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COMPARISON OF QUALITY CHARACTERISTICS OF FRESH AND PROCESSED STRAWBERRIES

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Abstract

Strawberries (Fragaria × ananassa) are highly appreciated for their sensory attributes and nutritional benefits, but their quality can vary significantly between fresh and processed forms. This study aimed to compare the quality characteristics of fresh strawberries of three different varieties, namely, 'Karima', 'Auge' and 'Monterey' with their processed counterparts in the forms of jelly and syrup. Key parameters such as color, texture, total soluble solid content (°Brix), total acidity, vitamin C and phenolic compounds were evaluated. Fresh strawberries exhibited superior color, firmness, and higher levels of bioactive compounds, including vitamin C and phenolics, compared to the processed products. However, jelly and syrup retained substantial soluble solids and demonstrated an extended shelf life, making them suitable alternatives for long-term consumption. Processing led to significant changes in pH and acidity, with jelly maintaining a better balance between sweetness and tartness compared to syrup. Although antioxidant activity decreased during processing, both jelly and syrup still provided notable health benefits. This study highlights the trade-offs between sensory and nutritional quality in fresh and processed strawberries, offering insights into their uses and consumers' preferences.

Key words: *Fragaria x ananassa, jelly, syrup, acidity, TSS, total phenolic content, vitamin C.*

INTRODUCTION

Strawberries (*Fragaria* × *ananassa*) are among the most consumed fruits worldwide, appreciated not only for their appealing sensory attributes including their vibrant color, juicy texture, and distinct aroma, but also for their high nutritional value (Hannum, 2004).

Strawberries are particularly rich in vitamin C, phenolic compounds and flavonoids (Giampieri et al., 2012; Kumar et al., 2020; Cao et al., 2011).

These bioactive compounds are associated with numerous health benefits, including anti-inflammatory, anti-cancer, cardioprotective and antioxidant effects (Meyers et al., 2003; Tulipani et al., 2008). However, several other fruits contain high levels of antioxidant molecules, a previous study demonstrated an increase in serum antioxidant capacity in humans after including strawberries in their diet (Seyhun, 2008). Strawberry fruits have a high vitamin C content, which ranges between 40-70 mg/100 g. Vitamin C is usually considered as an indicator of nutrient quality during food processing and storage, as it is generally observed that if ascorbic acid is well retained, the other nutrients are also well retained (Sapei & Hwa, 2014).

Due to their high perishability (from 5 to 7 days at 0°C and relative humidity of 95%) strawberries are often subjected to various processing methods such as freezing, drying, and thermal treatments to extend shelf life and facilitate year-round availability while preserving key nutrients (Nunes et al., 2005; Ornelas-Paz et al., 2013; Pereira et al., 2014). However, these processes can induce significant changes in their physicochemical and sensory qualities, including texture, color, flavor, and nutrient content (Patras et al., 2010; Fernández-León et al., 2013).

For example, heat processing may lead to the degradation of thermolabile nutrients like vitamin C, while freezing can affect texture due to ice crystal formation (Karakaya et al., 2011).

Comparative studies which investigated fresh and processed strawberries have provided different findings, with some suggesting minimal losses in quality depending on the method used, while others report significant alterations in both chemical composition and consumer acceptability (Šamec et al., 2016; Huber & Oparka, 2001). Understanding how different processing techniques affect the overall quality characteristics of strawberries is critical for optimizing preservation strategies and ensuring to obtain a healthful, high-quality products to consumers.
Therefore, the main aim of this study was to compare the quality characteristics of fresh strawberries of three different varieties, such as, 'Karima', 'Auge' and 'Monterey' with their processed counterparts as jelly and syrup. By identifying the most favorable preservation techniques, this research seeks to balance shelf-life extension with minimal compromise to nutritional and sensory integrity.

MATERIALS AND METHODS

Experimental site and plant material

In order to carry out this research strawberry plants were grown in the experimental plots of the Horticultural Research Station (46°76′N 23°61′E) of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. The experimental variants included three everbearing strawberry varieties, namely, 'Karima', also known as 'Aurora Karima', 'Auge' and 'Monterey' (Table 1).

Table 1. Description of strawberry varieties under study

Variety	'Karima'	'Auge'	'Monterey'
Appearance			
Characteristics	High yield, juicy texture, bright fruits, good taste and flavor, long shelf life	Good yield, long-conical and regular shape, high firmness and good flavor	High yield, large, moderately firm fruits with excellent flavor

Strawberry plants were planted in 2023 and grown în greenhouse in hill system (15 cm high, 50 cm wide hills) in two rows, with 30 cm between plants and 1.20-1.60 m between hills, covered with black agrotextile.
Fresh, fully ripened, free from mechanical damage or disease strawberry fruits were randomly harvested in September. In order to determine the physical fruit of each variety 50 fruits/variety were harvested in three replicates and measured to ensure the validity of the data. After harvest, the samples were transported to the laboratory under cooled conditions and stored at 4 °C until further analyses (within 24 hours).

Pomological traits of strawberries

To determine the variety-specific differences between strawberry fruits, different physical parameters were determined including fruit mass (M) and three linear dimensions such as length (L) and width (W) and thickness (T) as presented in Figure 1.

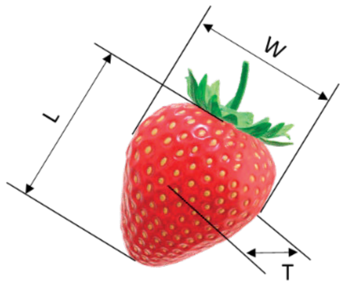

Figure 1. Representation of the three major dimensions of strawberry fruits: length (L), width (W) and thickness (T)

Strawberry mass (M) was measured by using an electronic digital balance (Kern EMB with 0.001 precision). The three linear dimensions namely, the major axis, length, (L), width (W) and thickness (T), were measured as shown in Figure 1, by using a digital vernier caliper (Quatros, accuracy ± 0.01) as suggested by Birania et al. (2022). The aspect ratio (AR) was then calculated according to Megat Ahmad Azman et al. (2020) as AR = L/W.

Sample preparation

Strawberries were washed under running distilled water, dried at room temperature, and homogenized using a blender to obtain a uniform puree. All analyses were conducted in triplicate using freshly prepared homogenates.

Determination of chemical fruit characteristics

To evaluate the chemical properties of the fruits total soluble solid content (TSS), titratable acidity (TA), Vitamin C content, total phenolic content and DPPH antioxidant activity were determined. TSS was measured using a digital hand-held refractometer (Kern Ora 10BA) and expressed as degrees Brix. A few drops of the strawberry juice were filtered through cheesecloth before measurement (Horwitz & Latimer, 2005). Titratable acidity was determined by titrating 10 mL of strawberry juice diluted with 40 mL of distilled water against 0.1 N NaOH using phenolphthalein as an indicator. Results were expressed as a percentage of citric acid equivalents as described by Nour et al. (2010).

Vitamin C (ascorbic acid) content was measured using the 2,6-dichlorophenolindophenol (DCPIP) titrimetric method (AOAC, 2000). A known volume of juice was titrated against a standardized DCPIP solution until a persistent pink endpoint was observed. Results were calculated based on a calibration curve using ascorbic acid standards and expressed as mg ascorbic acid per 100 g fresh weight (FW).

Total phenolic content was determined using the Folin-Ciocalteu method (Singleton & Rossi, 1965). An aliquot (0.5 mL) of fruit extract was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and 2 mL of 7.5% sodium carbonate. The mixture was incubated in the dark at room temperature for 30 minutes, and absorbance was measured at 765 nm using a UV–Vis spectrophotometer. Results were expressed as mg gallic acid equivalents (GAE) per 100 g FW.

Antioxidant activity was evaluated using the DPPH radical scavenging assay as described by Brand-Williams et al. (1995). A 0.1 mM DPPH solution was prepared in methanol. A 1 mL aliquot of the fruit extract was mixed with 2 mL of DPPH solution and incubated in the dark for 30 minutes. Absorbance was measured at 517 nm. The percentage of DPPH radical inhibition was calculated, and results were expressed as % inhibition or as Trolox equivalents (TE) per 100 g FW, based on a standard curve.

Preservation methods

Strawberry jelly was prepared using fresh, ripe strawberries (*Fragaria × ananassa*) following a traditional method with slight modifications. For each batch, 1 kg of whole strawberries was combined with 700 g of granulated sugar. The mixture was allowed to rest at low temperature (refrigerated) until the fruit naturally released juice and a syrup formed. Once syrup formation was evident, 1.5 g of citric acid was added to enhance acidity and preserve color and flavor.

The resulting mixture was then divided into two equal portions: one for making jelly and the other retained as syrup. The jelly portion was heated until the syrup reached a rolling boil. At this stage, the whole strawberries were added back into the boiling syrup and the mixture was simmered for an additional 15 minutes to allow proper infusion and thickening.

After cooking, the hot jelly was immediately poured into sterilized glass jars (Figure 2). The filled jars were then subjected to heat sterilization (e.g., in a water bath) to ensure microbial safety and shelf stability during storage.

Figure 2. Strawberry jelly as the final product

The strawberry syrup was obtained from the liquid portion separated during the strawberry jelly preparation process. The reserved strawberry syrup was first analyzed for its total soluble solids (TSS) using a refractometer. The syrup was then concentrated by boiling until it reached 70% TSS, ensuring a rich consistency and long shelf life. Once the target TSS was achieved, the hot syrup was poured into sterilized glass containers (Figure 3).

Figure 3. Strawberry syrup as the final product

To ensure microbial safety and product stability, a double sterilization process was applied: the filled containers were heat-processed (in a boiling water bath), and then sterilized a second time after 24 hours. This method preserves the flavor, color, and nutritional properties of the strawberries while producing a high-quality, shelf-stable syrup suitable for direct consumption or as a sweetener in various food applications (Kalt, 2005).

Statistical analyses

All the data recorded during this research have been statistically processed and interpreted accordingly. The data presented are means±standard error. To determine the differences between varieties and then fresh and processed variants Tukey's HSD test was performed at $p<0.05$.

RESULTS AND DISCUSSIONS

Pomological traits such as fruit dimensions, mass (weight), and firmness are the most important and critical indicators of strawberry fruit quality, which influence directly consumer preference, marketability, postharvest performance, and processing suitability (Temocico et al., 2019). The current analysis of three cultivars - 'Karima', 'Auge', and 'Monterey' - revealed significant variation in these traits (Table 2), consistent with prior findings that highlight the genetic background and environmental influence on strawberry morphology and texture (Nunes et al., 2020; Kafkas & Oğuz, 2023).

Fruit length, width, and thickness are primary morphological parameters that determine fruit shape and overall visual attractiveness. The results show that 'Auge' exhibited the greatest fruit length (48.21 mm), significantly higher than both 'Karima' and 'Monterey', suggesting a more elongated fruit shape. In contrast, 'Karima' had the largest width (29.96 mm) and thickness (22.80 mm), indicating a more rounded or conical fruit shape. These variations were also reflected in the aspect ratio (length/width), where 'Auge' showed a significantly higher value (1.68), aligning with consumer preferences for uniform and elongated fruit, as noted by Verma et al. (2023). A higher aspect ratio often correlates with a perception of premium quality and is important for fresh market sales (Lewers et al., 2020).

Table 2. Pomological traits of strawberry fruits

Variety	Fruit length (mm)	Fruit width (mm)	Fruit thickness (mm)	Aspect ratio	Fruit mass (g)	Firmness (kgf/cm^2)
'Karima'	37.22±1.22 a	29.96±1.64 c	22.80±0.91 c	1.24±0.89 a	16.10±1.18 a	2.24±1.00 c
'Auge'	48.21±0.99 b	28.61±0.82 a	19.53±1.42 a	1.68±0.67 b	15.09±0.77 a	1.94±0.83 b
'Monterey'	37.26±1.03 a	29.28±0.62 b	21.89±1.06 b	1.27±0.72 a	29.50±1.72 b	1.23±1.0 a

[*]Data shown are means±standard error. Different lowercase letters within the trait indicate statistically significant differences between varieties according to Tukey's HSD test at $p<0.05$ and $n = 30$.

In terms of fruit mass, 'Monterey' significantly outperformed the other cultivars, averaging 29.50 g per fruit - nearly double that of 'Karima' (16.10 g) and 'Auge' (15.09 g). This suggests that 'Monterey' has high potential for commercial production, where larger fruit size often preferred due to its visual impact and economic advantage per unit. Similar high fruit mass has been reported in high-yielding day-neutral cultivars (Nunes et al., 2009). However, this size advantage comes with trade-offs in fruit firmness, which is critical for mechanical handling, transport, and shelf life.

Firmness data showed that 'Karima' had the highest value (2.24 kgf/cm^2), followed by 'Auge' (1.94 kgf/cm^2), while 'Monterey' had the lowest (1.23 kgf/cm^2). Firmness is a key determinant of postharvest quality, as it affects resistance to bruising, pathogen susceptibility, and water loss. Laguerre et al. (2023) emphasize that higher firmness contributes to extended shelf-life and improved handling, which is essential in long-distance transport scenarios. Thus, while 'Monterey' may be preferred for size, its reduced firmness may limit its postharvest suitability without advanced packaging or storage technologies. These findings highlight the importance of balancing size and texture traits when selecting cultivars for specific production or market objectives. For instance, 'Monterey' may be ideal for fresh local markets prioritizing size, while 'Karima' could be better suited for processing or export markets that require firmer fruit with longer shelf-life. Moreover, these trait variations offer valuable data for breeding programs aimed to improve both consumer satisfaction and postharvest resilience (Mezzetti et al., 2018; Predieri et al., 2021).

The total soluble solids (TSS) content, expressed in °Brix, is a crucial quality parameter in strawberries as it reflects the sugar concentration and overall sweetness perceived by consumers (Karakasova et al., 2017). As shown in Figure 4, the TSS values among the three tested strawberry cultivars exhibited no statistically significant differences.

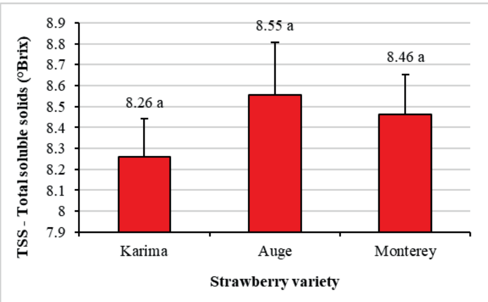

Figure 4. Total soluble solid content of fresh strawberries. Data shown are means±standard error. Same lowercase letters above the bars indicate no statistically significant differences between the varieties according to Tukey's HSD test at $p<0.05$ and n = 30

'Auge' variety recorded the highest TSS value (8.55°Brix), followed by 'Monterey' (8.46°Brix), while 'Karima' had the lowest mean TSS (8.26°Brix). These results are consistent with findings from Temocico et al. (2019), who reported TSS values ranging from 6.30 to 13.20°Brix among several strawberry genotypes. Similarly, Nunes et al. (2020) observed similar values in TSS among certain cultivars ranging between 6.42 and 8.92°Brix grown under similar agro-climatic conditions, highlighting the influence of genotype as well as growing environment and harvest maturity.

From consumer's point of view, TSS levels above 8°Brix are generally considered acceptable for fresh market strawberries, contributing positively to taste and flavor perception (Hancock, 2000). Therefore, all three cultivars evaluated in this study meet or exceed this threshold, suggesting comparable market potential in terms of sweetness.

Beside the total soluble solid content titratable acidity (TA) and the total soluble solids to titratable acidity ratio (TSS/TA) are key determinants of strawberry flavor quality, as they represent the balance between sweetness and sourness, a critical factor in consumer acceptability (Liu et al., 2016; Hancock, 2000). The results presented in Figure 5 show significant differences among the three evaluated strawberry cultivars in both acidity and sugar-acid balance.

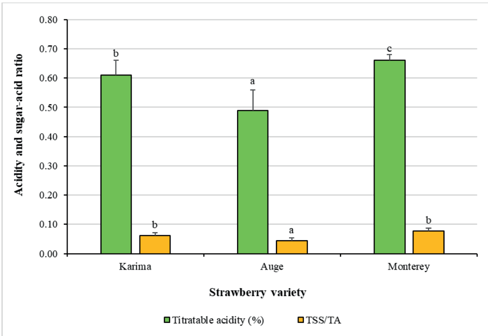

Figure 5. Titratable acidity and sugar-acid ratio in the strawberry varieties analysed. Data shown are means±standard error. Different lowercase letters above the bars indicate statistically significant differences between varieties within the same trait according to Tukey's HSD test at $p<0.05$ and n = 30

'Monterey' exhibited the highest titratable acidity (0.66%), followed by 'Karima' (0.61%), while 'Auge' recorded the lowest acidity (0.49%). These results are consistent with previous findings by Andrade et al. (2015) and Nunes et al. (2020), who noted significant genotypic variation in acidity among strawberry cultivars grown under similar environmental conditions. Higher acidity levels, such as those seen in 'Monterey', can contribute to a sharper taste profile, which may be desirable in processing applications like jelly production.

In contrast, the TSS/TA ratio, a key indicator of perceived sweetness, was the highest in

'Monterey' (0.077), followed by 'Karima' (0.062), while 'Auge' exhibited the lowest ratio (0.044). Despite having the highest acidity, 'Monterey' also maintained a relatively high TSS/TA ratio, suggesting a well-balanced flavor profile. These findings are in accordance with earlier studies indicating that the sugar-acid ratio plays a more decisive role in consumer preferences than sweetness or acidity alone (Kader, 2008). For instance, a study by Scott et al. (2021) reported that cultivars with moderate acidity but high TSS/TA ratios tend to be preferred in sensory evaluations. From this perspective, 'Karima' and 'Monterey' might be more favorable for fresh consumption due to their better sweetness-acidity balance, whereas the lower TSS/TA ratio in 'Auge' may result in a comparatively bland or sour taste. Therefore, due to its lower acidity, may require marketing adjustments or blending with sweeter cultivars for processing purposes.

The chemical composition of strawberries, including vitamin C, titratable acidity, pH, total phenolic compounds, and antioxidant capacity (DPPH), plays a vital role in determining their nutritional quality and health-promoting properties. This study aimed to assess how these chemical parameters vary among strawberry varieties ('Karima', 'Auge', and 'Monterey') in fresh fruits and processed into syrup and jelly.

Processing fruits, including strawberries, often leads to a significant reduction in their bioactive chemical compounds, particularly vitamin C, phenolics, and antioxidants. These compounds are sensitive to heat, oxygen exposure, and changes in pH, which commonly occur during thermal processing methods such as boiling, pasteurization, or jelly preparation (Patras et al., 2010; Tulipani et al., 2009). For example, vitamin C, a water-soluble and heat-sensitive compound, can degrade rapidly during cooking, while phenolic compounds may undergo oxidation or polymerization, reducing their antioxidant capacity (Crespo et al., 2010). Despite these losses, the extent of degradation varies depending on the processing technique, temperature, and duration. Some methods, such as syrup preparation under controlled conditions, may better retain nutritional quality compared to more intense processing like jam or jelly production. Therefore, selecting gentle processing methods and optimizing parameters are crucial for preserving the health-promoting properties of strawberries and other fruits.

The results of this study revealed that the vitamin C content varied significantly among cultivars and processing methods (Table 3). Fresh fruits had the highest levels, with 'Monterey' showing the greatest concentration (23.79 mg/100 g), followed by 'Karima' (23.09 mg/100 g) and 'Auge' (20.34 mg/100 g). These values are within the range reported by Skender et al. (2015) and Gündüz & Özdemir et al. (2014), who noted that vitamin C content in fresh strawberries typically ranges between 20 and 90 mg/100 g depending on cultivar and growing conditions.

Processing substantially reduced vitamin C content, particularly in jelly form. Among all cultivars, jelly had significantly lower vitamin C levels, with reductions ranging from 40% to 60%. This degradation is attributed to the thermal sensitivity of ascorbic acid during cooking and prolonged exposure to oxygen (Patras et al., 2010). The vitamin C content in syrup remained relatively higher than in jelly, particularly in 'Monterey' (24.62 mg/100 g), which suggest shorter processing times and better preservation conditions.

Titratable acidity was the highest in fresh fruits for all cultivars, especially in 'Monterey' (0.66%), aligning with previous results (Šamec et al., 2016). Acid content declined sharply in processed samples, especially in jellies, where values dropped to 0.14-0.17% (Table 3). This reduction may result from acid degradation during heating and dilution during syrup or jelly formulation (Hancock, 2000). Conversely, pH values slightly increased in processed forms, which corresponds with the observed decline in acidity. For example, the pH of 'Monterey' increased from 3.66 in fresh fruit to 3.80 in syrup. This increase might be explained by the syrup formation which usually dilutes natural acids slightly, reducing both TA and sometimes raising the pH.

Table 3. Chemical properties of fresh and processed strawberry fruits

Variety	Fruit sample	Vitamin C (mg/100 g)	Titratable acidity (%)	pH	Total phenolic compounds (mg GAE/100 g)	DPPH (µmol TE/g FW)
'Karima'	fresh	23.09±1.16 bB	0.61±0.01 cB	3.44±0.20 bB	421.07±30.12 cA	17.90±1.33 cA
	syrup	21.33±2.33 bB	0.41±0.03 bB	3.69±0.32 cB	215.82±18.39 bA	14.52±1.02 bA
	jelly	11.40±1.81 aA	0.14±0.02 aA	3.18±0.17 aA	110.97±21.03 aA	12.21±0.98 aA
'Auge'	fresh	20.34±3.45 bA	0.49±0.03 bA	3.22±1.00 bA	511.33±19.87 cB	19.70±0.46 cB
	syrup	19.76±2.72 bA	0.21±0.11 aA	3.39±0.99 cA	236.78±22.33 bB	16.99±1.00 bB
	jelly	12.60±1.02 aB	0.15±0.05 aB	3.11±0.87 aA	150.15±29.41 aB	13.44±0.87 aB
'Monterey'	fresh	23.79±1.99 bB	0.66±0.22 cC	3.66±0.69 bC	609.11±17.42 bC	22.30±0.96 cC
	syrup	24.62±0.76 bC	0.48±0.76 bC	3.80±0.33 cC	239.47±27.21 aB	20.45±1.11 bC
	jelly	13.72±0.99 aC	0.17±0.08 aC	3.49±0.47 aB	180.40±18.33 aC	14.55±1.32 aC

*Data shown are means±standard error. Different lowercase letters within the trait indicate statistically significant differences between fresh and processed fruit samples according to Tukey's HSD test at $p<0.05$ and $n = 30$. Different capital letters show significant differences between varieties within the same chemical trait and sample form (fresh, syrup and jelly).

Phenolic content, a major determinant of antioxidant activity, was the highest in fresh strawberries and decreased significantly with processing. Among fresh samples, 'Monterey' exhibited the highest TPC (609.11 mg GAE/100 g), followed by 'Auge' (511.33 mg GAE/100 g) and 'Karima' (421.07 mg GAE/100 g). These values are comparable to those reported by Tulipani et al. (2008) for high-antioxidant strawberry cultivars.

Jelly production caused the greatest phenolic loss, with values decreasing by more than 60% in all varieties. 'Karima' jelly had the lowest phenolic content (110.97 mg GAE/100 g), indicating its higher susceptibility to degradation. Heat processing, oxygen exposure, and pH changes during jelly preparation can contribute to phenolic degradation (Crespo et al., 2010).

DPPH radical scavenging activity, an indicator of antioxidant capacity, followed a similar trend to total phenolics. Fresh fruits showed the highest antioxidant activity, with 'Monterey' reaching 22.30 µmol TE/g FW. Processing reduced DPPH values in all cases, particularly in jelly samples, where values decreased to 12.21-14.55 µmol TE/g FW. These trends reaffirm the close correlation between phenolic content and antioxidant potential (Scalzo et al., 2005).

Notably, despite reductions, 'Monterey' maintained higher antioxidant activity in both processed forms compared to the other cultivars, making it a promising candidate for functional food products with retained health benefits.

CONCLUSIONS

Processing strawberries into syrup and jelly significantly affects their chemical composition, especially reducing vitamin C, phenolic compounds, and antioxidant activity. Among the studied cultivars, 'Monterey' consistently retained higher levels of bioactive compounds in both fresh and processed forms, suggesting its superiority for both fresh consumption and value-added processing. These findings underscore the importance of cultivar selection and optimized processing techniques to preserve nutritional quality.

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