)	33.31	13.32	9.04	67.89
T_2- Hogland solution (80 %)	30.17	14.08	11.43	81.30
T_3- Hogland solution (130 %)	26.85	19.36	16.57	85.41
T_4- Hogland solution (200 %)	28.43	14.65	10.95	74.78
F test	*	*	*	*
S. Em	0.17	0.19	0.25	1.02
CD @ 5%	0.51	0.56	0.74	3.02

Fruit length

Fruit length is an important quality parameter that affects the overall appearance and marketability of strawberries. In this study, T_3 (Hoagland solution 130 %) produced the longest fruits (32.64 mm), significantly outperforming the other treatments. This suggests that a nutrient concentration of 130 per cent of the Hoagland solution is optimal for maximizing fruit elongation. The results are consistent with findings by Telgote and Mishra (2024), who reported that sufficient nutrient availability, particularly potassium and nitrogen, promotes cell elongation and fruit growth, resulting in longer fruits. On the other hand, T_1 (Hoagland solution 50 %) recorded the shortest fruits (18.30 mm). The reduced fruit length in this treatment is likely due to nutrient deficiency, which can limit cell division and elongation during fruit development. Borgognone *et al.* (2013) and Noh *et al.* (2017) observed that inadequate nutrient supply can lead to smaller fruit sizes due to restricted growth and development of the fruit tissues (Table 2).

Fruit diameter

Fruit diameter is another key quality attribute that influences the perceived size and appeal of strawberries. T_3 (Hoagland solution 130 %) produced the largest fruit diameter (27.31 mm). The significant increase in fruit diameter in this treatment indicates that an elevated nutrient concentration supports not only elongation but also the radial expansion of the fruit. Giri *et al.* (2024) noted that optimal nutrient supply enhances both cell division and expansion in the fruit, leading to increased fruit diameter and overall size. In contrast, T_1 (Hoagland solution 50 %) had the smallest fruit diameter (17.20 mm), reflecting the impact of nutrient deficiency on fruit growth. The smaller diameter observed in T_1 could be due to the limited availability of essential nutrients, which are crucial for promoting cell division and expansion within the fruit. Roostaa and Hamidpour (2011) highlighted those suboptimal nutrient levels often result in smaller fruits due to inadequate cell growth and expansion (Table 2).

Fruit weight

Fruit weight is a critical parameter that directly impacts yield and market value. T_3 (Hoagland solution 130 %) produced the heaviest fruits (13.41 g), indicating that this nutrient concentration is highly effective in promoting substantial fruit growth. The increased fruit weight in T_3 can be attributed to the adequate nutrient supply, which supports the accumulation of both water and dry matter in the fruit. This finding aligns with the reports of Magwaza *et al.* (2020), who reported that optimal nutrient concentrations are essential for maximizing fruit weight by enhancing both the growth and metabolic activity of the fruit tissues. On the other hand, T_1 (Hoagland solution 50 %) resulted in the lightest fruits (6.86 g). The reduced fruit weight in this treatment is likely due to nutrient limitations that restrict the accumulation of dry matter and water in the fruit. Shah *et al.* (2011) observed that nutrient-deficient conditions often lead to lower fruit weights due to the plant's inability to allocate sufficient resources towards fruit development (Table 2).

Fruit volume

Fruit volume is closely related to both the weight and size of the fruit and is an important quality attribute for consumer acceptance. T_3 (Hoagland solution 130 %) again showed superior performance, with the highest fruit volume of 17.90 cm^3. The increased fruit volume in this treatment reflects the combined effects of greater fruit length, diameter, and weight, all of which contribute to a larger overall fruit size. This suggests that a nutrient concentration of 130 per cent of the Hoagland solution provides the optimal conditions for maximizing fruit volume, as it supports extensive growth in all dimensions of the fruit. Hanic *et al.* (2012) emphasized that adequate nutrient supply is critical for achieving large fruit volumes, as it ensures that the fruit can grow both in size and weight.

Conversely, T_1 (Hoagland solution 50 %) had the smallest fruit volume at 8.368 cm^3, further highlighting the negative impact of nutrient deficiency on fruit development. The smaller fruit volume observed in T_1 is likely due to the limited cell division and expansion, which result from insufficient nutrient availability. Noh *et al.* (2017) reported that suboptimal nutrient levels can lead to smaller fruit volumes by restricting the growth potential of the fruit (Table 2).

Table 2: Effect of various nutrient regimes on fruit length, fruit length, fruit diameter, fruit weight and fruit volume of strawberry cv. Sweet Sensation under Ebb and flow system of hydroponics

Treatments	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	Fruit volume (cm^3)
T_1- Hogland solution (50 %)	18.30	17.20	6.86	8.36
T_2- Hogland solution (80 %)	22.77	18.26	7.77	10.01
T_3- Hogland solution (130 %)	32.64	27.31	13.41	17.90
T_4- Hogland solution (200 %)	24.54	21.47	9.79	12.09
F test	*	*	*	*
S. Em	0.29	0.24	0.06	0.17
CD @ 5%	0.88	0.71	0.17	0.50

*-Significant; S. Em-Standard error mean; CD- Critical difference; NS- Non significant

Yield per plant

The total yield per plant represents the overall fruit production, which is a critical determinant of the productivity of the strawberry plants. T_3 (Hoagland solution 130 %) produced the highest yield per plant (222.44 g), significantly outperforming the other treatments. This suggests that a nutrient concentration of 130 per cent of the Hoagland solution is optimal for maximizing fruit production in strawberry plants. The enhanced yield in T_3 can be attributed to the optimal nutrient availability, which supports robust vegetative growth, flowering, and fruit set, leading to higher fruit production. This finding aligns with the results of Giri *et al.* (2024), who reported that optimal nutrient concentrations enhance both vegetative and reproductive growth, resulting in increased yields. On contrary, T_1 (Hoagland solution 50 %) recorded the lowest yield per plant (62.12 g), indicating that nutrient deficiency severely limits fruit production. The reduced yield in T_1 is likely due to the insufficient nutrient supply, which restricts the ability of plant to develop and sustain a large number of fruits. Roostaa and Hamidpour (2011) reported that suboptimal nutrient levels often result in lower yields due to inadequate support for fruit development and maturation (Table 3).

Marketable yield per plant

Marketable yield per plant is a key parameter that reflects the proportion of the total yield that meets market standards for quality, size, and weight. T_3 (Hoagland solution 130 %) outperformed the other treatments, with the highest marketable yield per plant (187.86 g). The high marketable yield in T_3 indicates that the fruits produced under this nutrient concentration not only had a higher total yield but also met the quality standards required for marketability. This suggests that an elevated nutrient concentration supports the production of high-quality fruits with the desired size, weight, and appearance. Pezzarossa *et al.* (2014) emphasized that optimal nutrient management is crucial for maximizing marketable yield by enhancing both the quantity and quality of the fruits produced. In contrast, T_1 (Hoagland solution 50 %) had the lowest marketable yield per plant (31.63 g), reflecting the impact of nutrient deficiency on fruit quality. The lower marketable yield in this treatment may be due to smaller fruit size, lower weight, or inferior quality, all of which can be attributed to the limited nutrient availability. Shah *et al.* (2011) reported that nutrient-deficient conditions often result in lower marketable yields due to the production of fruits that do not meet the required market standards for size and quality (Table 3).

Percent marketable yield per plant

The percent marketable yield per plant is a measure of the proportion of the total yield that is of marketable quality. T_3 (Hoagland solution 130 %) recorded the highest percent marketable yield (84.48 %), indicating that a significant majority of the fruits produced under this treatment met market standards. The high percent marketable yield in T_3 suggests that optimal nutrient concentrations not only enhance total fruit production but also improve the overall quality of the fruits, making them more suitable for the market. This finding is consistent with the study by Magwaza *et al.* (2020), who reported that well-balanced nutrient concentrations are essential for producing high-quality fruits that are more likely to be marketable. On the other hand, T_1 (Hoagland solution 50 %) had the lowest percent marketable yield (51.02 %), indicating that a substantial portion of the fruits produced under this treatment did not meet market standards. The lower percent marketable yield in T_1 may be due to the production of smaller, less uniform fruits with lower weights and poorer appearance, all of which can result from nutrient deficiencies. Hanic *et al.* (2012) suggested that suboptimal nutrient levels often lead to a higher proportion of non-marketable fruits due to compromised fruit quality (Table 3).

Table 3 : Effect of various nutrient regimes on yield per plant, marketable yield and per cent marketable yield of strawberry cv. Sweet Sensation under Ebb and flow system of hydroponics

Treatments	Yield per plant (g)	Marketable yield per plant (g)	Per cent Marketable yield
T_1- Hogland solution (50 %)	62.12	31.63	51.02
T_2- Hogland solution (80 %)	88.83	53.07	59.86
T_3- Hogland solution (130 %)	222.44	187.86	84.48
T_4- Hogland solution (200 %)	107.29	73.10	68.12
F test	*	*	*
S. Em	1.71	0.70	0.48
CD @ 5%	5.14	2.10	1.44

*-Significant; S. Em-Standard error mean; CD- Critical difference; NS- Non significant

Total soluble solids

Total soluble solids are a measure of the sugars and other soluble substances in the fruit, which contribute to its sweetness and overall flavour. In this study, T_3 (Hoagland solution 130 %) recorded the highest TSS (9.46 °Brix), indicating that this nutrient concentration is optimal for maximizing the sugar content in the fruits. The increased TSS in T_3 suggests that the elevated nutrient availability supports the accumulation of sugars and other soluble solids, enhancing the sweetness and overall flavour of the strawberries. This finding aligns with the results of Yeganeh *et al.* (2024), who reported that optimal nutrient concentrations enhance the synthesis and accumulation of sugars in fruits, leading to higher TSS values. On contrary, T_1 (Hoagland solution 50 %) had the lowest TSS (8.51 °Brix), indicating that nutrient deficiency limits the accumulation of sugars in the fruits. The reduced TSS in this treatment may be due to the insufficient supply of nutrients required for the synthesis of sugars and other soluble compounds during fruit development. Roostaa and Hamidpour (2011) noted that suboptimal nutrient levels often result in lower TSS values due to the limited availability of essential nutrients for sugar synthesis (Table 4).

Titratable acidity

Titratable acidity is an important parameter that contributes to the tartness of the fruit and balances its sweetness. T_3 (Hoagland solution 130 %) recorded the lowest titratable acidity (0.82 %), which, combined with its high TSS, suggests that this nutrient concentration promotes a sweeter taste profile with less tartness. The reduced acidity in T_3 may be due to the optimal nutrient supply that supports balanced metabolic processes, reducing the accumulation of organic acids in the fruit. Giri *et al.* (2024) observed that adequate nutrient concentrations help maintain a balance between sugar and acid synthesis, leading to a more desirable taste profile in fruits. Conversely, T_1 (Hoagland solution 50 %) had the highest titratable acidity (1.01 %), indicating that nutrient deficiency may lead to an accumulation of organic acids in the fruit, resulting in a more tart flavour. The higher acidity in T_1 could be due to the stress induced by nutrient limitation, which may alter the plant's metabolic pathways, leading to increased acid synthesis. Hanic (2012) reported that nutrient-deficient conditions can increase the acidity of fruits as a result of metabolic imbalances caused by stress (Table 4).

TSS to Titratable acid ratio (TSS: Acid)

The TSS: Acid ratio is a critical indicator of the flavour balance in fruit, as it reflects the interplay between sweetness and tartness. T_3 (Hoagland solution 130 %) recorded the highest TSS: Acid ratio (11.57), indicating that this nutrient concentration produces fruits with a more favorable balance of sweetness and acidity. The high TSS: Acid ratio in T_3 suggests that the fruits are likely to have a sweeter and more palatable flavour, making them more appealing to consumers. This finding is consistent with the results of Magwaza *et al.* (2020), who found that well-balanced nutrient concentrations enhance the TSS: Acid ratio by promoting sugar accumulation while maintaining lower acidity levels. On the other hand, T_1

(Hoagland solution 50 %) had the lowest TSS: Acid ratio (8.42), indicating that the fruits from this treatment are more tart and less sweet. The lower TSS: Acid ratio in T_1 may be due to the combined effects of lower TSS and higher acidity, which result from nutrient deficiency. Shah *et al.* (2011) noted that suboptimal nutrient levels often lead to lower TSS: Acid ratios, as the fruits have reduced sugar content and higher acidity, leading to a less desirable flavour profile (Table 4).

Table 4 : Effect of various nutrient regimes on TSS, titratable acidity and TSS to titratable acidity (TSS: Acid) of strawberry cv. Sweet Sensation under Ebb and flow system of hydroponics

Treatment	TSS (ºBrix)	Titratable Acidity (%)	TSS: Acid
T_1- Hogland solution (50 %)	8.51	1.01	8.42
T_2- Hogland solution (80 %)	8.87	0.93	9.53
T_3- Hogland solution (130 %)	9.46	0.82	11.57
T_4- Hogland solution (200 %)	9.07	0.86	10.53
F test	*	*	*
S. Em	0.03	0.01	0.19
CD @ 5%	0.08	0.04	0.58

*-Significant; S. Em-Standard error mean; CD- Critical difference; NS- Non significant

Total sugar, reducing sugar, and non-reducing sugar

Total sugar content, along with the proportions of reducing and non-reducing sugars, is crucial for determining the sweetness and overall taste of the fruit. T_3 (Hoagland solution 130 %) recorded the highest total sugar content at 8.73 per cent, with the highest levels of reducing (6.94 %) and non-reducing sugars (1.88 %). These results indicate that this nutrient concentration is optimal for maximizing sugar synthesis and accumulation in the fruits, leading to a sweeter taste. The higher sugar content in T_3 suggests that the nutrient supply supports the metabolic pathways involved in sugar synthesis and storage. Pezzarossa *et al.* (2014) highlighted that optimal nutrient management enhances the production of both reducing and non-reducing sugars, contributing to a higher overall sweetness in the fruit. On the other hand, T_1 (Hoagland solution 50 %) had the lowest total sugar content (7.19 %), with lower levels of reducing (5.80 %) and non-reducing sugars (1.40 %). The reduced sugar content in this treatment reflects the impact of nutrient deficiency on the ability of plant to synthesize and accumulate sugars in the fruit. The lower sugar levels may result from limited photosynthetic activity and reduced carbon allocation to the fruit due to inadequate nutrient supply. Roostaa and Hamidpour (2011) observed that nutrient-deficient conditions often lead to lower sugar content in fruits, resulting in less sweet and less palatable products (Table 5).

Table 5 : Effect of various nutrient regimes on total sugar, reducing sugar and non-reducing sugar of strawberry cv. Sweet Sensation under Ebb and flow system of hydroponics

Treatment	Total sugar (%)	Reducing Sugar (%)	Non reducing sugar (%)
T_1- Hogland solution (50 %)	7.19	5.80	1.4
T_2- Hogland solution (80 %)	8.25	6.11	1.62
T_3- Hogland solution (130 %)	8.73	6.94	1.88
T_4- Hogland solution (200 %)	8.56	6.73	1.81
F test	*	*	*
S. Em	0.04	0.06	0.02
CD @ 5%	0.11	0.17	0.07

*-Significant; S. Em-Standard error mean; CD- Critical difference; NS- Non significant

The results of this study underscore the importance of providing optimum amount of nutrients for enhanced yield and quality of strawberry cv. Sweet sensation under ebb and flow system of hydroponics. Under this hydroponic system moderately high amount of nutrient concentration (Hoagland 130 %) found to be the best for higher yield and quality of strawberry plants.

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