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Varietal variations in fruit quality parameters in strawberry (*Fragaria×ananassa*) harvested at different stages of color development

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Summary: Present investigation reports the fruit quality of five strawberry cultivars ('Rania', 'Winter Dawn', 'Winter Star', 'Camarose' and 'Navelia') harvested at different stages of color development. These cultivars showed significant variations in their chemical composition. The highest and significant values of fruit weight, hue angle and total sugars were recorded in 'Winter Star' cultivar at full red stage. Total phenolics and ascorbic acid content were higher in 'Camarose' as compared to other cultivars. These parameters and reducing sugar content in strawberry fruits showed a direct relationship with DPPH radical scavenging activity. 'Winter Star' exhibited highest anthocyanin content form 25% red to full ripe red stage of fruit color development with most intensive color. Total soluble sugars, reducing sugars, pH, °Brix values increased from green to full red stage whereas titratable acidity showed the reverse trend. These cultivars showed significant differences in their physicochemical and biochemical composition at different stages of ripening in agroclimatic conditions of Punjab area of northwest India.

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Key words: strawberry, fruit quality, color development, growth stages, phenols

Introduction

Strawberry (*Fragaria×ananassa*) is a flavoured fresh and processed fruit having vital role in human nutrition nowadays. It is cultivated worldwide with the production of 8.8 million tonnes recorded in year 2020 (FAOSTAT 2020). Strawberries are enriched with excellent dietary sources such as ascorbic acid, folate, minerals, fibre, and also contain several bioactive phytochemicals including anthocyanins, flavanols and phenolic acids (Nunes et al., 2021). Ascorbic acid, polyphenols and bioactive phytochemicals present in strawberry fruits possess antioxidant, antiviral, anti-inflammatory, antiaging and anticarcinogenic properties (Shivavedi et al., 201; Gasparrini et al., 2017; Gasparrini et al., 2021).

Fruit ripening is a complex process contributed by number of biochemical and physiological processes due to changes in gene expression and various enzyme activities (Janurianti et al., 2021). Strawberry fruit ripening is divided into five different stages; first stage begins with white fruit; 2nd, 3rd, 4th and 5th stages are 25, 50, 75 and 100% red fruit, respectively. Fruit ripening is influenced by hormonal changes, pigment biosynthesis, sugar and acid metabolism. Therefore, fruit possesses different nutritional quality at different levels of ripeness (Nunes et al., 2021). Color, taste and texture of the fruit are main parameters that influence the acceptability of fruit (Zeliou et al., 2018). Changes in fruit size, shape, texture, and pigmentation (green to red) coincide with elevation in content of soluble solids and the production of natural aroma and flavour compounds (Abera et al., 2023). Total antioxidant capacity of strawberry mainly depends on the high vitamin C and also on the contents of polyphenols, flavonoids and anthocyanins (Capocasa et al., 2008). Anthocyanins, antioxidant activity, glucose and fructose content increased with development, while sucrose accumulates by the end of maturity.

Strawberry production is not developed to its full potential in Punjab state of northwest India. The fruit is in great demand in the market as compared to its production. So, it is important to enhance the domestic production of high yielding strawberry cultivars with satisfactory fruit quality, that appeals to consumers. Both sensory and nutritional quality components are important and can be influenced by cultivars, climate, stages of maturation or storage methods (Nunes et al., 2021). The present study has been conducted to determine the fruit quality of selected strawberry cultivars recommended for cultivation in this region of India. The study also helps to identify the cultivar which possess higher antioxidant potential and best characters for human consumption.

Materials and methods

Plant material

Fresh fruits of five strawberry cultivars ('Rania', 'Winter Dawn', 'Winter Star', 'Camarose' and 'Navelia'), grown in year 2020-21 at the experimental fields of department of Soil, Water and Engineering, Punjab Agricultural University, Ludhiana were used in present investigation. The soil type was

classified as sandy loam, with an average of 140 mm rainfall, and 6-35°C temperature conditions during the season. Healthy runners with bare roots were transplanted during mid-October with spacing of 30 cm x 30 cm on 20 cm raised beds with 80 cm width and silver-black polyethylene mulch (30 µ thickness). Drip irrigation was used to irrigate and fertigate the fields using the season. Plants were covered with low tunnel plastic sheets (50 µ thickness) from end-December to mid-February to minimize winter injury. The flowers were tagged on the day of anthesis, and fruits were harvested at four different stages viz. white (S1), 50% red (S 2), 75% red (S3) and full red (S4) color stages (***Figure 1***). Fruits (500 g) of each cultivars were taken by random choice; packed in plastic containers and brought to the laboratory for immediate analysis. The fruits were mashed in a pestle mortar and analysed for various physicochemical and nutritional parameters and antioxidant capacity. Three replicates were used per analysis. The fruit size was estimated with digital Vernier's Calliper, and fruit weight was recorded with electronic weighing balance.

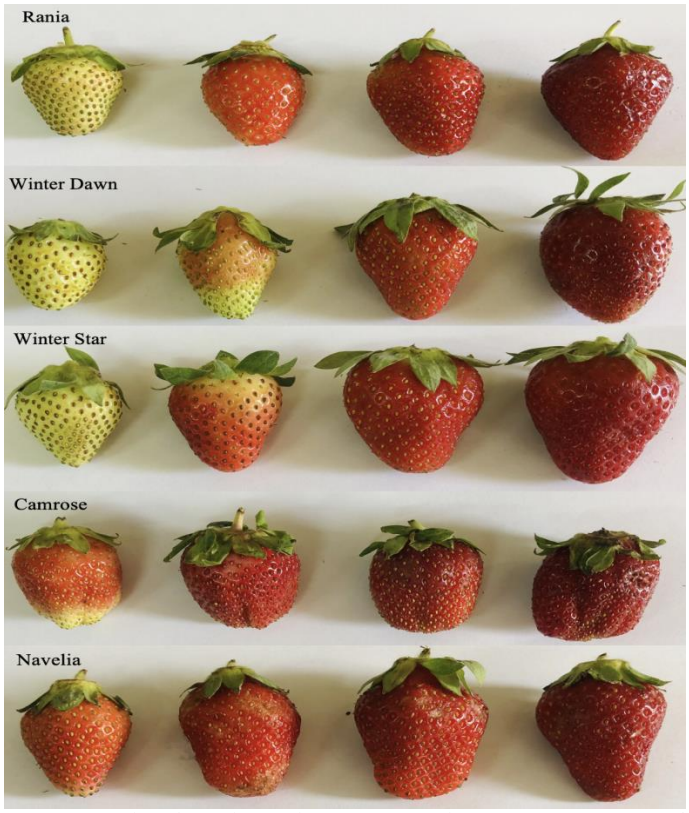


Figure 1. Fruits of 'Rania', 'Winter Dawn', 'Winter Star', 'Camrose' and 'Navelia' cultivars harvested at different developmental stages (S1, S2, S3, S4)

Total soluble solids, titratable acidity and fruit color coordinates

Total soluble solids (TSS), were determined using a digital refractometer (APAL-1, Model 3810, Japan) and expressed in °Brix. Titratable acidity (TA) was determined by titration with 0.1 N NaOH (Ranganna, 2007). pH value was noted using a pH meter (Mettler Toledo, Switzerland). Fruit color coordinates (L*, a*, b*, C* and h*) were randomly measured on two opposite sites at fruit equator using Color Flex Spectrophotometer (Hunter Lab Color Flex, Hunter Associates Inc., Reston, VA, USA) and expressed in CIE units (Hunter, 1975). *L** defines the lightness, and *a** and *b** define the colour between red and green, and blue and yellow, respectively.

Total sugars, reducing sugars and ascorbic acid

Fruit pulp was homogenized with 80% ethanol and refluxed twice for 20 min. Ethanol was evaporated from the supernatants and 10 ml volume was made by adding distilled water. This extract was used for the estimation of total sugars and reducing sugars by the standard procedure mentioned in Kaur et al. (2018). Ascorbic acid content was estimated by homogenizing fresh strawberry fruits using 10% tricholoacetic acid (TCA) and centrifuged to collect the supernatant. To an aliquot, 1 mL of TCA and Folin Ciocalteau reagent was added and incubated for 20 min at 37 °C. Absorbance was recorded at 760 nm and expressed as mg ascorbic acid g^{-1} fresh weight as described by Jagota & Dani (1982).

Phenolic constituents, flavonoids, anthocyanins and DPPH radical activity

Fruit pulp was refluxed with twice with methanol for 1 h. The filtrates were combined; diluted to known volume and used for the estimation of phenols and flavanols. For estimation of total phenols, added 2.5 mL of Folin-Ciocalteu reagent each to 0.5 mL of diluted extract or standard solutions (gallic acid in the range of 20–100 µg). The mixture was vortexed followed by addition of 7.5 mL of 7% Na_2CO_3 solution after 5 min. The contents were diluted to 50 mL with distilled water and further incubated for 2 h at room temperature. Optical density was measured at 760 nm (Swain & Hills, 1959) and total phenolics were expressed as mg gallic acid equivalents g^{-1} (fw).

For flavanols, 5 ml of methanolic extract was evaporated and 0.1 M methanolic aluminium chloride was added to it. Optical density was measured at 420 nm and contents were calculated as µg rutin equivalents g^{-1} fw (Nair & Vaidyanathan, 1964).

Strawberry fruit pulp (2 g) was homogenized in 18 mL of HCl (0.5%, v/v in methanol) and refrigerated for 1 h for extraction of the anthocyanin pigments. The extracts were filtered and the absorbance of the clear liquid was measured at 520 nm. The anthocyanin content was calculated by the formula: Abs 520 × dilution factor × (AxB). Here A = 433.2 (molecular weight of pelargonidin) and B is the molar extinction coefficient with a value of 2.908×10^4. The results were expressed as mg pelargonidin 100 g^{-1} fruit fresh weight.

For determination of DPPH· radical scavenging capacity, a known volume of the fruit extract in methanol was mixed with methanolic DPPH solution (1 mmol/L) and volume was made to 3 mL with methanol. The mixture was incubated at room temperature for 15 min in dark. The optical density was recorded at 517 nm against the blank and Percent DPPH radical scavenging activity was calculated.

Statistical analysis

The experiment was set up as a complete randomized design in year 2020 with three replicates; each comprising 50 plants in each replication. Data were analysed by one-way ANOVA at the level of 5% significance using CPCS1 software developed by Punjab Agricultural University, Ludhiana. Experimental data were presented as mean ± SE. Pearson product-moment correlation coefficient (r) analysis was done to study the relationship among all parameters in strawberry fruit and principal component analysis was carried out to examine the interrelations between different parameters.

Results

Physiochemical parameters

Fruit weight significantly increased from S1 to S4 stage except for 'Navelia' cultivar where it showed a decline from S3 to S4 (***Table 1***). Fruit weight also differed significantly among cultivars. Initially 'Navelia' cultivar showed highest fruit weight when the fruit was white in color and values were almost double as compared to 'Rania', 'Winter Dawn' and 'Winter Star' cultivars. Highest increase in fruit weight was observed in 'Winter Star' along with color development with maximum values at S2 to S4 stages as compared to other cultivars. The length of strawberry fruits at different color development stages ranged from 22.17 to 39.59 mm whereas breadth varied from 17.25 to 34.01 mm (***Table 1***). Both length and breadth of fruits varied amongst different stages as well as cultivars. 'Camarose' fruits were smaller in size and had significantly lower length and breadth values as compared to other studied cultivars.

Fruit colour parameters also showed significant changes among different stages and cultivars (***Table 2***). L^* values decreased as the strawberry fruits changed colour from white to red (S1-S4 stage). Among cultivars, minimum L* value (21.45) was observed in 'Navelia' at S4 whereas maximum L* value (59.90) was observed in 'Camarose' at S1. L* value was maximum in 'Camarose' and minimum in 'Winter Star' at all the stages of ripening. 'Rania' and 'Navelia' cultivars showed significant decline in L* values throughout the development period whereas in other cultivars significant drop in L* values was observed from S1 to S2 only. L* values of white and 50% red fruit were higher than the L* values of fully red strawberries due to natural colour development of fruit with ripening. The b* value decreased, whereas a* value increased significantly with fruit color development from S1 to S4. a* value indicates the superficial red colour of strawberry fruit and increased during fruit development from S1 to S3 and then declined. Initially, there was a greater increase in a* values in all the cultivars. Maximum increase in a* value was recorded in 'Camarose' followed by 'Rania' cultivar. The chrome* of strawberries significantly decreased from white (S1) to full red stage (S4). Highest c* values were observed in 'Camarose' at all the stages of colour development and minimum in 'Winter Star' cultivar. All other cultivars showed the decline in hue angle from S1 to S3 and then value again increase at full red colour stage except for 'Winter Dawn'. The maximum decrease in hue angle was recorded in 'Camarose' from S1 to S4.

Total soluble solids, acidity and pH

TSS continued to increase during ripening (***Figure 2a***), although some non-significant changes were also recorded in between different stages of color development. Mean TSS content increased significantly by 1.37-fold with fruit color development; with values of 10.04 °Brix at S4 in comparison to 7.32 °Brix at S1. Among cultivars, 'Camarose' showed approximately two-fold increase in °Brix values from S1 to S4 and minimum changes were reported in 'Winter Star' as values changed by 1 ºBrix. A decreasing trend was observed in TA values (%) along with fruit color development (***Figure 2b***). Significant variation was observed between S1 and S4 stages where the values of acidity varied from 14.08% ('Winter Dawn') at S1 to 4.35% ('Winter Star') at S4. Mean values also decreased significantly from 8.96% at S1 to 5.63% at S4. pH plays an important role on sensorial quality of strawberry fruits. It varied from 3.55 to 4.15 in strawberry cultivars at white stage (S1) and it increased significantly with the ripening of strawberry fruits with values in the range of 4.03 to 4.85 at full red stage (S4) among all the cultivars (***Figure 2c***). Maximum value of pH among cultivars was observed in ''Rania'' (4.85) and minimum was observed in 'Winter Star' (4.03) at full red stage (S4).

Total sugars, reducing sugars and ascorbic acid

Total sugars content increased in all the cultivars from S1 to S4 stage (***Figure 3a***). 'Rania' exhibited highest total sugars content at S1 stage when the fruits were white in color. The sugar content varied among cultivars with maximum content in 'Winter Star' (96.95 mg g^{-1}) and minimum content in 'Winter Dawn' (72.84 mg g^{-1}) at S4 stage. Maximum increase of 2.2 folds in sugars content was observed in 'Winter Star' from S1 to S4 stage. Reducing sugars followed the similar trends as seen in case of total sugars. An increase of 1.5-fold was observed in the mean value of reducing sugars with color development where the content was 55.26 mg g^{-1} at S4, as compared to 36.87 mg g^{-1} at S1. 'Navelia' recorded maximum RS content at all the stages of fruit ripening and minimum content was reported in fully red fruits of 'Rania' (48.93 mg g^{-1}) at S4 (***Figure 3b***). A minute variation was observed in mean content of Vitamin C along with color development stages. 'Camarose' exhibited highest Vitamin C content from S1 to S3 as compared to other cultivars (***Figure 3c***). Ascorbic acid content in 'Winter Dawn' and 'Navelia' cultivars showed significant increase between S3 and S4 whereas 'Camarose' showed the reverse trend. Maximum content of Vitamin C was observed in 'Camarose' (0.53 mg g^{-1}) at S2.

Phenolics, flavanols, anthocyanins and antioxidant activity in strawberry fruits

Total phenolic content in strawberry fruits ranged from 2.53 to 5.12 mg g^{-1} from S1 to S4 among all the cultivars (***Figure 4a***). The phenolic content declined from half red (S2) to full red (S4) stage in all the cultivars except 'Winter Dawn'. 'Camarose' exhibited highest phenolic content among studied cultivars at all the stages of color development. The content of flavanols was significantly higher at S4 than S1 (***Figure 4b***). Slight variations were observed among all the cultivars with respect to flavanol content at all the developmental stages. Similarly, gradual increase in anthocyanin content attributing to bright red color observed with the fruit developmental stages (***Figure 4c***). There were significant variations in DPPH radical scavenging activity in fruits of strawberry cultivars at different stages of fruit color development (***Figure 4d***). After initial increase, DPPH radical scavenging activity decreased drastically at S4 than S1 in all the cultivars except 'Camarose' where the activity showed a continuous decline from S1 to S4. DPPH radical scavenging activity at S1 follow the order as 'Camarose' > 'Navelia' > 'Rania' > 'Winter Star' > 'Winter Dawn'. Activity was maximum in 'Navelia' and minimum in 'Winter Star' at full red stage. There was significant differences in DPPH radical scavenging activity between studied cultivars at different stages of color development and it decreased during ripening.

Table 1. Changes in the fruit weight and size of five strawberry cultivars during color development.

Cultivars	Stages			
	S1	S2	S3	S4
	Fruit weight (g)			
Rania	4.74 ± 0.11	7.85 ± 0.33	10.10 ± 0.19	10.62 ± 0.24
Winter Dawn	5.55 ± 0.12	6.84 ± 0.09	11.10 ± 0.08	11.72 ± 0.07
Winter Star	5.97 ± 0.10	11.83 ± 0.26	17.14 ± 0.10	17.56 ± 0.05
Camrose	9.05 ± 0.28	10.95 ± 0.23	11.36 ± 0.18	13.63 ± 0.53
Navelia	10.55 ± 0.57	15.67 ± 0.14	16.38 ± 1.25	12.04 ± 0.62
Mean	**7.17 ± 0.24**	**10.63 ± 0.21**	**13.22 ± 0.36**	**13.11 ± 0.30**
Critical difference (P<0.05)	Cultivars (A)= 0.42 Stages (B)= 0.37 AB= 0.83			
Fruit size (mm)				
Rania	30.00 ± 1.51* 20.94 ± 1.96	31.66 ± 4.40* 25.11 ± 0.88	32.19 ± 2.20* 27.63 ± 2.59	35.68 ± 3.40* 27.05 ± 3.47
Winter Dawn	28.41 ± 2.42* 21.93 ± 1.01	30.83 ± 2.86* 23.35 ± 2.02	36.20 ± 1.42* 27.37 ± 0.61	35.70 ± 3.03* 28.17 ± 2.63
Winter Star	29.78 ± 1.27* 23.30 ± 1.22	37.52 ± 3.34* 27.55 ± 2.21	39.59 ± 1.88* 34.01 ± 2.12	28.01 ± 2.16* 24.65 ± 1.42
Camrose	22.17 ± 1.89* 17.42 ± 4.03	26.09 ± 1.25* 20.79 ± 2.07	27.15 ± 3.15* 19.92 ± 2.69	25.67 ± 3.87* 17.32 ± 3.99
Navelia	29.27 ± 4.27* 17.25 ± 2.31	34.32 ± 3.31* 21.85 ± 3.06	37.31 ± 5.54* 28.04 ± 6.06	27.93 ± 6.01* 19.38 ± 1.97
Mean	**27.93 ± 2.27*** **20.17± 2.11**	**32.08 ± 3.03*** **23.73 ± 2.05**	**33.19 ± 2.84*** **26.37 ± 2.81**	**30.89 ± 3.69*** **23.83 ± 2.70**
Critical difference (P<0.05)	Length-Cultivars (A)= 4.54 Stages (B)= 4.06 AB= 9.08 Breadth-Cultivars (A)= 3.18 Stages (B)= 2.85 AB= 6.36			

Correlation studies and principal component analysis of different cultivars and their quality parameters

The correlation of various biochemical and physiological parameters of strawberry cultivars was highlighted in the correlation plot illustrated in ***Figure 5***, which clearly showed that total sugars, hue angle, pH, fruit size and anthocyanin are negatively correlated with reducing sugars, vitamin C, DPPH, phenols, L, a*, b*, c*, flavanols, acidity and TSS. Reducing sugars showed a strong positive correlation with vitamin C (r=0.919) and DPPH scavenging activity (r=0.981). Acidity was inversely correlated to pH and total sugars. L*, a*, b* & C* values were positively related to each other however, hue angle showed a negative relation with a*, b* & C* at 5% level of significance. Anthocyanins showed a negative relation with vitamin C and DPPH activity at 5% significance and with reducing sugars at 1% level of significance. Total phenolics were positively correlated to DPPH scavenging activity, color parameters, vit c and reducing sugars.

Principal component analysis (PCA) performed on whole set of average values revealed information on the variables mainly influencing the physicochemical parameters and changes during color development in these cultivars. First principal component (PC1) contributed 43.4% and second (PC2) 28.3% (***Figure 6***) which explained 71.7% of the total variability. PCA reveals interrelation among analysed parameters; and positioning of analysed strawberry cultivars in comparison to each other. Fruit weight, total sugars, hue angle, anthocyanin and pH are grouped together on left side of the PCA plot while reducing sugars, vitamin C, DPPH, phenols, L*, a*, b*, c*, flavanols, acidity, pH and TSS on the right side of the PCA plot. The parameters in PC1 and PC2 are related to each other in that component. TSS and reducing sugars are related as their contents increase with ripening of fruit. A hierarchical clustering analysis according to Euclidean distances, based on fruit composition variations among different cultivars of strawberry, is presented in ***Figure 7***. Clusters indicate fruit traits that co-varied under a given condition and highlight the differences in various parameters among different cultivars.

Table 2. Changes in the fruit color parameters of five strawberry cultivars during development.

Cultivars	Stages			
	S1	**S2**	**S3**	**S4**
		L*		
Rania	43.95 ± 6.43	31.05 ± 0.49	29.55 ± 0.07	22.40 ± 1.41
Winter Dawn	44.95 ± 6.58	26.50 ± 2.40	29.60 ± 2.69	26.55 ± 0.21
Winter Star	34.60 ± 3.54	24.20 ± 3.96	23.90 ± 1.70	22.30 ± 4.24
Camrose	59.90 ± 0.42	43.20 ± 3.54	30.60 ± 0.28	29.85 ± 0.07
Navelia	42.00 ± 4.95	33.00 ± 7.64	28.25 ± 3.61	21.45 ± 3.61
Mean	**45.08 ± 4.38**	**31.59 ± 3.61**	**28.38 ± 1.67**	**24.51 ± 1.91**
Critical difference (P<0.05)		Cultivars (A)= 3.95 Stages (B)= 3.53 AB= 7.90		
		a*		
Rania	-4.20 ± 6.08	17.05 ± 4.17	17.55 ± 2.62	11.45 ± 1.06
Winter Dawn	-3.35 ± 0.21	12.85 ± 3.32	17.80 ± 2.12	17.20 ± 0.85
Winter Star	-5.10 ± 2.26	16.45 ± 0.21	13.05 ± 1.77	5.20 ± 5.52
Camrose	-6.35 ± 0.35	24.30 ± 1.70	25.45 ± 1.91	21.75 ± 3.18
Navelia	-3.90 ± 0.28	8.00 ± 10.61	17.30 ± 0.99	6.90 ± 1.70
Mean	**-4.58 ± 1.84**	**15.73 ± 4.00**	**18.23 ± 1.88**	**12.50 ± 2.46**
Critical difference (P<0.05)		Cultivars (A)= 2.76 Stages (B)= 2.47 AB= 5.52		
		b*		
Rania	27.80 ± 3.25	15.15 ± 0.78	12.15 ± 3.32	10.25 ± 0.49
Winter Dawn	26.45 ± 3.04	16.65 ± 1.77	14.75 ± 1.91	11.65 ± 1.06
Winter Star	23.50 ± 0.42	12.40 ± 4.38	9.90 ± 0.57	7.55 ± 2.19
Camrose	32.80 ± 2.83	24.40 ± 0.57	15.10 ± 0.14	13.90 ± 3.11
Navelia	23.75 ± 2.05	19.60 ± 4.38	16.25 ± 3.18	9.55 ± 0.21
Mean	**26.86 ± 2.32**	**17.64 ± 2.38**	**13.63 ± 1.82**	**10.58 ± 1.41**
Critical differenc (P<0.05)		Cultivars (A)= 2.58 Stages (B)= 2.31 AB= 5.16		
		C*		
Rania	28.39 ± 4.08	22.86 ± 3.63	21.36 ± 4.04	15.39 ± 0.46
Winter Dawn	26.66 ± 3.04	21.06 ± 3.43	23.12 ± 2.85	20.78 ± 1.30
Winter Star	24.10 ± 0.07	20.74 ± 2.79	16.42 ± 1.06	9.50 ± 4.76
Camrose	33.41 ± 2.84	34.45 ± 0.80	29.60 ± 1.71	25.82 ± 4.36
Navelia	24.07 ± 2.07	22.67 ± 0.05	23.83 ± 1.45	11.82 ± 1.16
Mean	**27.33 ± 2.42**	**24.36 ± 2.14**	**22.87 ± 2.22**	**16.67 ± 2.41**
Critical difference (P<0.05)		Cultivars (A)= 2.86 Stages (B)= 2.56 AB= 5.73		
		Hue angle		
Rania	102.77 ± 4.24	42.06 ± 5.56	34.37 ± 3.40	41.89 ± 4.01
Winter Dawn	97.24 ± 0.37	52.69 ± 4.28	39.63 ± 0.29	34.08 ± 1.11
Winter Star	102.24 ± 5.47	41.37 ± 2.35	37.36 ± 5.32	66.39 ± 16.10
Camrose	100.97 ± 0.33	45.15 ± 2.66	30.73 ± 1.65	32.41 ± 2.04
Navelia	99.33 ± 0.13	77.76 ± 15.52	42.99 ± 7.23	54.45 ± 6.10
Mean	**100.51 ± 2.11**	**51.81 ± 6.14**	**37.02 ± 3.58**	**45.84 ± 5.87**
Critical difference (P<0.05)		Cultivars (A)= 6.31 Stages (B)= 5.64 AB= 12.62		

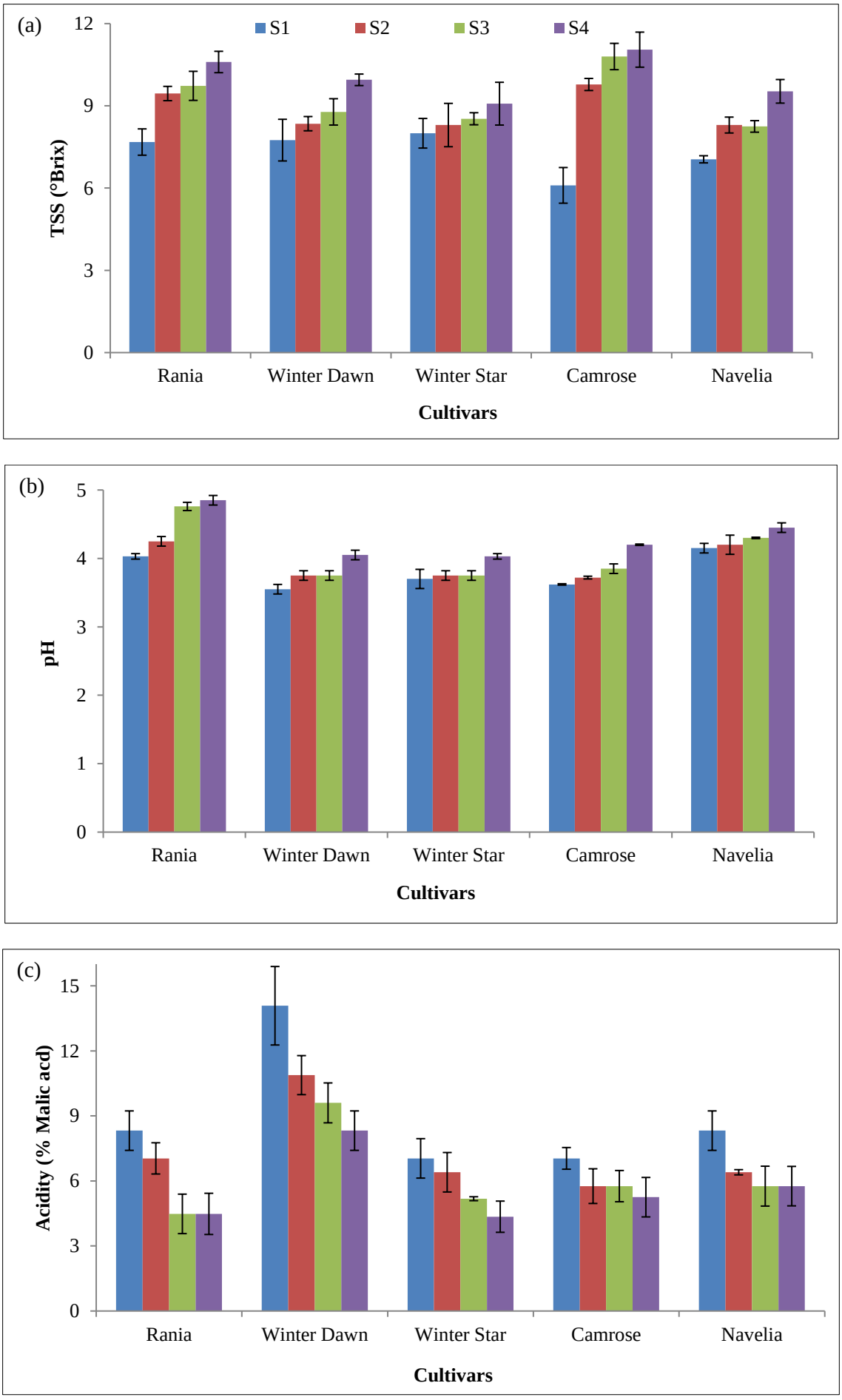
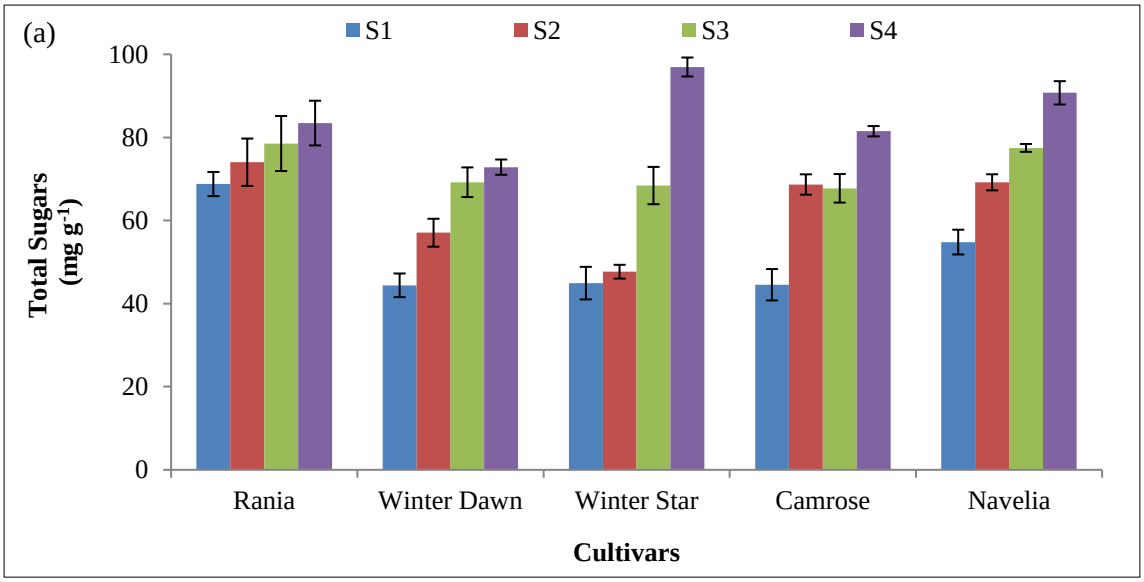
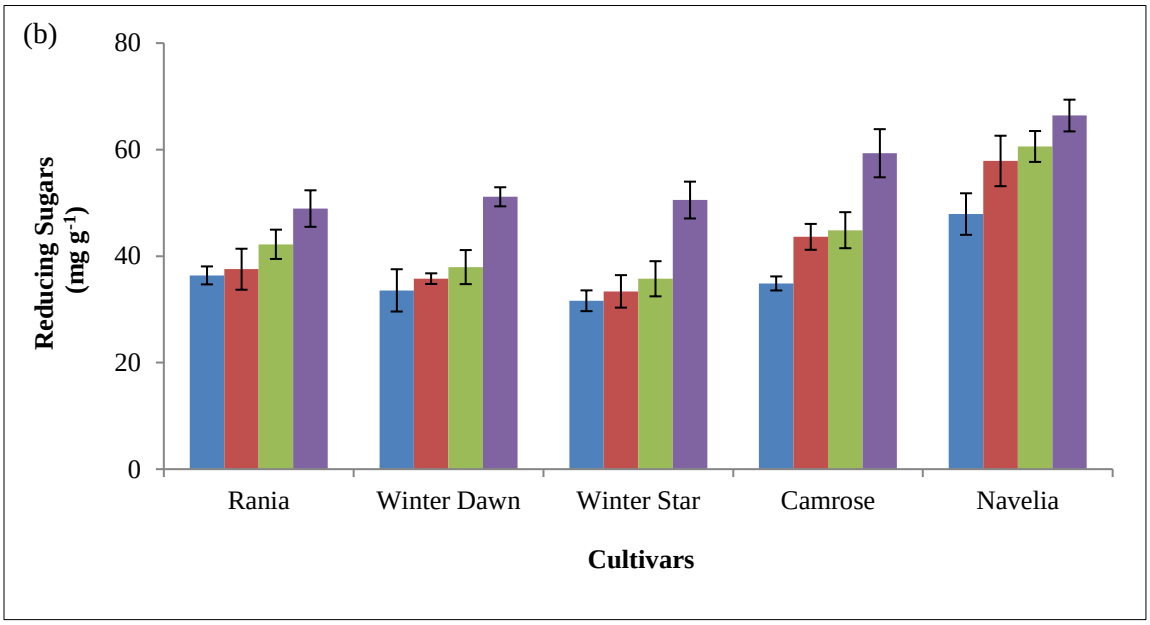


Figure 2. Changes in (a) total soluble solids, (b) pH and (c) titratable acidity of strawberry fruits during development.





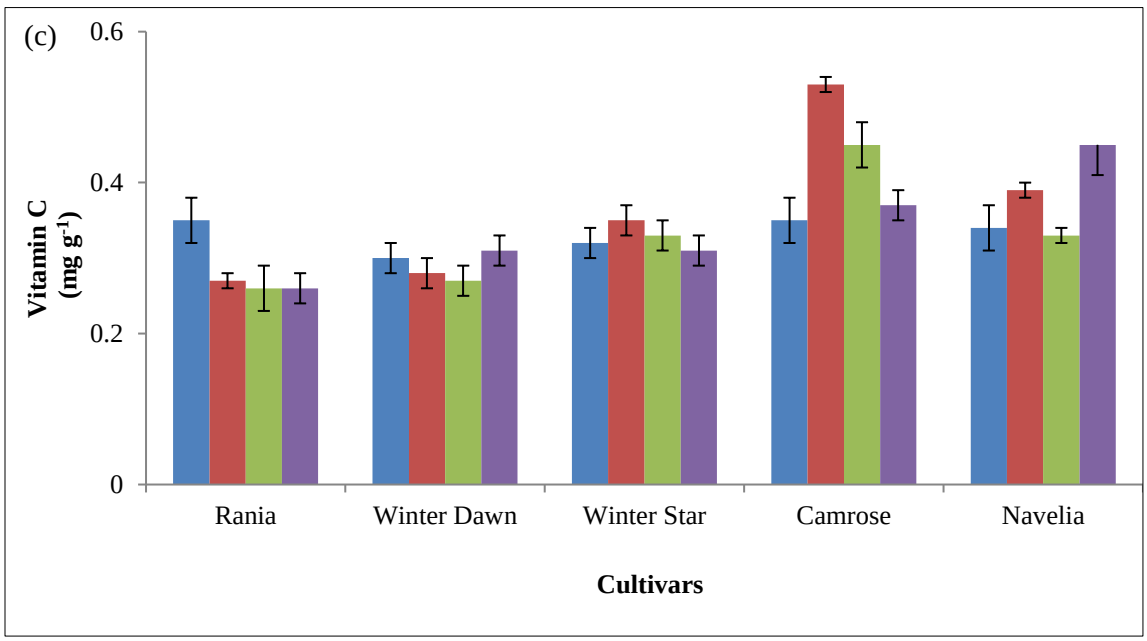


Figure 3. Changes in (a) total sugars, (b) reducing sugars and (c) vitamin C contents of strawberry fruits during development.

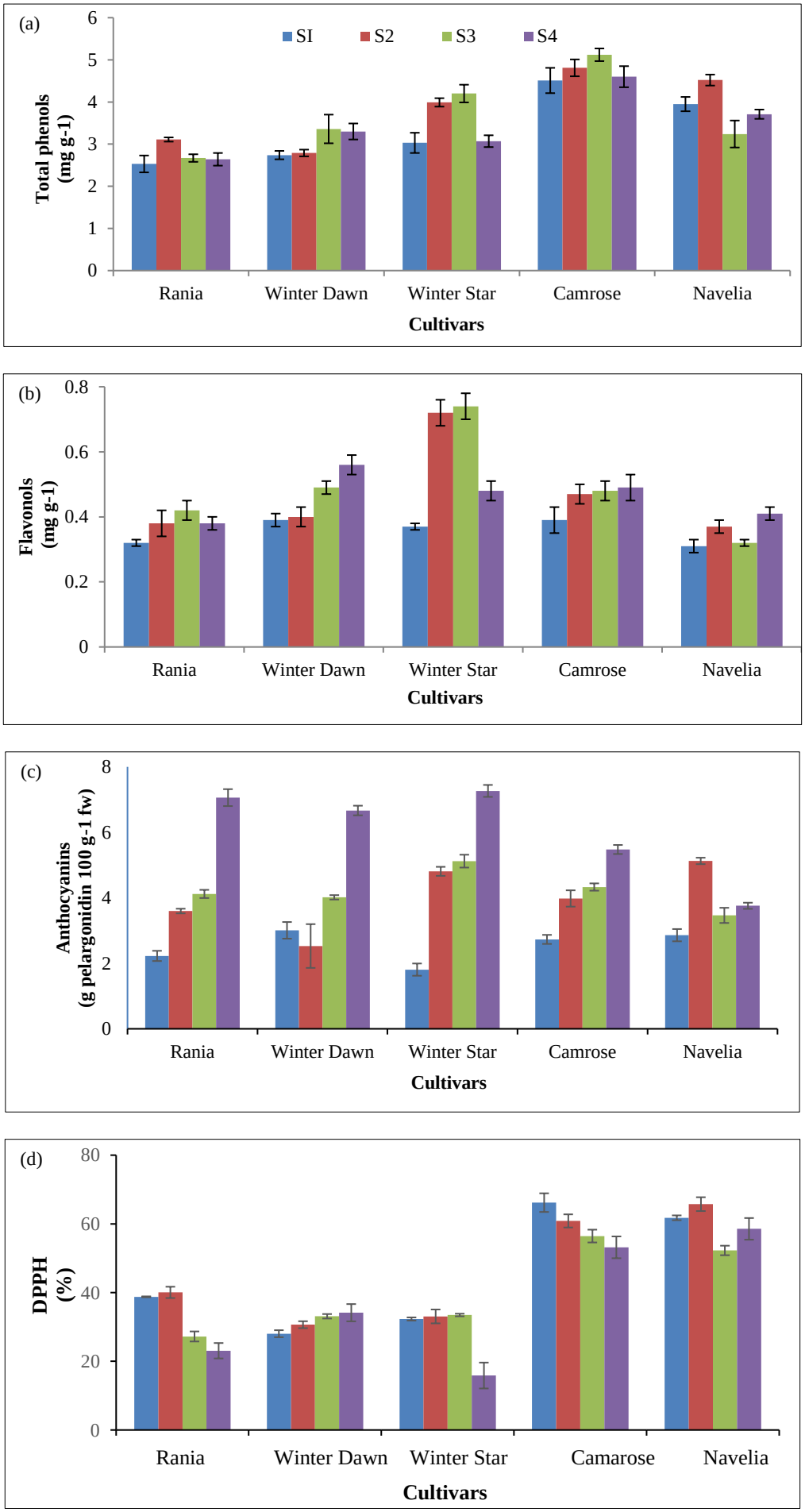


Figure 4. Changes in (a) total phenolics, (b) flavanols, (c) anthocyanins and (d) DPPH scavenging activity of strawberry fruits during development.

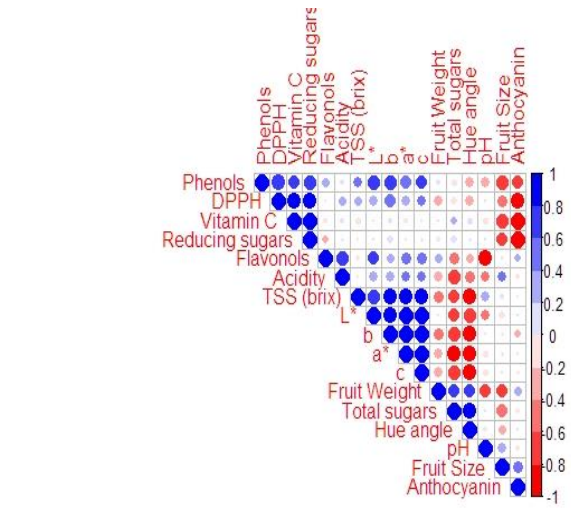


Figure 5. Pearson's correlation matrix between quality parameters in different strawberry cultivars. Strong correlations are displayed by high color intensity and large circle size whereas smaller circles with weak colors showed weak correlation coefficient. The scale colors denote whether the correlation is positive (blue) or negative (red)

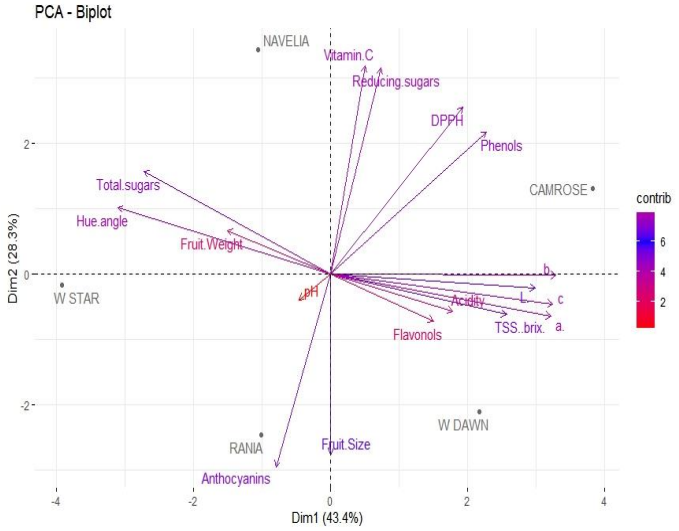


Figure 6. Principal component analysis (PCA) biplot distinguishes different quality parameters with various cultivars at different stages of color development.

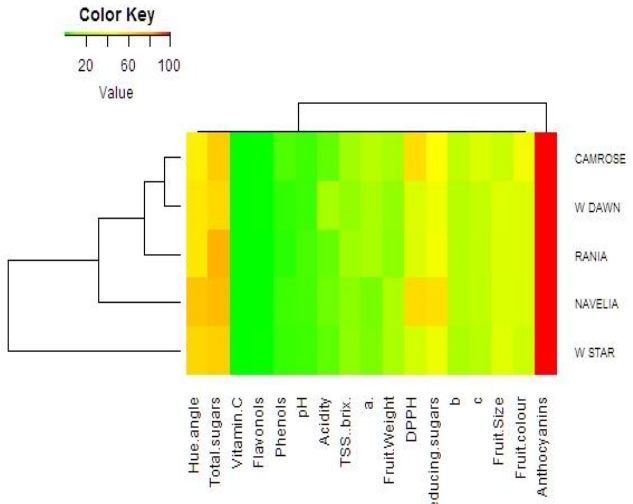


Figure 7. Heatmap and hierarchical cluster analysis of quality parameters in strawberry cultivars highlighting differences in response to different stages of color development. The color of each cell depicts the abundance of individual parameter; green indicates a significant decrease, and red represents a significant increase in content.

Discussion

Strawberry fruit has an initial phase of growth and enlargement followed by a maturation phase and fruits become softer, redder and sweeter during fruit ripening process. The fruit growth curve is either single sigmoid as a function of time or biphasic, depending upon the genotype (Miura et al., 1990). Most of the receptacle growth is attributed to the cortex and pith cells, where cortex is considered as the primary contributor to the fruit size. Cell division mainly occurs before anthesis and is responsible for only 15-20% of the total growth. The rest of fruit growth occurs due to cell enlargement (Moore et al., 1970). Kim et al (2013) observed the fresh weights of strawberry fruits in the range of 8.7 to 11.7 g at the white stage and values further increased with fruit ripening. Fruit ripening from white to red color stages takes 5-10 days under field conditions and it depends on air temperature. Strawberries progress from the half red to the three-quarters red stage within 2–3 days on the plant (Ménager et al., 2004). The change in colour of fruits is considered as one of the most common harvesting indices as loss of green colour in fruits has been noticed usually when they start ripening. This is due to breakdown of chlorophyll molecules that in turn, is mediated through chlorophyllase enzyme. Changes in pH is due to oxidative stress, leakage of organic acids from vacuoles and synthesis of secondary metabolites such as carotenoids, anthocyanins and other pigments which suppress the expression of chlorophyll pigment (Wills et al., 1998). The enzyme chlorophyllase hydrolyses chlorophyll into chlorophyllide and phytol, followed by substitution of hydrogen atom in place of Mg atom which results in the formation of brown coloured pheophorbide (Yamauchi, 2015). The changes in fruit colour with onset of ripening also indicate the biosynthesis and accumulation of numerous pigments such as ß-carotene, anthocyanins - light red to blue (in strawberry), lycopene, xanthophylls and violaxanthin (Gundewadi et al., 2018). Kim et al. (2018) reported significant difference in the fruit colour parameters were among cultivars at different fruit development stages. Similar observations of L* have been made by earlier authors also Kim et al. (2013), Hwang et al. (2019), Parra-Palma et al. (2020). The increase in b^* values of strawberry fruits decreased with a rapid rise in a^* values along with fruit development might be due to change of strawberry fruit colour from green to red along with maturity (Ménager et al., 2004). Hue angle decreased from white to one-half red fruit and then remains steady as the fruit ripening progresses further. The chroma* of the strawberries increased from the color break to the three-quarters colored stage and then decrease or hold steady through the final red color stage during development in the field (Ihl et al., 1999; Ménager et al., 2004).

The major soluble constituents of strawberry fruits indicate the presence of soluble sugars, vitamins, amino acids while TA represent organic acids (Liu et al., 2016). TSS, TA and ratio of TSS/TA are important factors for evaluating fruit quality. In the present study, TSS tended to increase along with ripening. However, the TA of white, 50% red and 75% strawberry fruits expressed as malic acid equivalents tended to decline with fruit ripening. Fruits harvested at 75% red and full red stages did not show significant changes in TA as they ripened. Number of authors have reported similar changes in TSS for many strawberry cultivars during ripening and values were in the range of 4.8-10.9% (Ménager et al., 2004; Ornelas-Paz et al., 2013; Nunes et al., 2021). The highest increase in TSS in

'Camarose' cultivar corresponded to maximum increase in RS content in these fruits (***Figure 2***). It has been reported that TSS of fruits harvested at different stages of colour development increased which might be due to accumulation of total sugars and reducing sugars on solubilization of cell wall hemicelluloses and polyuronides (Huber, 1984; Wang et al., 2013). TA content in different cultivars varied with 'Winter Dawn' having highest TA values at different stages of fruit ripening. The decrease in TA during different stages might be due to low ascorbic acid content in fruits as ascorbic acid content decreased from S1 to S2 in 'Rania' and then values remain almost same from S2 to S4. Fruits of 'Rania' and 'Navelia' cultivars showed same TA at S3 and S4. Nunes et al. (2006) reported similar findings that three-quarter, and full red coloured 'Oso Grande' and 'Sweet Charly' strawberries showed similar TA. The decline in acidity content during ripening might also be attributed to increase in the membrane permeability which allows acids to be stored in the respiring cells resulting in the formation of respective acids salts coupled with a drop in the amount of organic acid translocated from the leaves (Moing et al., 2001). Saridas et al. (2022) also reported that TSS and TA values vary according to the cultivar's response to environmental conditions during maturation and ripening. The sweetness of strawberry fruits depends upon TSS/TA ratio that increased during the ripening process as reported in earlier studies (Ornelas-Paz et al., 2013; Nunes et al., 2021). At ripened stage, TSS/TA ratios of 7.73, 7.28, 6.85, 6.36, 5.39, and 5.35 were measured for the strawberry cultivars 'Camino Real', 'Tudla', 'Sweet Charlie', 'Dover', 'Aromas', and 'Camarosa' respectively. Cultivar 'Tochiotome' presented highest TSS/TA ratio and 'Sachinoka' exhibited the lowest ratio for TSS/TA. The low TSS/TA ratio might be due to higher temperature sensitivity increasing the fruit respiratory rate leading to lower TSS and high TA values (Liu et al., 2016). The changes in pH in strawberry fruits are in accordance with earlier studies by Capacasa et al. (2008) and Nunes et al. (2021). Strawberry is a naturally acidic fruit with pH<6 due to presence of malic, citric and quinic acids, the composition of these may vary according to cultivar type (Liu et al., 2016). Strawberries with pH>3 are sensorially better accepted due to low acidity (Oliveira et al., 2015). Sugars act as precursors of flavor compounds and also used as an energy source in the ripening process. Based upon the type of fruit and place of its ripening (on/off the plant), their inner sugar levels tend to raise with ripening because of either import of sugars from the parent plant or starch mobilization within the fruits. Akšic et al. (2019) reported that glucose (41%), fructose (41%) and sucrose (17%) account for approximately 99% of the total sugars and their contents vary at the commercial stage in strawberry fruits. Gundewadi et al. (2018) observed a gradual increase in the ascorbic acid content along with fruit growth. However, the amounts decreased as the fruit attained maturity and started ripening. The initial increase in the vitamin C content during fruit ripening could be due to increased synthesis of some metabolites that promote synthesis of vitamin C precursors. The reduction in vitamin C content at later stages of fruit maturity and ripening might be due to its oxidation to dehydroascorbic acid (Wills et al., 2007). The ascorbic acid content reported in present studies is in accordance with the previous studies (Del Pozo-Insfran et al., 2006; Bordonaba & Terry, 2010) who also recorded 0.6 mg/g vitamin C on average in strawberry fruits. Moing et al. (2001) reported that the ascorbic acid content ranges from 0.3 to 1.2mg/g^{-1} fw in strawberry & hence, it makes an important contribution to the fruit nutritional value.

Strawberries possess large number of bioactive compounds such as anthocyanins, flavanols, flavan-3-ols and phenolic acids (Jaiswal, 2020). The composition of phenols and flavanols is the major contributing factor towards the quality and flavour characteristics of fruits and vegetables. A gradual change occurs in some secondary metabolites along with maturity due to commencement of phenolic pathways (Ghasemzadeh & Ghasemzadeh, 2011). Numerous authors have reported non-uniform values of phenolic content in strawberry cultivars because of their dependence on climatic conditions, cultivation system, cultivars and harvest time (Ariza et al., 2015; Gündüz & Özdemir, 2014). Antioxidant capacity of many berries including strawberry, determined in terms of DPPH is attributed mainly to vitamin C and phenolic compounds. Several authors have reported increase in the anthocyanin content with strawberry fruit ripening in the field from full size 'White turning red' to full-size 'three-quarters red stage' (Voća et al., 2014; Sirijan et al., 2020; Janurianti et al., 2021). Kim et al. (2013) observed anthocyanin contents < 2.3 mg 100g^{-1} fw at green and white stages in strawberry cultivars and values increased by approximately 16.7 to 26.4 folds at red stage than the early fruit developmental stages. Total soluble phenolics decreased from the color break stage to the three-quarters colored stage during ripening in the field and increased at the final ripening (***Figure 4***). A significant increase was recorded in the total anthocyanins content of strawberries ripened in the field regardless of the initial color stage (***Figure 4***) while the chlorophyll content declines. Cyanidin-3-glucoside and pelargonidin-3-glucoside contributed to the red and orange-brown color, respectively in strawberries and their contents increased significantly from the color break to the final red color stage in fruit ripened in the field (Saridas et al., 2021). Tulipani et al. (2008) reported the decline in DPPH radical scavenging activity was primarily due to decrease in ellagitannins and proanthocyanidin-like tannins. Kafkas et al. (2007) did not observe statistical correlation between TSS & total sugars in ripening strawberries from several cultivars. A strong correlation between total phenolics and antioxidant activity of strawberry fruits has been reported (Shin et al., 2008; Kim & Shin, 2015). Roussos et al. (2009) also observed a strong correlation mainly with total phenolics or Vit C content and antioxidant activity of strawberry fruit extracts. Earlier studies also reported a linear correlation of antioxidant capacity with the phenolics content (r=0.942) and ascorbic acid concentration (r=0.950) but not with anthocyanins (Ferreyra et al., 2007; Oszmianski & Wojdylo, 2009). Anthocyanins pigments contribute to typical colour of strawberry fruit, however, the colour of anthocyanins depends on the hydroxylation pattern of their B-ring. Cerezo et al. (2010) mentioned that the degree of antioxidant activity is determined by the sugar substituent and levels of antioxidant activity were higher in mono-glucoside anthocyanin than rutinoside at neutral pH and depends on the relative abundance of the compounds. A correlation in DPPH, vitamin C, reducing sugars and phenolics in PC2 indicated that antioxidant activity of fruit was due to these parameters and these observations are in accordance to earlier studies reported by Minutti-López Sierra et al. (2019). These factors indicated that strawberry cultivar 'Camarose' with higher L* and c* value can be more attractive on the market for consumers.

Conclusions

Strawberry cultivars differ in their physicochemical and biochemical composition in agroclimatic conditions of Punjab area of northwest India. Highest total phenolics were in 'Camarose' cultivar at S3 stage and antioxidant activity at S1 stage. Anthocyanins were maximum at full red stage in all the cultivars as compared to other stages except 'Navelia'. TSS and reducing sugars were also highest in all the studied cultivars at full red stage with maximum TSS in Winter star and reducing sugars in 'Navelia' cultivar. Vitamin C was maximum in 'Camarose' from green to 75% red stage among all cultivars. Titratable acidity was highest in 'Winter dawn' at all the stages whereas pH showed maximum values in 'Rania' cultivar. More detailed studies of phenolics and anthocyanin profiling during ripening of cultivars and their relation to color and flavour needs to be carried out to study the fruit quality and which can be further used to strengthen the strawberry breeding program.

References

Abera, D., Zerihun, M., Yenasew, A. (2023): Effect of variety and agro-ecology on physio-chemical and organoleptic quality of avocado fruit grown in Ethiopia. Cogent Food and Agriculture. 9: 2273637. https://doi.org/10.1080/23311932.2023.2273637

Akšić, M.F., Tosti, T., Sredojević, M., Milivojević, J., Meland, M., Natić, M. (2019): Comparison of sugar profile between leaves and fruits of blueberry and strawberry cultivars grown in organic and integrated production system. Plants. 8: 205. https://doi.org/10.3390/plants8070205

Ariza, M.T., Martínez-Ferri, E., Domínguez, P., Medina, J.J., Miranda, L., Soria, C. (2015): Effects of harvest time on functional compounds and fruit antioxidant capacity in ten strawberry cultivars. Journal of Berry Research. 5(2): 71–80. https://doi.org/10.3233/JBR-150090

Bordonaba, J. G., Terry, L.A. (2010): Manipulating the taste-related composition of strawberry fruits (*Fragaria×ananassa*) from different cultivars using deficit irrigation. Food Chemistry. 122(4): 1020–1026. https://doi.org/10.1016/j.foodchem.2010.03.060

Capocasa, F., Scalzo, J., Mezzetti, B., Battino, M. (2008): Combining quality and antioxidant attributes in the strawberry: The role of genotype. Food Chemistry. 111(4): 872–878. https://doi.org/10.1016/j.foodchem.2008.04.068

Cerezo, A.B., Cuevas, E., Winterhalter, P., Garcia-Parrilla, M.C., Troncoso, A.M. (2010): Isolation, identification, and antioxidant activity of anthocyanin compounds in Camarosa strawberry. Food Chemistry. 123(3): 574–582. https://doi.org/10.1016/j.foodchem.2010.04.073

Del Pozo-Insfran, D., Duncan, C.E., Yu, K.C., Talcott, S.T., Chandler, C.K. (2006): Polyphenolics, ascorbic acid, and soluble solids concentrations of strawberry cultivars and selections grown in a winter annual hill production system. Journal of the American Society for Horticultural Science. 131(1): 89–96. https://doi.org/10.21273/JASHS.131.1.89

Ferreyra, R.M., Viña, S.Z., Mugridge, A., Chaves, A.R. (2007): Growth and ripening season effects on antioxidant capacity of strawberry cultivar Selva. Scientia Horticulturae. 112(1): 27–32. https://doi.org/10.1016/j.scienta.2006.12.001

Food and Agriculture Organization of the United Nations (2019): FAOSTAT.

Gasparrini, M., Forbes-Hernandez, T.Y., Giampieri, F., Afrin, S., Alvarez-Suarez, J.M., Mazzoni, L., Mezzetti, B., Quiles, J.L., Battino, M. (2017): Anti-inflammatory effect of strawberry extract against LPS-induced stress in RAW 264.7 macrophages. Food and Chemical Toxicology. 102: 1–10. https://doi.org/10.1016/j.fct.2017.01.018

Gasparrini, M., Forbes-Hernandez, T.Y., Cianciosi, D., Quiles, J.L., Mezzetti, B., Xiao, J., Giampieri, F., Battino, M. (2021): The efficacy of berries against lipopolysaccharide-induced inflammation: A review. Trends in Food Science and Technology. 117: 74–91. https://doi.org/10.1016/j.tifs.2021.01.015

Ghasemzadeh, A., Ghasemzadeh, N. (2011): Flavonoids and phenolic acids: Role and biochemical activity in plants and human. Journal of Medicinal Plants Research. 5(31): 6697-6703. https://doi.org/10.5897/JMPR11.1404

Gundewadi, G., Reddy, V.R., Bhimappa, B. (2018): Physiological and biochemical basis of fruit development and ripening-a review. Journal of Hill Agriculture. 9(1): 7-21. https://doi.org/10.5958/2230-7338.2018.00003.4

Gündüz, K., Özdemir, E. (2014): The effects of genotype and growing conditions on antioxidant capacity, phenolic compounds, organic acid and individual sugars of strawberry. Food Chemistry. 155: 298–303. https://doi.org/10.1016/j.foodchem.2014.01.064

Huber, D.J. (1984): Strawberry Fruit Softening: The Potential Roles of Polyuronides and Hemicelluloses. Journal of Food Science. 49: 1310–1315. https://doi.org/10.1111/j.1365-2621.1984.tb14976.x

Hunter R. S. (1975): The measurement of appearance. 2nd edn. Chichester: John Wiley and Sons.

Hwang, H., Kim, Y.-J., Shin, Y. (2019): Influence of ripening stage and cultivar on physicochemical properties, sugar and organic acid profiles, and antioxidant compositions of strawberries. Food Science and Biotechnology. 289(6): 1659–1667. https://doi.org/10.1007/s10068-019-00610-y

Ihl, M., San Martín, A., Bifani, V. (1999): Preliminary report on colour quality measured as chlorophyllase activity in strawberries at different stages of maturity. Acta Horticulturae. 485: 181–186. https://doi.org/10.17660/ActaHortic.1999.485.24

Jagota, S.K., Dani, H.M. (1982): A new colorimetric technique for the estimation of vitamin C using Folin phenol reagent. Analytical Biochemistry. 127: 178–182.

Jaiswal, A.K. (2020): Nutritional composition and antioxidant properties of fruits and vegetables. Elsevier Science & Technology, San Diego.

Janurianti, N.M.D., Utama, I.M.S., Gunam, I.B.W. (2021): Colour and quality of strawberry fruit (*Fragaria x ananassa* Duch.) at different levels of maturity. Sustainable Environment Agricultural Science. 5(1): 22–28. https://doi.org/10.22225/seas.5.1.3166.22-28

Kafkas, E., Koşar, M., Paydaş, S., Kafkas, S., Başer, K.H.C. (2007): Quality characteristics of strawberry genotypes at

different maturation stages. Food Chemistry. 100(3): 1229–1236. https://doi.org/10.1016/j.foodchem.2005.12.005

Kaur, M., Sharma, S., Singh, D. (2018): Influence of selenium on carbohydrate accumulation in developing wheat grains. Communications in Soil Science and Plant Analysis. 49(13): 1650–1659. https://doi.org/10.1080/00103624.2018.1474903

Kim, S.K., Bae, R.N., Na, H., Ko, K.D., Chun, C. (2013): Changes in physicochemical characteristics during fruit development in June-bearing strawberry cultivars. Horticulture, Environment and Biotechnology. 54(1): 44–51. https://doi.org/10.1007/s13580-013-0166-z

Kim, Y.-J., Shin, Y. (2015): Antioxidant profile, antioxidant activity, and physicochemical characteristics of strawberries from different cultivars and harvest locations. Journal of the Korean Society for Applied Biological Chemistry. 58: 587–595. https://doi.org/10.1007/s13765-015-0085-z

Liu, L., Ji, M., Chen, M., Sun, M., Fu, X., Li, L., Gao, D., Zhu, C. (2016): The flavor and nutritional characteristic of four strawberry varieties cultured in soilless system. Food Science and Nutrition. 4: 858–868. https://doi.org/10.1002/fsn3.346

Ménager, I., Jost, M., Aubert, C. (2004): Changes in physicochemical characteristics and volatile constituents of strawberry (cv. Cigaline) during maturation. Journal of Agricultural and Food Chemistry. 52(5): 1248–1254. https://doi.org/10.1021/jf0350919

Minutti-López Sierra, P., Gallardo-Velázquez, T., Osorio-Revilla, G., Meza-Márquez, O.G. (2019): Chemical composition and antioxidant capacity in strawberry cultivars (*Fragaria* x *ananassa* Duch.) by FT-MIR spectroscopy and chemometrics. CyTA - Journal of Food. 17(1): 724–732. https://doi.org/10.1080/19476337.2019.1645211

Miura, H., Imada, S., Yabuuchi, S. (1990): Double sigmoid growth curve of strawberry fruit. Journal of the Japanese Society for Horticultural Science. 59: 527–531. https://doi.org/10.2503/jjshs.59.527

Moing, A., Renaud, C., Gaudillère, M., Raymond, P., Roudeillac, P., Denoyes-Rothan, B. (2001): Biochemical changes during fruit development of four strawberry cultivars. Journal of the American Society for Horticultural Science. 126(4): 394–403. https://doi.org/10.21273/JASHS.126.4.394

Moore, J.N., Brown, G.R., Brown, E.D. (1970): Comparison of factors influencing fruit size in large-fruited and small-fruited clones of strawberry. Journal of the American Society for Horticultural Science. 95(6): 827–831. https://doi.org/10.21273/JASHS.95.6.827

Nair, M., P., Vaidyanathan, C.S. (1964): A colorimetric method for determination of pyrocatechol and related substances. Analytical Biochemistry. 7: 315–321. https://doi.org/10.1016/0003-2697(64)90136-8

Nunes, M.C.N., Brecht, J.K., Morais, A.M., Sargent, S.A. (2006): Physicochemical changes during strawberry development in the field compared with those that occur in harvested fruit during storage. Journal of the Science of Food and Agriculture. 86(2): 180–190. https://doi.org/10.1002/jsfa.2314

Nunes, G., Teixeira, F., Schwarz, K., Camargo, C.K., Resende, J.T.V.D., Santos, E.F.D., Franco, B.C., Novello, D. (2021): Influence of genetic variability on the quality of strawberry cultivars: sensorial, physical-chemical and nutritional characterization. Acta Scientiarum Agronomy. 43: e46862. https://doi.org/10.4025/actasciagron.v43i1.46862

Oliveira, A., Gomes, M.H., Alexandre, E.M.C., Poças, F., Almeida, D.P.F., Pintado, M. (2015): Phytochemicals preservation in strawberry as affected by pH modulation. Food Chemistry. 170: 74–83. https://doi.org/10.1016/j.foodchem.2014.07.156

Ornelas-Paz, J.D.J., Yahia, E.M., Ramírez-Bustamante, N., Pérez-Martínez, J.D., Escalante-Minakata, M.D.P., Ibarra-Junquera, V., Acosta-Muñiz, C., Guerrero-Prieto, V., Ochoa-Reyes, E. (2013): Physical attributes and chemical composition of organic strawberry fruit (*Fragaria x ananassa* Duch, Cv. Albion) at six stages of ripening. Food Chemistry. 138: 372–381. https://doi.org/10.1016/j.foodchem.2012.11.006

Oszmianski, J., Wojdyło, A. (2009): Comparative study of phenolic content and antioxidant activity of strawberry puree, clear, and cloudy juices. European Food Research and Technology. 228: 623–631. https://doi.org/10.1007/s00217-008-0971-2

Parra-Palma, C., Morales-Quintana, L., Ramos, P. (2020): Phenolic content, color development, and pigment−related gene expression: A comparative analysis in different cultivars of strawberry during the ripening process. Agronomy. 10(4): 588. https://doi.org/10.3390/agronomy10040588

Ranganna, S. (2007): Handbook of analysis and quality control for fruit and vegetable products. Tata McGraw-Hills Publishing Company Limited, New Delhi.

Roussos, P.A., Denaxa, N.-K., Damvakaris, T. (2009): Strawberry fruit quality attributes after application of plant growth stimulating compounds. Scientia Horticulturae. 119: 138–146. https://doi.org/10.1016/j.scienta.2008.07.021

Saridas, M.A., Simsek, O., Donmez, D., Kacar, Y.A., Kargi, S.P. (2021): Genetic diversity and fruit characteristics of new superior hybrid strawberry (*Fragaria* × *ananassa* Duchesne ex Rozier) genotypes. Genetic Resources and Crop Evolution. 68: 741–758. https://doi.org/10.1007/s10722-020-01020-4

Sarıdaş, M.A., Ağçam, E., Akbaş, F.C., Akyıldiz, A., Paydaş Kargı, S. (2022): Comparison of superior bred strawberry genotypes with popular cultivars in terms of fruit bioactive compounds over the full range of harvest dates. South African Journal of Botany. 147: 142–152. https://doi.org/10.1016/j.sajb.2022.01.010

Shin, Y., Ryu, J.-A., Liu, R.H., Nock, J.F., Watkins, C.B. (2008): Harvest maturity, storage temperature and relative humidity affect fruit quality, antioxidant contents and activity, and inhibition of cell proliferation of strawberry fruit. Postharvest Biology and Technology. 49: 201–209. https://doi.org/10.1016/j.postharvbio.2008.02.008

Shivavedi, N., Kumar, M., Tej, G.N.V.C., Nayak, P.K. (2017): Metformin and ascorbic acid combination therapy ameliorates type 2 diabetes mellitus and comorbid depression in rats. Brain Research. 1674: 1–9. https://doi.org/10.1016/j.brainres.2017.08.019

Sirijan, M., Pipattanawong, N., Saeng-on, B., Chaiprasart, P. (2020): Anthocyanin content, bioactive compounds and physico-chemical characteristics of potential new strawberry cultivars rich in-anthocyanins. Journal of Berry Research. 10(3): 397–410. https://doi.org/10.3233/JBR190487

Swain, T., Hillis, W.E. (1959): The phenolic constituents of *Prunus domestica*. I. - The quantitative analysis of phenolic constituents. Journal of the Science of Food and Agriculture. 10: 63–68. https://doi.org/10.1002/jsfa.2740100110

Tulipani, S., Mezzetti, B., Capocasa, F., Bompadre, S., Beekwilder, J., De Vos, C.H.R., Capanoglu, E., Bovy, A., Battino, M. (2008): Antioxidants, phenolic compounds, and nutritional quality of different strawberry genotypes. Journal of Agricultural and Food Chemistry. 56(3): 696–704. https://doi.org/10.1021/jf0719959

Voća, S., Žlabur, J., Dobričević, N., Jakobek, L., Šeruga, M., Galić, A., Pliestić, S. (2014): Variation in the bioactive compound content at three ripening stages of strawberry fruit. Molecules. 19: 10370–10385. https://doi.org/10.3390/molecules190710370

Wang, D., Zhang, H., Wu, F., Li, T., Liang, Y., Duan, X. (2013): Modification of pectin and hemicellulose polysaccharides in relation to aril breakdown of harvested longan fruit. International Journal of Molecular Sciences. 14(12): 23356–23368. https://doi.org/10.3390/ijms141223356

Wills, R.B.H., Golding, J.B. (2016): Physiology and biochemistry, in Wills, R.B.H., Golding, J.B. (eds) Postharvest: An introduction to the physiology and handling of fruit and vegetables. 6th edn. Wallingford: CABI, pp. 34–62. https://doi.org/10.1079/9781786391483.0034

Wills, R.B.H., Miller, J.C.B., Matawie, K.M. (1998): Relationship between glycaemic index and nutrient composition of fruit and vegetables. International Journal of Food Properties. 1: 89–94. https://doi.org/10.1080/10942919809524569

Yamauchi, N. (2015): Postharvest chlorophyll degradation and oxidative stress, in Kanayama, Y., Kochetov, A. (eds) Abiotic Stress Biology in Horticultural Plants. Tokyo: Springer Japan, pp. 101–113. https://doi.org/10.1007/978-4-431-55251-2_8

Zeliou, K., Papasotiropoulos, V., Manoussopoulos, Y., Lamari, F.N. (2018): Physical and chemical quality characteristics and antioxidant properties of strawberry cultivars (*Fragaria* × *ananassa* Duch.) in Greece: assessment of their sensory impact. Journal of the Science of Food and Agriculture. 98: 4065–4073. https://doi.org/10.1002/jsfa.8923