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RESEARCH ARTICLE

The influence of different fertigation levels on the functional quality characteristics of three different strawberry (*Fragaria* × *ananassa* Duch.) varieties cultivated under protected conditions

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Abstract

The strawberry, a member of the Rosaceae family, is one of the most significant fruit crops due to its widespread cultivation and the high appreciation it garners for its distinctive aroma, bright red colour, juicy texture and delightful sweetness. A field study was conducted during 2021-2022 to assess "the influence of different fertigation levels on the functional quality characteristics of 3 different strawberry (*Fragaria* × *ananassa* Duch.) varieties cultivated under protected conditions". The study employed a Factorial Randomized Complete Block Design, encompassing 12 treatment combinations, replicated 3 times. The application of 100 % RDF of NPK significantly impacted the functional quality characteristics of strawberries. The findings indicate that the highest values for total soluble solids (11.00 ° Brix), total sugars (7.70 %), reducing sugars (5.40 %), non-reducing sugars (2.31 %), TSS: acidity ratio (14.28), juice content (45.32 %), fruit pH (3.79 %), antioxidants (0.19 %), phenols (1.20 %), fruit volume (12.89 cm^3), fruit firmness (1.68 kg/cm^2), specific gravity (1.04 g/cc) and shelf life (2.24 days) were observed under the fertigation level F_3 (100 % RDF of NPK). Additionally, minimum acidity (0.77 %) and minimum physiological loss in weight (5.36 g) were also recorded at this fertigation level. The aim of this study is to enhance fruit production, increase yields and extend the shelf life of strawberries. By exploring factors such as fertigation levels and cultivars, this study provides valuable insights that promote sustainable and efficient practices. These findings hold promise for shaping the future of strawberry cultivation, facilitating increased yields and prolonged preservation.

Keywords

Antioxidants; juice content; total soluble solids; phenols; fruit volume; vitamins

Introduction

The strawberry (*Fragaria* × *ananassa* Duch.), is renowned for its popularity and delectable characteristics, including vibrant colour, sweet taste and versatile uses. Belonging to the Rosaceae family, the strawberry has received widespread praise for its appealing qualities and culinary versatility (1). The modern cultivated strawberry (*Fragaria* × *ananassa* Duch.), is a hybrid of 2 octoploid species, primarily dioecious, namely *F. chilonensis* and *F. virginiana* (2). Strawberries are considered an accessory fruit and are consumed in large quantities (3). They are rich in natural antioxidants, phenolic compounds and anthocyanins, making them a highly nutritious fruit choice (4). The presence of vitamins and minerals in strawberries enhances their health benefits and nutritional value (5-7). In particular, strawberries are rich in vitamin C, which is important for boosting the immune system and promoting healthy skin (5).

Furthermore, strawberries contain folate, which is crucial for cell growth and development, especially during pregnancy (8). Strawberry holds a distinguished status as one of the most significant fruit crops, thriving in temperate, tropical and subtropical regions. This versatile and widely cultivated fruit is recognized for its enticing flavour, vibrant appearance and adaptability to diverse climatic conditions (9). It is one of the few fruit crops that offer faster returns on investment and exceptionally high returns per unit area. The fruit's increasing market demand, adaptability to various agro-climatic conditions and short harvesting period contribute to its attractiveness for farmers (10). Strawberry cultivation has become a very popular and profitable venture in India (11). In recent years, there has been a notable increase in strawberry cultivations, with farmers from states such as Punjab, Haryana, Delhi, Uttar Pradesh, Rajasthan, Madhya Pradesh, Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Maharashtra, Karnataka and Tamil Nadu showing significant interest in this crop (12). The subtropical strawberry varieties being grown in India possess distinctive features and advantages (9).

India cultivates strawberries over an area of approximately 3000 ha, yielding a total production of 14000 tonnes annually (13). In Himachal Pradesh, strawberries are primarily cultivated on 500 ha, producing 2200 tonnes (13). The lower slopes of Himachal Pradesh are ideal for cultivating high-quality fruits, while the medium and high alpine regions are suitable for producing exceptional runners (14). The optimal planting time for strawberries in Himachal Pradesh is between September and October. This strategic period allows for adequate preparation and the crop is typically ready for harvest approximately 4-6 months after planting (10). This time frame ensures favourable growing conditions and optimal development, aligning with the region's climatic conditions for successful strawberry cultivation (15). In Himachal Pradesh, the blossoming season for strawberries begins in February. Optimal temperature conditions during this period are crucial for successful cultivation. Ideal night temperature range between 7 to 13 °C, while daytime temperatures range between 22 to 23 °C (16). The cultivation of strawberries is significantly influenced by specific temperature parameters, under scoring the importance of favourable climatic conditions for the crop's growth and development (16). The cultivars Camarosa and Chandler are short-day plants, while Winter Dawn is day-neutral plant. These cultivars hold promise for commercial success due to their ability to produce high fruit yields during a desirable market window (17). Chandler, Winter Dawn and Camarosa are particularly well-suited for the agro-climatic conditions of district Sirmour. However, the performance of these 3 cultivars under varying fertigation levels has not been thoroughly evaluated, especially in the context of protected cultivation (18).

Applying fertilizers through a reliable drip irrigation technique can significantly enhance plant nourishment by providing more effective and timely nutrient delivery. In contrast to broadcasting, where fertilizers are not efficiently utilized by the plant, fertigation ensures precise and uniform application of nutrients to the wetted area where active roots are concentrated (19). This method improves fertilizer application efficiency, reduces production costs and minimizes the risk of groundwater pollution from fertilizer leaching. Fertigation involves adjusting the amount and concentration of applied nutrients to meet the actual nutritional requirements of the crop throughout the growing season (20). In modern intensive farming systems, fertigation has proven particularly effective in enhancing soil fertility and promoting sustainable agricultural practices (21). The adoption of drip irrigation and fertigation is crucial for improving nutrient utilization while minimizing water and fertilizer usage, ultimately reducing irrigation and fertilizer costs (21). Fertigation plays a significant role in boosting crop yield under drip irrigation. Including NPK in a comprehensive nutrition program for strawberries is essential, as these minerals are vital for ensuring productivity, enhancing fruit quality and preventing environmental contamination and unnecessary expenditures (22).

This study holds significant importance because functional quality characteristics have gained prominence in the agricultural sector. With consumers increasingly prioritizing not only the quantity but also the nutritional content, antioxidant capacity and sensory attributes of fruits like strawberries, understanding how fertigation levels can enhance these qualities becomes crucial. This investigation focuses on the specific impact of different fertigation levels on the functional qualities of strawberry varieties, introducing a novel approach to cultivation. The study aims to elucidate the effects of varied nutrient concentrations on key functional qualities, such as antioxidant levels and vitamin content. By providing a fresh perspective on adjusting fertigation for maximum yield and improved nutritive qualities, the research seeks to offer practical recommendations for growers. Additionally, comparing the responses of 3 strawberry varieties to different fertigation levels aims to identify potential variations in functional quality. The ultimate goal is to guide fertigation practices for enhanced functional quality in protected cultivation, considering implications for sustainability. The study aims to enhance fruit production, increase yields and extend the shelf life of strawberries. By exploring factors such as fertigation levels and cultivars, this study aims to provide valuable insights that promote sustainable and efficient practices. These findings hold promise for shaping the future of strawberry cultivation by facilitating increased yields and prolonged preservation.

Materials and Methods

Experimental location

The field experiment was conducted at the Experimental Research Farm Chhapang, part of Dr. Khem Singh Gill, Akal College of Agriculture, Eternal University, Baru Sahib in Himachal Pradesh. This site is located approximately 4 km from the main university building. Geographically, the experimental site is positioned at altitude of 30.73° in the North and a longitude of 77.31° in the East, at an elevation of 898 m above mean sea level.

Planting material

The strawberry cultivars Camarosa, Chandler and Winter Dawn were used as experimental material. Healthy runners, exhibiting uniform growth and free from diseases or injuries, were selected for the experiment at the Research Station Chapang after being separated from the mother plants. Throughout the duration of the experimentation, all plants were maintained according to the same horticultural guidelines.

Experimental procedure

The experiment was conducted using a Factorial-Randomized Block Design, with each treatment replicated 3 times across 3 plots. Four distinct fertigation levels were employed: control, 50 %, 75 % and 100 % of the recommended dose of NPK. Three strawberry cultivars-Camarosa, Chandler and Winter Dawn were used. Water-soluble fertilizers were applied via drip irrigation, with the recommended dose determined based on nitrogen, phosphorus and potassium requirements. To maintain consistency, plants received treatments consisting of plain distilled water supplemented with a minimal fertilizer. The runners of all 3 cultivars were transplanted into a matted row training system with a spacing of 90 cm between row and 30 cm between plants during the first week of October 2021. The experiment included the following treatment combinations:

- T_1 (Chandler + Control)
- T_2 (Chandler + 50 % RDF dose of NPK @ 75, 50, 60 kg/ha)
- T_3 (Chandler + 75 % RDF dose of NPK @ 112, 75, 90 kg/ha)
- T_4 (Chandler + 100 % RDF dose of NPK @ 150, 100, 120 kg/ha)
- T_5 (Winter Dawn + Control)
- T_6 (Winter Dawn + 50 % RDF dose of NPK @ 75, 50, 60 kg/ha)
- T_7 (Winter Dawn + 75 % RDF dose of NPK @ 112, 75, 90 kg/ha)
- T_8 (Winter Dawn +100 % RDF dose of NPK @ 150, 100, 120 kg/ha)
- T_9 (Camarosa + Control)
- T_{10} (Camarosa + 50 % RDF dose of NPK @ 75, 50, 60 kg/ha)
- T_{11} (Camarosa + 75 % RDF dose of NPK @ 112, 75, 90 kg/ha)
- T_{12} (Camarosa + 100 % RDF dose of NPK @ 150, 100, 120 kg/ha).

Determination of functional quality parameters

Total soluble solids (°Brix): Total soluble solids were measured using the standard AOAC method (23). The measurement was carried out with a hand-refractometer (ATAGO Pocket Refractometer). First, the surface of the refractometer prism was thoroughly cleaned with distilled water and dried with tissue paper. Strawberry juice was then placed on the prism and the reading was taken by looking through the eyepiece. The total soluble solids were expressed in degrees brix.

Total sugars, reducing sugars and non-reducing sugars: Total sugars, reducing sugars and non-reducing sugars were determined using the established AOAC Methodology (23). The sugar content is expressed as a percentage (%).

Acidity (%):The acidity was determined using the standard method (24). For this study, strawberry fruits from each treatment combination were used to estimate the titratable acidity. First, 25 g of strawberry pulp was crushed and combined with distilled water to make up approximately 250 mL in a volumetric flask. To estimate the acidity, 50 mL of the extract were taken. In each titration, 10 mL of juice extract was titrated against N/10 NaOH after adding a phenolphthalein indicator. The end point was indicated by a light pink colour and the acidity value was expressed as a % using the following equation:

$$\text{Acidity (\%)} = \frac{\text{Titrate value x Normality of alkali x equivalent weight of acid}}{\text{Sample taken for estimation x Volume of aliquate taken x}} \text{ x 100} \qquad \text{Eqn : 01}$$

TSS: acidity ratio: It was measured mathematically by dividing the value of TSS by the acidity. The observed data were expressed as the TSS: acidity ratio. The following equation was used to calculate the TSS: acid ratio:

$$\text{TSS/acidity ratio} = \frac{\text{TSS}}{\text{Acidity}} \qquad \text{Eqn : 02}$$

Juice content (%): The juice content was determined using the standard method (25). In brief, 5 mature strawberries were collected from each treatment combination and thoroughly washed with cool water. The fruits were weighed, sliced into 4 pieces and crushed with a grinder. The juice was then extracted using a muslin cloth. The juice content was calculated using the following equation:

$$\text{Juice content (\%)} = \frac{\text{Fruit Juice (mL)}}{\text{Weight of the fruit}} \text{ x 100} \qquad \text{Eqn : 03}$$

Fruit pH: The juice was extracted from each treatment in each replication and the pH was determined using the standard AOAC method (23) with a pH meter.

Antioxidant (%): The antioxidant content was determined using the DPPH method and expressed as a percentage (%).

Phenols: The determination of phenolic compounds in strawberry juice followed the previously described methodologies (25, 26). Initially, 5 g of fruit were crushed in 10 mL of 80 % ethanol and centrifuged at 15000 rpm for 20 min at 4 ºC. The resulting supernatant was collected and 2.8 L of distilled water were added. Subsequently, a 200 µL sample was mixed with 0.5 mL of 2 N Folin-Ciocalteau reagents, followed by the addition of 2 mL of 20 % Na_2CO_3 after 3 min. The absorbance was measured at a wavelength of 750 nm using a spectrophotometer with a 1 cm cuvette. The concentration of phenolic compounds was expressed as a percentage (%).

Fruit volume (cm³): The volume of each strawberry fruit was determined using the water displacement technique. Each fruit was submerged in a container filled with water and the volume of water displaced was measured directly using a 250 cm^3graduated cylinder. The measurements were conducted at a water temperature of 25°C and the volume was expressed in cubic centimetres (cm^3).

Fruit firmness (kg/cm²): The firmness of the fruits was measured using a TA-Plus Texture Analyzer (Texture Technologies Corp., NY), which determines the maximum penetration force (N) reached during tissue breakage. The measurement was recorded using a 10 mm diameter cylinder probe, a penetration depth of 3 mm and a cross-head speed of 1 mm s^{-1}. Each strawberry was divided into halves and the weight of each half was measured in the central region. The firmness scores of the fruits were calculated by averaging the results from three fruits for each sample.

Specific gravity (g/cc): The specific gravity of the strawberry fruits was determined by dividing the weight of each fruit by its volume. The result was expressed in g per cubic centimetres (g/cc).

Physiological loss in weight (g): The physiological loss in weight was assessed following a standard method (27). Initially, the weight of 5 fruits from each treatment combination was measured using a weighing machine at the time of harvesting. Subsequently, the fruits were weighed at 1 day intervals until they were no longer marketable. The physiological weight loss was then calculated using the following formula.

Physiological loss in weight = Initial weight (gm) – Final weight (gm) (Eqn. 4)

Shelf life (days): 5 mature fruits from each treatment combination were tested for hardness at harvest and again after a 2 day interval, while they were kept at room temperature (28.2 ºC). The remaining fruits that couldn't be sold were rejected. The number of days required for the fruits to remain in marketable condition was calculated and subsequently referred to as the shelf life (days).

Statistical analysis

Statistical analysis of the data for various fruit characteristics was performed using SAS software version 9.3 (SAS Institute Inc., Cary, NC, USA), with significance determined at $p \leq 0.05$.

Results

Functional quality characteristics of strawberry

During the investigation period, data on various functional quality parameters of strawberries, including total soluble solids (ºBrix), total sugars (%), reducing sugars (%), non-reducing sugars (%), TSS: acidity ratio and acidity (%) were documented. The results demonstrate significant effects of different fertigation levels, as depicted in Tables 1 and 2. The significant variation in interior quality characteristics among different cultivars of strawberry was attributed to the significant influence of varying fertigation levels. From the results of the experiment, the maximum values of total soluble solids (11.00 ºBrix), total sugars (7.70 %), reducing sugars (5.40 %), non-reducing sugars (2.31 %), TSS: acidity ratio (14.28) and minimum acidity (0.77 %) were documented under fertigation level F_3 (100 % recommended dose of NPK), followed by fertigation level

Table 1. The effect of different fertigation levels and cultivars on the total soluble solids (ºBrix), total sugars (%), reducing sugars (%), non-reducing sugars (%), acidity (%) and TSS: acidity ratio of strawberry

Treatments	Total soluble solids (ºBrix)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)	Acidity (%)	TSS: Acidity ratio
V_1	9.81	6.87	4.81	2.06	0.81	12.24
V_2	9.28	6.50	4.55	1.95	0.82	11.45
V_3	9.86	6.90	4.83	2.07	0.80	12.42
$CD_{0.05}$	0.15	0.11	0.07	0.03	0.01	0.22
Sem	0.05	0.03	0.03	0.01	0.02	0.08
F_0	7.30	5.11	3.57	1.53	0.87	8.42
F_1	9.47	6.63	4.64	1.99	0.81	11.74
F_2	10.83	7.59	5.31	2.28	0.79	13.73
F_3	11.00	7.70	5.40	2.31	0.77	14.26
$CD_{0.05}$	0.18	0.12	0.08	0.04	0.01	0.26
Sem	0.06	0.04	0.03	0.01	0.01	0.09

V_1= Chandler, V_2= Winter Dawn, V_3= Camarosa, F_0= Control, F_1= 50 % Recommended Dose of NPK Fertilizers, F_2= 75 % Recommended Dose of NPK Fertilizers, F_3= 100 % Recommended Dose of NPK Fertilizers. CD: Critical Difference, Sem: Standard Error of Mean

Table 2. Interaction effects of different fertigation levels and cultivars on the total soluble solids (°Brix), total sugars (%), reducing sugars (%), non-reducing sugars (%), acidity (%) and TSS: acidity ratio of strawberry

Treatment combination	Total soluble solids (°Brix)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)	Acidity (%)	TSS: Acidity ratio
T_1	7.26	5.08	3.56	1.53	0.85	8.55
T_2	9.88	6.92	4.84	2.08	0.81	12.20
T_3	10.89	7.63	5.34	2.29	0.8	13.67
T_4	11.20	7.84	5.49	2.35	0.77	14.55
T_5	7.21	5.05	3.53	1.51	0.88	8.31
T_6	8.67	6.07	4.25	1.82	0.81	10.66
T_7	10.91	7.64	5.35	2.29	0.79	13.71
T_8	10.33	7.23	5.06	2.17	0.79	13.14
T_9	7.42	5.19	3.63	1.56	0.87	8.39
T_{10}	9.86	6.90	4.83	2.07	0.8	12.37
T_{11}	10.70	7.49	5.24	2.25	0.78	13.83
T_{12}	11.48	8.03	5.62	2.41	0.75	15.10
$CD_{0.05}$	0.30	0.21	0.15	0.06	0.02	0.44
Sem	0.10	0.07	0.05	0.02	0.01	0.15

CD: Critical Difference, Sem: Standard Error of Mean

F_2 (75 % recommended dose of NPK), whereas minimum values were observed in fertigation level F_0 (0 % recommended dose of NPK). However, among the different cultivars, the Camarosa cultivar (V_3) exhibited the highest values of total soluble solids (9.86 °Brix), total sugars (6.90 %), reducing sugars (4.83 %), non-reducing sugars (2.07 %), TSS: acidity ratio (12.42) and lowest acidity (0.80 %), followed by the Chandler cultivar (V_1) and the lowest values were observed in the Winter Dawn cultivar (V_2). Furthermore, among the different interactions, the highest values of total soluble solids (11.48 °Brix), total sugars (8.03 %), reducing sugars (5.62 %), non-reducing sugars (2.41 %), TSS: acidity ratio (12.42) and minimum acidity (0.80 %) were found under the treatment T_{12} (Camarosa + 100 % RDF dose of NPK), followed by the treatment T_{11} (Camarosa + 75 % RDF dose of NPK), while minimum values were measured under the treatment T_5 (Winter Dawn + Control).

During the study period, data regarding the juice content (%), fruit pH, antioxidant (%) and phenols (%) essential interior quality parameters of strawberry were recorded. The results have highlighted significant impacts of different fertigation levels, as depicted in Tables 3 and 4. The interior quality parameters of diverse strawberry cultivars exhibited significant variation owing to the pronounced influence of varying fertigation levels. Based on the outcomes of the experiment, the highest values of juice content (45.32 %), fruit pH (3.79 %), antioxidants (0.19 %) and phenols (1.20 %) were observed under fertigation level F_3 (100 % recommended dose of NPK), followed by fertigation level F_2 (75 % recommended dose of NPK), with the lowest values recorded under fertigation level F_0 (0 % recommended dose of NPK). However, among the different cultivars, the Camarosa cultivar (V_3) demonstrated the highest values of juice content (43.80 %), fruit pH (3.65 %), antioxidants (0.18 %) and phenols (1.86 %), followed by the Chandler cultivar (V_1), with the lowest value observed in the Winter Dawn cultivar (V_2). Regarding different interactions, the maximum values of juice content (45.82 %), fruit pH (3.85 %), antioxidants (0.21 %) and phenols (2.02 %) were determined under treatment T_{12} (Camarosa + 100 % RDF dose of NPK), followed by treatment T_{11} (Camarosa + 75 % RDF dose of NPK), whereas minimum values were measured in treatment T_5 (Winter Dawn + Control).

During the investigation, data regarding the physical quality parameters of strawberry, including fruit volume (cm^3), fruit firmness (kg/cm^2), specific gravity (g/cc), physiological loss in weight (g) and shelf life (days) were recorded. The results indicate significant effects of

Table 3. Effect of different fertigation levels and cultivars on juice content (%), fruit pH, antioxidant (%) and phenols (%) of straw berry

Treatment	Juice content (%)	Fruit pH	Antioxidant (%)	Phenols (%)
V_1	42.70	3.54	0.17	1.91
V_2	42.39	3.52	0.16	1.86
V_3	43.80	3.65	0.18	1.92
$CD_{0.05}$	0.29	0.08	0.01	0.02
Sem	0.03	0.03	0.03	0.01
F_0	37.06	3.32	0.13	1.69
F_1	43.11	3.49	0.17	1.92
F_2	45.03	3.67	0.19	1.98
F_3	45.32	3.79	0.19	2.00
$CD_{0.05}$	0.18	0.09	0.10	0.02
Sem	0.04	0.03	0.01	0.01

V_1= Chandler, V_2= Winter Dawn, V_3= Camarosa, F_0= Control, F_1= 50 % Recommended Dose of NPK Fertilizers, F_2= 75 % Recommended Dose of NPK Fertilizers, F_3= 100 % Recommended Dose of NPK Fertilizers.CD: Critical Difference, Sem: Standard Error of Mean

Table 4. Interaction effects of different fertigation levels and cultivars on juice content (%), fruit pH, antioxidant (%) and phenols (%) of strawberry

Treatment	Juice content (%)	Fruit pH	Antioxidant (%)	Phenols (%)
T_1	37.74	3.33	0.13	1.68
T_2	42.58	3.38	0.17	1.95
T_3	45.08	3.70	0.18	2.00
T_4	45.39	3.74	0.20	2.01
T_5	37.01	3.22	0.13	1.69
T_6	43.08	3.48	0.16	1.84
T_7	44.71	3.59	0.18	1.95
T_8	44.74	3.78	0.18	1.96
T_9	36.44	3.42	0.12	1.71
T_{10}	43.66	3.62	0.18	1.97
T_{11}	45.30	3.72	0.20	1.99
T_{12}	45.82	3.85	0.21	2.02
CD $_{0.05}$	0.45	0.46	0.01	0.03
Sem	0.06	0.05	0.01	0.01

CD: Critical Difference, Sem: Standard Error of Mean

different fertigation levels, as depicted in Tables 5 and 6. The physical characteristics of diverse strawberry cultivars were influenced by the pronounced effects of varying fertigation levels. Based on the outcomes of the experiment, the highest values of fruit volume (12.89 cm^3), fruit firmness (1.68 kg/cm^2), specific gravity (1.04 g/cc), shelf life (2.24 days) and minimum physiological loss in weight (5.36 g) were recorded under fertigation level F_3 (100 % recommended dose of NPK), followed by fertigation level F_2 (75 % recommended dose of NPK), while the minimum values were observed under fertigation level F_0 (0 % recommended dose of NPK). However, among the various cultivars, the Camarosa cultivar (V_3) exhibited the maximum values of fruit volume (12.89 cm^3), fruit firmness (1.68 kg/cm^2), specific gravity (1.04 g/cc), shelf life (2.24 days) and minimum physiological loss in weight (5.36 g), followed by the Chandler cultivar (V_1), with the minimum values estimated under the Winter Dawn cultivar (V_2). Furthermore, among different interactions, the higher values of fruit volume (12.99 cm^3), fruit firmness (1.72 kg/cm^2), specific gravity (1.08 g/cc), shelf life (2.34 days) and minimum physiological loss in weight (4.84 g) were obtained under treatment T_{12} (Camarosa + 100 % RDF dose of NPK), followed by treatment T_{11} (Camarosa + 75 % RDF dose of NPK). Whereas the lowest values were measured in the treatment combination T_5 (Winter Dawn + Control).

Discussion

The present study indicates that varying fertigation levels and cultivars significantly influenced the functional quality parameters of strawberries compared to controls during the 2021-2022 experiment. Results demonstrates that among the different fertigation levels, F_3 (100 % recommended dose of NPK) showcased superiority over others. Additionally, among strawberries cultivar, Camarosa stood out as the most superior. Moreover, among the various treatment combinations, T_{12} (Camarosa + 100 % RDF of NPK) emerged as the most effective. The interaction between these factors was also found to be significant.

From the results of the current experiment, it was observed that the maximum values of total soluble solids (°Brix), total sugars (%), reducing sugars (%), non-reducing sugars (%), TSS: acidity ratio, antioxidant (%), phenols (%) and minimum acidity content (%) were attained with the application of the 100 % recommended dose of NPK fertilizer through fertigation, followed by the 75 % recommended dose of NPK. The significant enhancement in these parameters can be attributed to the accelerated metabolic transformation of starch and pectin into soluble compounds, along with the gradual translocation of sugars from leaves to mature fruit. Moreover, the decrease in acidity observed could be ascribed to the conversion of

Table 5. Effect of different fertigation levels and cultivars on the fruit volume (cm^3), fruit firmness (kg/cm^2), specific gravity (g/cc), physiological loss in weight (g) and shelf life (days) of strawberry

Treatment	Fruit volume (cm^3)	Fruit firmness (kg/cm^2)	Specific gravity (g/cc)	Physiological loss in weight (g)	Shelf life (days)
V_1	12.59	1.52	0.85	6.02	1.93
V_2	12.55	1.49	0.79	6.25	1.86
V_3	12.68	1.54	0.88	5.83	1.97
CD $_{0.05}$	0.02	0.01	0.01	0.32	0.04
Sem	0.01	0.01	0.02	0.13	0.01
F_0	12.27	1.27	0.60	6.68	1.33
F_1	12.56	1.52	0.80	6.38	1.93
F_2	12.70	1.59	0.92	5.72	2.19
F_3	12.89	1.68	1.04	5.36	2.24
CD $_{0.05}$	0.02	0.014	0.01	0.37	0.05
Sem	0.01	0.05	0.01	0.13	0.02

V_1= Chandler, V_2= Winter Dawn, V_3= Camarosa, F_0= Control, F_1= 50 % Recommended Dose of NPK Fertilizers, F_2= 75 % Recommended Dose of NPK Fertilizers, F_3= 100 % Recommended Dose of NPK Fertilizers.CD: Critical Difference, Sem: Standard Error of Mean

Table 6. Interaction effects of different fertigation levels and cultivars on the fruit volume (cm^3), fruit firmness (kg/cm^2), specific gravity (g/cc), physiological loss in weight (g) and shelf life (days) of strawberry

Treatment combinations	Fruit volume (cm^3)	Fruit firmness (kg/cm^2)	Specific gravity (g/cc)	Physiological loss in weight (g)	Shelf life (days)
T_1	12.26	1.27	0.60	6.66	1.32
T_2	12.54	1.52	0.82	6.58	1.84
T_3	12.67	1.60	0.92	5.59	2.27
T_4	12.87	1.67	1.06	5.26	2.30
T_5	12.26	1.24	0.56	6.77	1.31
T_6	12.54	1.51	0.74	6.35	1.89
T_7	12.67	1.57	0.89	5.96	2.08
T_8	12.87	1.66	0.98	5.94	2.09
T_9	12.39	1.31	0.63	6.61	1.36
T_{10}	12.61	1.53	0.85	6.21	2.04
T_{11}	12.74	1.61	0.96	5.62	2.21
T_{12}	12.99	1.72	1.08	4.86	2.34
$CD_{0.05}$	0.04	0.03	0.02	0.43	0.08
Sem	0.01	0.01	0.01	0.22	0.03

CD: Critical Difference, Sem: Standard Error of Mean

organic acids into sugars during fruit maturation through photosynthesis. These findings are consistent with previous studies conducted on Nagpur mandarin and Chandler strawberry respectively (28-31). Furthermore, the Camarosa cultivar exhibited maximum values for total soluble solids (°Brix), total sugars (%), reducing sugars (%), non-reducing sugars (%), TSS: acidity ratio, antioxidant (%), phenols (%) and low acidity content (%). This observation is likely attributed to a combination of factors, including hot days and cool nights as well as the genetic makeup of the genotype and favourable environmental conditions. These findings align with results reported by studies conducted on strawberries (14, 32, 33).

Moreover, among the various treatment combinations, it was evident that treatment T_{12} (Camarosa + 100 % RDF of NPK) outperformed other treatments and the interaction between factors was found to be significant. The outcomes of the experiment revealed that maximum values of total soluble solids (°Brix), total sugars (%), reducing sugars (%), non-reducing sugars (%), TSS: acidity ratio, antioxidants (%), phenols (%) and low acidity content (%) were achieved under treatment T_{12} (Camarosa + 100 % RDF of NPK). This superior performance may be attributed to the optimal quantity of nitrogen, phosphorous and potassium within the plant system, crucial for enhancing plant growth, along with the genetic makeup of the cultivar and favourable climatic conditions. This result aligns with the findings of previous studies conducted on strawberry and guava cv. L-49 respectively (34-36).

The application of the 100 % recommended dose of NPK through drip irrigation led to a significant increase in fruit volume (cm^3), juice content, fruit pH and specific gravity (g/cc). The collected data indicates that the highest values for fruit volume (cm^3), juice content, pH and specific gravity (g/cc) were observed with the 100 % recommended dose of NPK through drip, followed by the 75 % recommended dose of NPK through drip. This finding may be attributed to improved metabolite synthesis and enhanced nutrient absorption and transfer to the fruits. These results are consistent with previous studies (10, 37), which reported significant increases in fruit volume (cm^3), juice content, fruit pH and specific gravity (g/cc) with the application of NPK fertilizers via drip irrigation.

The Camarosa cultivar demonstrated superior values for quality parameters, including fruit volume (cm^3), juice content (%), fruit pH and specific gravity (g/cc). This superiority can be attributed to a combination of factors such as hot days, cool nights, the genetic makeup of the genotype and favourable climatic conditions. These findings align with prior research conducted by (14, 32, 33) on strawberries.

In contrast, among various treatment combinations, it was evident that treatment T_{12} (Camarosa + 100 % RDF of NPK) displayed superior efficacy compared to other treatments, with a significant interaction observed. The results of the current experimentation highlight that the maximum values for fruit volume (cm^3), juice content (%), fruit pH and specific gravity (g/cc) were achieved under treatment T_{12} (Camarosa + 100 % RDF of NPK). This phenomenon can be attributed to the well-balanced proportions of nitrogen, phosphorus and potassium within the plant system, crucial for enhancing plant growth. Furthermore, the genetic makeup of the cultivar, combined with favourable climatic conditions, likely contributed to the observed higher values of these characteristics. The consistency of these results with investigations conducted by (28, 35-38) on strawberries provides robust support for the reliability and applicability of the findings of the present study.

The collected data indicates that the highest values for fruit firmness (kg/cm^2) and specific gravity (g/cc) were observed with the 100 % recommended dosage of NPK via drip, followed by the application of 75 % of the recommended NPK dose through drip. This phenomenon may be attributed to an increased uptake of nutrients and their efficient transfer to fruits, along with heightened metabolite production, ultimately enhancing fruit firmness, as indicated by (39, 40). Moreover, potassium plays a pivotal role in regulating stomatal activities, preventing moisture loss through skin control and enhancing water absorption capacity in plants, contributing to increased fruit firmness (41). The congruence of these results with investigations conducted by (5, 10) on strawberries provides robust support for the reliability and applicability of the findings of the present study.

Furthermore, it was observed that the minimum physiological loss in weight was observed with the 100 % recommended dosage of NPK applied via drip, followed by 75 % of the recommended dose of NPK through drip, with a record durations of 2.24 days. In contrast, the control treatment exhibited the highest weight loss. The reduced weight loss observed with NPK application may be explained by chemical modifications within the fruits, facilitating the retention of more water compared to the rate of evaporation. Furthermore, this effect could be linked to alterations in specific protein components of the cell, enhancing their affinity for water (42). The consistency of these results with investigations carried out by (5, 10) on strawberries significantly bolsters the reliability and applicability of the present study's findings.

However, the maximum shelf life of fruits was recorded with the 100 % recommended dosage of NPK applied via drip, followed by 75 % of the recommended dose of NPK via drip, while the minimum shelf life was observed under the control treatment. The osmotic effects of these treatments on tissue integrity or potassium may have accelerated this process by softening the tissue, preventing weight loss and extending shelf life. Fruit shelf life significantly increased during the initial storage period of 0–2.24 days across all treatments, indicating that it is most likely caused by moisture loss in fruit kept at room temperature. Variations between the treatments became apparent after 2.24 days of storage(5, 10, 42).

On the contrary, the Camarosa cultivar exhibited superior values for quality parameters, including fruit firmness (kg/cm^2), shelf life (days) and minimal physiological weight loss (g). This observation can be attributed to a combination of hot days, cool nights, the genetic makeup of the genotype and favourable environmental conditions. These outcomes align with the findings reported in previous studies by (14, 32, 33) on strawberries. Furthermore, it was observed that among the various treatment combinations, treatment T_{12} (Camarosa + 100 % RDF of NPK) demonstrated superior efficacy compared to the other treatments, with a significant interaction found between factors. The findings of the present investigation indicate that the maximum values for fruit firmness (kg/cm^2), shelf life (days) and minimal physiological weight loss (g) were achieved under treatment T_{12} (Camarosa + 100 % RDF of NPK). This could be attributed to the appropriate proportion of nitrogen, phosphorous and potassium in the plant system, crucial for enhancing plant growth. Additionally, the inherited characteristics of the plant, combined with favourable environmental conditions, may contribute to enhanced expressions of these traits. This result is in accordance with the findings of (5, 10, 36) pertaining to guava cv. L-49 and Chandler strawberries respectively.

Conclusion

It can be concluded that, employing fertigation to administer the recommended dose of NPK fertilizers (150, 100 and 120 kg/ha) in 7 divided doses from December to March at 15day intervals led to superior functional quality parameters of strawberries compared to applying the recommended dose of fertilizer through conventional methods. The application of the 100 % recommended dose of NPK fertilizers via drip irrigation significantly impacted the functional quality parameters of strawberry fruit. Throughout the course of the research, Camarosa emerged as the superior cultivar in terms of both the overall fresh fruit quality and the maintenance of functional quality parameters. It is strongly recommended to use treatment T_{12} (Camarosa cultivar with 100 % recommended dose of NPK fertilizers) to increase the functional quality parameter. Additionally, this study aims to explore the influence of different nutrient concentrations on critical functional qualities of strawberries, including antioxidant levels and vitamin content. By doing so, it offers practical guidance to growers by introducing novel insights into adjusting fertigation techniques for optimal yield and enhanced nutritional qualities. Furthermore, through comparing the responses of three strawberry varieties to varying fertigation levels, the research uncovers potential disparities in functional quality. Moreover, the study suggests that altering cultivation conditions and selecting suitable strawberry cultivars can lead to improved nutritional value and increased yields, presenting farmers with opportunities to enhance profitability.

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Authors' contributions

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Compliance with ethical standards

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

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