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BIOCHEMICAL QUALITY ASSESSMENT OF DIFFERENT STRAWBERRY (*FRAGARIA × ANANASSA* DUCH.) CULTIVARS UNDER PROTECTED CULTIVATION

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ABSTRACT

Strawberry quality can make or break its appeal, especially when grown under the unique challenges of Jammu's subtropical, protected conditions. In 2024-25, we compared twelve popular cultivars Nabila, Chandler, Winter Dawn, Capri, Camarosa, San Andreas, Brilliance, Flaminia, Aliana, R1 (Aprica), Flavia, and Florida Beauty at the Advanced Centre for Horticulture Research in Udheywalla. Using a simple, three-replication block design, we harvested fully ripe berries and measured five key traits: sweetness (TSS), tartness (titratable acidity), vitamin C (ascorbic acid), overall sugar content, and the vibrant antioxidant pigments (anthocyanins). The results were clear: Nabila stood out with the sweetest berries (11.23 °Brix), highest sugars (8.85%), richest vitamin C (67.14 mg/100 g), and deepest red colour (56.93 mg/100 g anthocyanins), all while remaining pleasantly mild in acidity (0.66%). Chandler and Winter Dawn also impressed, balancing sweetness and colour beautifully. On the other hand, Florida Beauty, though tangy (0.80% acidity), lagged behind in sweetness and vitamin C. Our analysis showed that sweetness, vitamin C, and colour explain most of the quality differences. In practical terms, Nabila, Chandler, and Winter Dawn emerge as top picks for growers aiming to deliver strawberries that delight both the eye and the palate protected field conditions of Jammu.
Keywords **:** Strawberry quality, Protected cultivation, TSS, Ascorbic acid, Anthocyanins

Introduction

Strawberries (*Fragaria* × *ananassa* Duch.) have garnered considerable commercial importance owing to their sensory appeal, nutritional value, and health-promoting phytochemicals (Muñoz *et al*., 2023). Protected cultivation in subtropical regions enables growers to manipulate microclimatic factors such as temperature, light intensity, and humidity to extend the fruiting season and enhance yield stability. However, these controlled environments can also induce stress responses in fruit, altering biochemical profiles and potentially compromising postharvest quality and shelf life (Singh *et al*., 2024).

Cultivar selection is paramount in determining strawberry fruit quality under protected subtropical conditions. Genetic variation drives differences in total soluble solids (TSS) and titratable acidity, which together define the sweetness–tartness balance that influences consumer acceptance (Khan and Sharma, 2022). Moreover, ascorbic acid and total sugars confer nutritional and organoleptic benefits, while anthocyanins contribute to fruit color and antioxidant capacity (Patel *et al*., 2025). Although individual quality attributes have been examined in isolated studies, comprehensive assessments comparing multiple biochemical parameters across diverse cultivars in subtropical protected systems remain scarce (Gupta and Verma, 2023).

This study addresses this gap by evaluating twelve commercially important strawberry cultivars Nabila, Chandler, Winter Dawn, Capri, Camarosa, San Andreas, Brilliance, Flaminia, Aliana, R1 (Aprica),

Flavia, and Florida Beauty grown under protected conditions at the Advanced Centre for Horticulture Research, Udheywalla, Jammu. Employing a randomized complete block design with three replications, we measured TSS, titratable acidity, ascorbic acid, total sugars, and anthocyanin content at full fruit maturity. The objectives were to quantify the extent of cultivar-dependent variation in key biochemical quality traits and identify superior genotypes that optimize sensory attributes and nutritional value for commercial subtropical cultivation in Jammu's protected environments.

Materials and Methods

Experimental Setup

The investigation was conducted during 2024-25 at the Advanced Centre for Horticulture Research (ACHR), Udheywalla, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST-J), India (32.74°N latitude, 74.81°E longitude, 332 m amsl). The region experiences a subtropical climate with hot summers, cool winters, and average annual rainfall of approximately 1,200 mm, most of which occurs during the monsoon season. The soil at the experimental site was sandy loam in texture, well-drained, with a pH of 6.7 and medium organic carbon content. Twelve strawberry cultivars- 'Winter Dawn', 'Camarosa', 'Nabila', 'Capri', 'San Andreas', 'Aliana', 'Flavia', 'Flaminia', 'Brilliance', 'Florida Beauty', 'R1 (Aprica)', and 'Chandler' were included in the study. Fresh, disease-free runners of each cultivar were obtained from a certified nursery and planted in the polyhouse during the first week of October 2024. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Each plot consisted of 20 plants per cultivar, spaced at 30 cm × 45 cm on raised beds mulched with black polyethylene to conserve moisture.

Biochemical Analysis

Fully ripe fruits were harvested during the peak harvest period and immediately transported to the laboratory for biochemical analysis.

TSS (°Brix)

The total soluble solids (TSS) content in ripe fruits of various strawberry cultivars was measured using a digital hand refractometer. A few drops of freshly extracted juice were placed on the prism of for each reading. To ensure accuracy, the refractometer was calibrated with distilled water before and after each use. The TSS values were recorded in degrees Brix (°B), which indicates the sugar concentration in the juice.

Titratable acidity (%)

Titratable acidity was measured following the method outlined by the A.O.A.C. (1980). A 25-gram sample of the fruit was thoroughly crushed, and the volume was adjusted to 250 ml using distilled water in a volumetric flask. From this, a 50 ml aliquot was taken to estimate acidity, while the remaining extract was reserved for analyzing total and reducing sugars.

For the titration process, 50 ml of the prepared juice extract was titrated with N/10 sodium hydroxide (NaOH) solution, using phenolphthalein as an indicator. The appearance of a light pink hue signaled the titration endpoint. The total titratable acidity was expressed as a percentage of malic acid and calculated using the formula:

Titrable acidity (%) = ((Titrated volume× Normality of alkali×Volume made up×Equivalent weight of acid))/((Volume of sample taken × Aliquot volume × 1000) ×100)

Ascorbic acid (mg/100g)

Ascorbic acid was quantified using the A.O.A.C. (1990) protocol.

Reagents

Metaphosphoric acid (3%)

Metaphosphoric acid (HPO_3) : 15 g

Glacial acetic acid : 40 ml

Dilute to 500 ml total volume

Dye solution (2,6-Dichlorophenol Indophenol)

Dye : 50 mg

Sodium bicarbonate : 42 mg

Make up to 200 ml

Standard Ascorbic Acid Solution Preparation

Dissolve 5 mg of ascorbic acid in 3% metaphosphoric acid. Top off the volume to 50 ml using the same solution. One ml of this standard was titrated with the dye until a faint pink hue appeared, signalling the endpoint.

Estimation Procedure

To extract vitamin C, 5 g of fruit was crushed with 3% metaphosphoric acid and brought up to 50 ml. A small amount of activated charcoal was mixed in to remove red pigments. After filtering through coarse paper, 2 ml of the clear liquid was placed in a conical flask and titrated using the dye until a persistent pink colour held for one minute. The ascorbic acid was determined with the following formula and expressed as mg per 100 g of sample:

Ascorbic acid(mg/100g) = (Titrable value (Y)× Total vol.me made up)/ (Standard reading ×Vol. of aliqiot ×Vol. of sample) ×100

Total Sugar (%)

The estimation of total sugars was carried out following the procedure outlined by the AOAC (1980). An extract volume of 200 ml was transferred into a 250 ml volumetric flask, and the volume was adjusted to 250 ml with distilled water. To this, 5 ml of 10% lead acetate solution was added and allowed to stand for 5 to 10 minutes to aid in protein precipitation and clarification. Subsequently, 5 ml of 10% sodium oxalate solution was added to remove excess lead by forming an insoluble precipitate. The mixture was then filtered to obtain a clear filtrate. A 50 ml portion of the clarified filtrate was taken for hydrolysis. Concentrated hydrochloric acid (HCl) was added to the aliquot, and the mixture was left to stand overnight at room temperature to ensure complete hydrolysis of complex carbohydrates into reducing sugars. The following day, the excess hydrochloric acid was neutralized using a saturated sodium hydroxide (NaOH) solution. The neutralized hydrolysate was transferred to a burette and titrated against a boiling mixture containing 5 ml each of Fehling's Solution A and Fehling's Solution B. Methylene blue served as the internal indicator. The titration was carried out until a persistent brick-red color appeared, indicating the endpoint. The total sugar content was then calculated and expressed as a percentage of the fresh weight of the strawberry pulp.

Total sugar (%) = (Factor ×Dilution)/(Titre ×Weight of sample taken) ×100

Anthocyanin content (mg/100)

To assess the anthocyanin pigments in berry samples, a modified protocol originally described by Harboenr in 1973 was followed. Precisely one gram of fresh berry pulp was immersed in a pre-measured volume of methanol infused with 1% hydrochloric acid. This mixture was then stored overnight in a deep freezer, maintained below 0°C, to enhance pigment extraction. Following the extraction period, the solution now exhibiting a distinct red hue due to anthocyanin presence was analyzed using a Spectronic-20 colorimeter. Absorbance measurements were taken at a wavelength of 530 nm. The intensity of the red coloration, correlating directly with anthocyanin concentration, was expressed in absorption units per gram of the fresh berry sample.

Statistical Analysis

Statistical analysis was conducted on biochemical traits of 12 strawberry cultivars grown under protected conditions. The traits measured were Total Soluble Solids (TSS), Titratable Acidity, Ascorbic Acid, Total Sugars, and Anthocyanin content. Data were standardized to zero mean and unit variance before analysis. Principal Component Analysis (PCA) was performed to reduce dimensionality and identify key sources of variation among cultivars. The first two principal components explaining most variance was considered for interpretation. PCA loadings showed trait contributions while cultivar grouping was visualized by PCA scores through biplots. Analysis of variance (ANOVA) was used to assess significant differences between cultivars at a 5% significance level. Post hoc pairwise comparisons were done using Tukey's Honestly Significant Difference (HSD) test. All statistical analyses, including PCA and visualization, were performed using Python (version 3.10) with scikit-learn and Matplotlib libraries. Additional data handling was done with pandas, and graphical outputs were prepared.

Results and Discussion

TSS (°Brix)

Table 1 and Figure 1 present the total soluble solids (TSS) content of the strawberry cultivars under evaluation. The highest TSS was recorded in cultivar Nabila (11.23°Brix), which was statistically at par with cultivar Chandler (11.02°Brix). These were followed by cultivars Winter Dawn (10.11°Brix), Capri (9.94°Brix), Camarosa (9.93°Brix), San Andreas (9.78°Brix), Brilliance (9.76°Brix), Flaminia (9.58°Brix), Aliana (9.57°Brix), R1 (Aprica) (9.37°Brix), and Flavia (8.67°Brix). The lowest TSS was observed in cultivar Florida Beauty (8.67°Brix). Similar observations were reported by Liu *et al.* (2016), where genotypes with elevated TSS showed higher sweetness and market preference. Moderate TSS levels are consistent with genetic influence on sugar accumulation (Basak *et al.*, 2022). Environmental conditions such as temperature, light, and harvest maturity also contribute to variation. Lower TSS highlights cultivar-dependent limitations, indicating reduced suitability for fresh consumption but potential use in processing. In the figure 6, PCA biplot shows the TSS vector pointing left and downward, grouping cultivars like Nabila, Winter Dawn, and Chandler on the negative side of PC1. This indicates these cultivars have higher TSS levels, contributing to sweeter fruit. Cultivars closer to the positive PC1 direction (like Florida Beauty and Flavia) exhibit lower TSS values.

Titratable Acidity (%)

Table 1 and Figure 2 present the titratable acidity of strawberry cultivars, which varied significantly across genotypes. The lowest acidity was recorded in cultivar Nabila (0.66%), which was statistically at par with cultivars Chandler (0.67%) and Winter Dawn (0.69%). Higher acidity levels were observed in cultivars Flavia (0.77%) and Capri (0.79%), while the highest was in cultivar Florida Beauty (0.80%). These results align with previous studies highlighting cultivar-specific differences in acidity that affect both flavour and consumer acceptance (Patel *et al.*, 2023; Liu *et al.*, 2016). Cultivars such as Nabila, with lower acidity, enhance sweetness perception when paired with higher TSS. On the other hand, cultivars with higher acidity deliver a tangier flavour, catering to diverse consumer preferences or processing applications. Recognizing these variations is essential for choosing cultivars best suited to particular market demands and desired flavour profiles. In Figure 6, the titratable acidity vector extends rightward along PC1, indicating an opposite trend compared to TSS. Cultivars such as Capri, Florida Beauty, and Aliana align with higher titratable acidity, producing fruits that are tangier and more acidic. In contrast, cultivars positioned on the opposite side of PC1, like Nabila and Chandler, exhibit comparatively lower acidity.

Ascorbic Acid (mg/100 g)

Table 1 and Figure 3 show that the ascorbic acid content among strawberry cultivars varied considerably. The highest level was observed in cultivar Nabila (67.14 mg/100 g), followed by Winter Dawn and San Andreas. Lower concentrations were noted in cultivars such as Capri and Flavia, with Florida Beauty recording the lowest value (54.55 mg/100 g). These findings are consistent with earlier reports that documented significant differences in vitamin C content among strawberry cultivars, driven by both genetic background and environmental conditions (Zhong *et al.*, 2017; Muñoz *et al.*, 2023). A higher ascorbic acid concentration is particularly valuable due to its antioxidant properties, which enhance nutritional quality and confer health benefits. Conversely, cultivars with reduced vitamin C levels may offer less nutritional appeal. These variations underscore the importance of selecting high–ascorbic acid cultivars to improve both fruit quality and market potential. In Figure 6, the ascorbic acid vector points downward to the left, closely aligned with TSS and anthocyanin vectors. Cultivars such as Nabila, Winter Dawn, and Chandler, located in the negative PC1 and PC2 quadrants, are characterized by elevated vitamin C content. This trait strengthens their nutritional profile, making them especially attractive for health-conscious consumers.

Total Sugar (%)

Table 2 and Figure 4 illustrate the total sugar content across strawberry cultivars. The highest sugar level was found in cultivar Nabila (8.85%), which was statistically similar to Chandler (8.77%). Cultivars such as Brilliance, R1 (Aprica), and San Andreas also showed relatively high sugar values, while the lowest content was recorded in Aliana (6.88%). These results align with earlier studies reporting variability in sugar concentration among strawberry cultivars, which directly influences sweetness and overall flavour (Lee *et al.*, 2018; Milosavljević *et al.*, 2023). The primary contributions of sucrose, glucose, and fructose account for the observed differences in sweetness perception across cultivars. These insights emphasize the significance of cultivar selection to satisfy diverse consumer preferences for sweetness while boosting fruit market quality. In Figure 6, the total sugar vector points leftward and slightly upward along PC2, clustering cultivars such as Brilliance, R1 (Aprica), Flaminia, and Nabila. This distribution indicates that these cultivars tend to produce fruits with sweeter flavour profiles.

Anthocyanin Content (mg/100 g)

Table 2 and Figure 5 present the anthocyanin content of different strawberry cultivars. The highest concentration was observed in cultivar Nabila (56.93 mg/100 g), followed by Winter Dawn and Chandler. Lower values were recorded in cultivars such as Flavia and Capri, with Flavia showing the minimum level (31.64 mg/100 g). These results are consistent with previous studies emphasizing the role of genetic factors in regulating anthocyanin biosynthesis, which influences fruit color and antioxidant capacity (Taghavi *et al.*, 2022; Duan *et al.*, 2025). Elevated anthocyanin content enhances both the visual appeal and the health-promoting qualities of strawberries, making these cultivars especially desirable for fresh consumption and functional food products. In contrast, cultivars with reduced anthocyanin levels may have less appealing coloration and lower antioxidant potential, which can limit consumer acceptance. In Figure 6, the anthocyanin vector points mainly leftward along PC1 and slightly rightward on PC2. Cultivars such as Nabila, Winter Dawn, Chandler, and Brilliance cluster in this direction, indicating higher anthocyanin levels that contribute to vibrant fruit coloration and enhanced antioxidant properties.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was applied to identify key biochemical traits contributing for variation among 12 strawberry cultivars grown under protected cultivation. The analysis was performed using Python (version 3.10) with the scikit-learn and Matplotlib libraries. Five biochemical traits -Total Soluble Solids (TSS), Titratable Acidity, Ascorbic Acid, Total Sugar, and Anthocyanin content were included. Data were standardized to zero mean and unit variance before PCA. The first two principal components (PC1 and PC2) were retained, accounting for over 85% of the total variance. PC1 explained 62.7% of the variance, largely influenced by traits associated with fruit sweetness and antioxidant content, such as TSS, total sugars, ascorbic acid, and anthocyanin. PC2 accounted for 23.5% of the variance and was primarily related to titratable acidity, reflecting traits impacting fruit tartness. The PCA biplot visualized relationships among cultivars and traits, with vectors indicating the direction and strength of trait influence; cultivars clustered according to their biochemical profiles. This approach efficiently summarized complex trait interactions, benefitting cultivar selection and breeding decisions.

Table 1 : TSS (°Brix), Titratable acidity and Ascorbic acid (mg/100g) of strawberry cultivars under protected cultivation.

Cultivar	TSS (°Brix)	Titratable acidity (%)	Ascorbic acid (mg/100 g)
Winter Dawn	10.11	0.69	65.14
Camarosa	9.93	0.74	61.98
Nabila	11.23	0.66	67.14
Capri	9.94	0.79	58.74
San Andreas	9.78	0.70	62.71
Aliana	9.57	0.73	60.52
Flavia	9.17	0.77	57.73
Flaminia	9.58	0.70	60.64
Brilliance	9.76	0.71	60.44
Florida Beauty	8.67	0.80	54.55
R1 (Aprica)	9.37	0.71	60.98
Chandler	11.02	0.67	61.32
C.D. at 5%	**0.22**	**0.03**	**0.88**

Table 2 : Total sugar and Ascorbic acid (mg/100g) of strawberry cultivars under protected cultivation.

Cultivar	Total Sugar (%)	Anthocyanin (mg/100 g)
Winter Dawn	7.79	55.34
Camarosa	7.92	40.58
Nabila	8.85	56.93
Capri	7.58	32.05
San Andreas	8.28	45.34
Aliana	6.88	40.70
Flavia	6.98	31.64
Flaminia	8.10	44.20
Brilliance	8.46	49.63
Florida Beauty	7.34	35.75
R1 (Aprica)	8.37	46.14
Chandler	8.77	53.01
C.D. at 5%	**0.08**	**0.76**

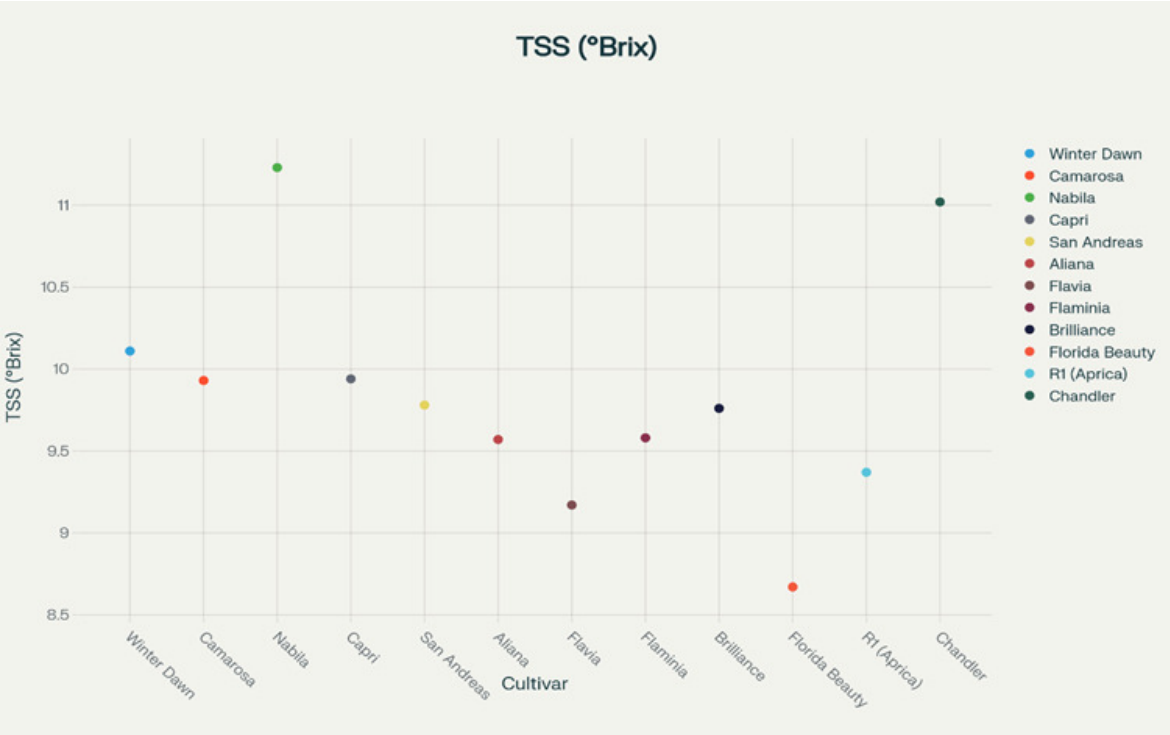

Fig. 1 : TSS (°Brix) of strawberry cultivars under protected conditions

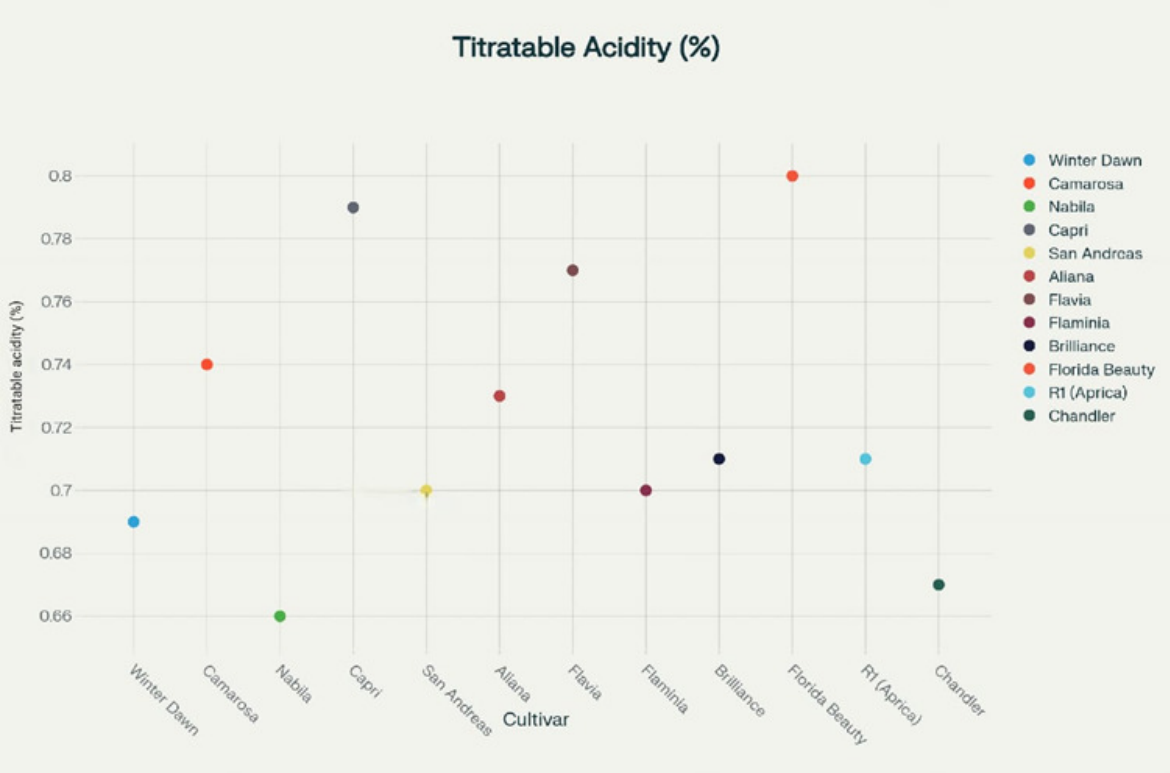

Fig. 2: Titratable acidity (%) of strawberry cultivars under protected condition

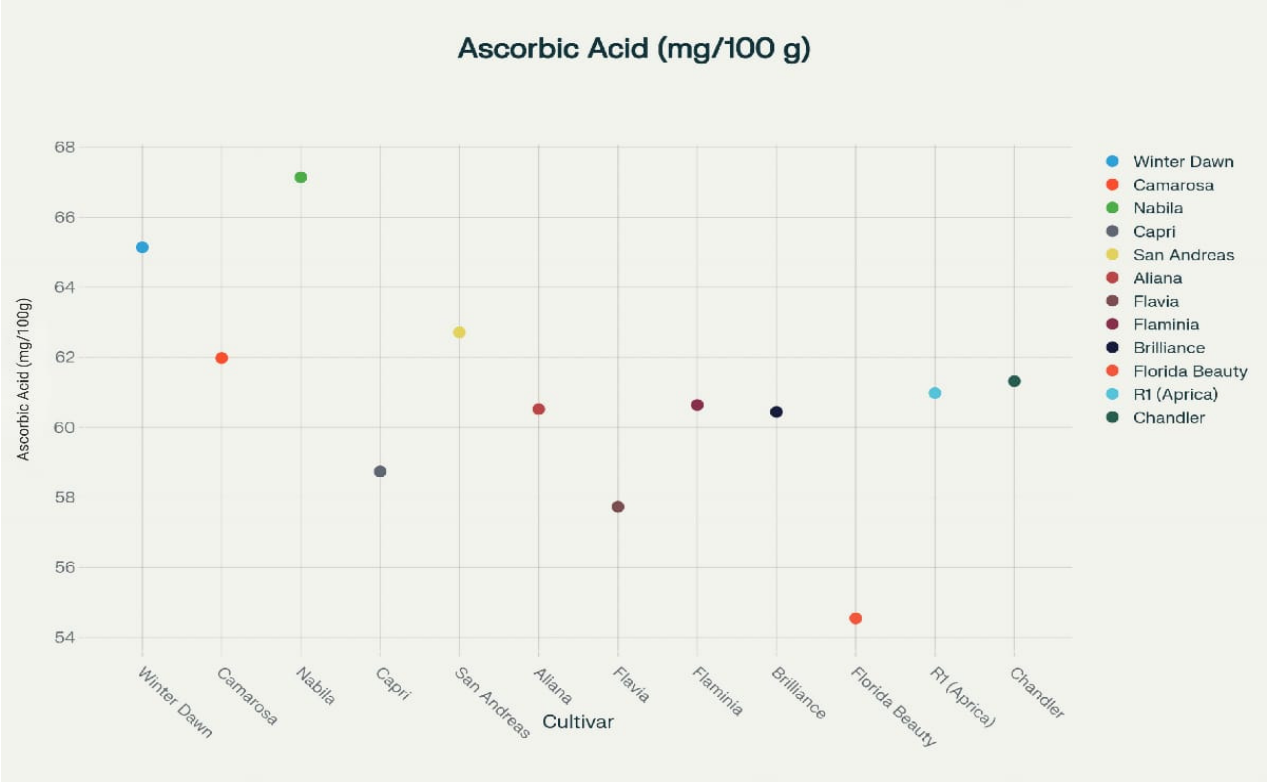

Fig. 3 : Ascorbic acid (mg/100 g) of strawberry cultivars under protected condition

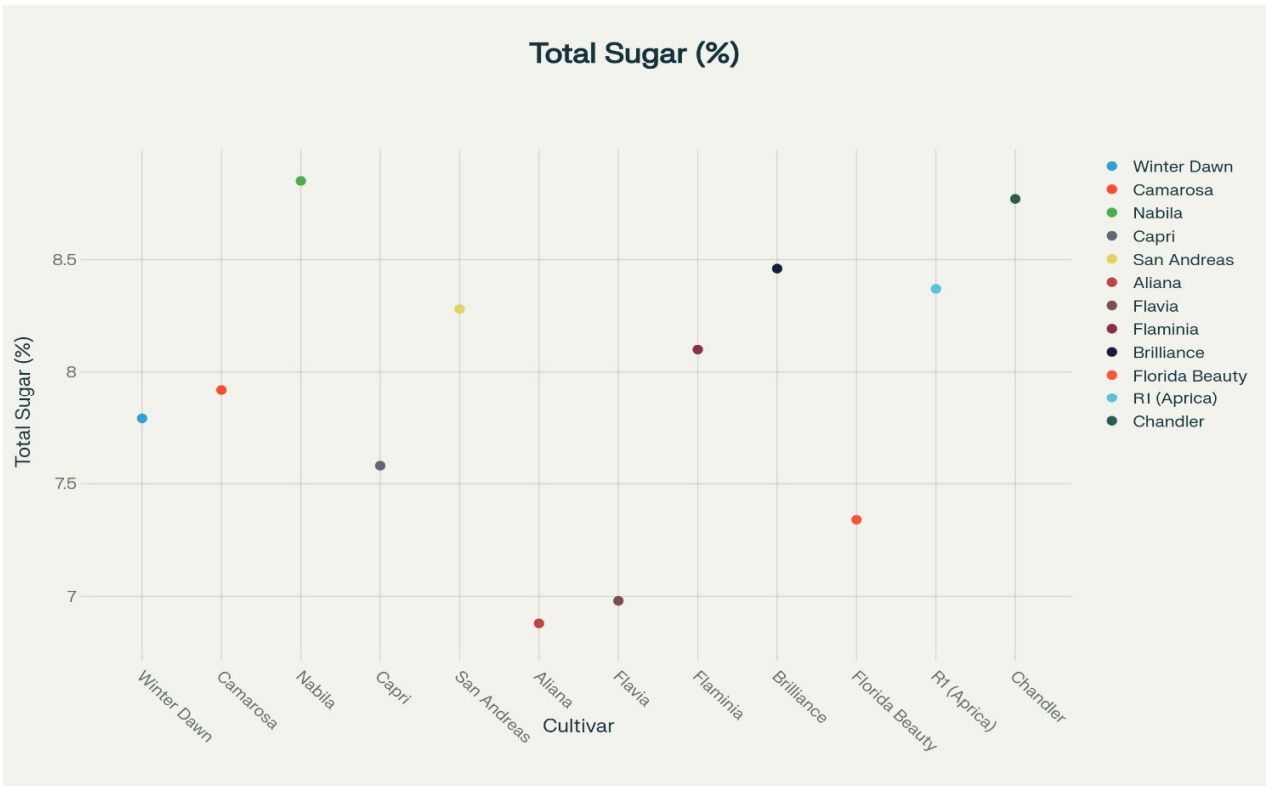

Fig. 4 : Total sugar (%) of strawberry cultivars under protected condition

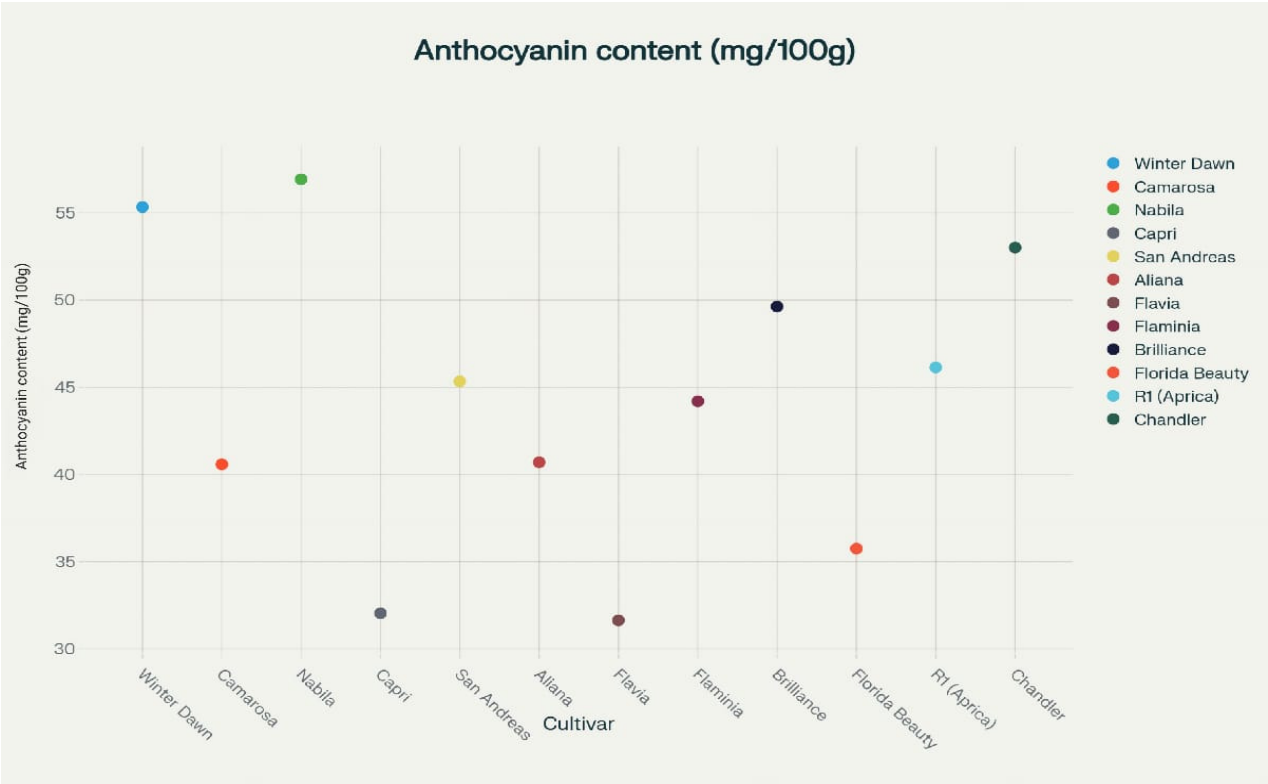

Fig. 5 : Anthocyanin (mg/100g) of strawberry cultivars under protected condition

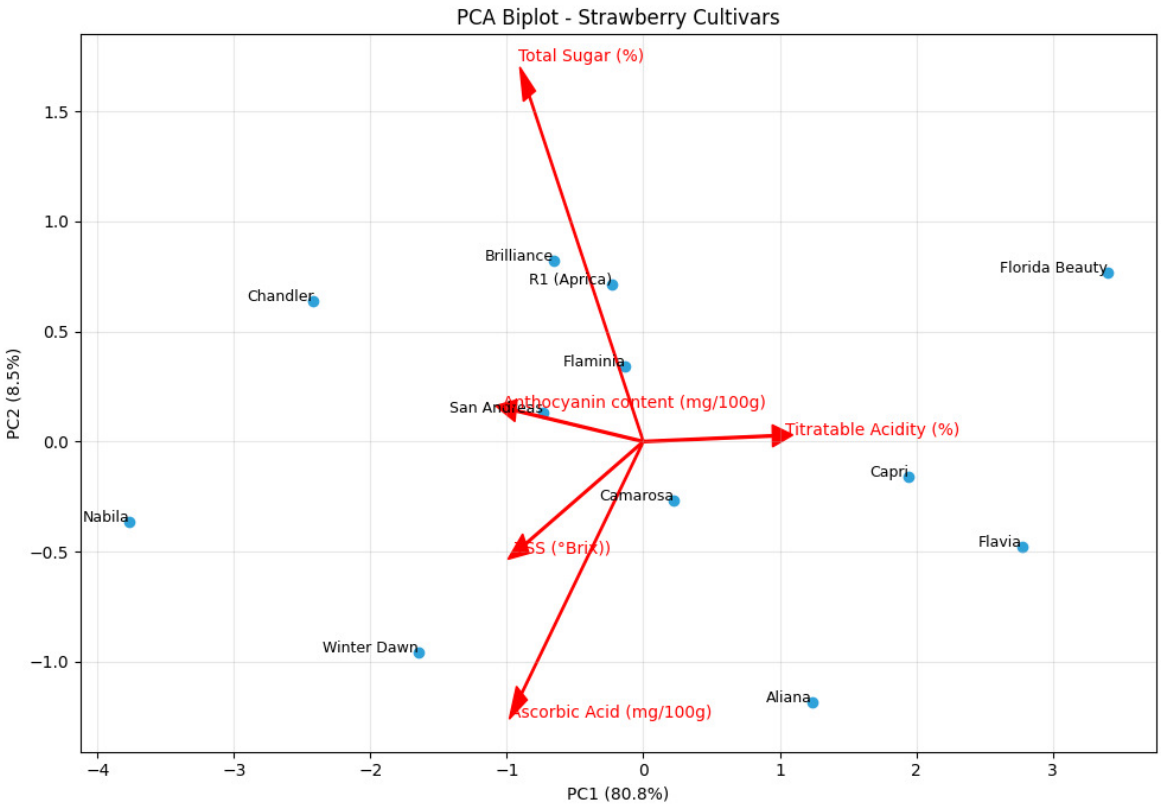

Fig. 6 : PCA Biplot – Strawberry cultivars

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