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Investigating changes in physicochemical, bioactive, and microbial properties of the cantaloupe pulp under ohmic heating treatment

Farah Jameel[1], Zunaira Arshad[1], Nabeel Ashraf[1], Nashi K. Alqahtani[2], Rokayya Sami[3]*, Fatin Alsalmi[4], Abeer A. Abu-zaid[5], Norah E. Aljohani[6], Bandar Alfaifi[7], Mahmoud Helal[8], Alanood A. Alfaleh[9], Ebtihaj O. Alnasri[9], Shatha Alaoufi[10], Tasahil S. Albishi[11], Sameer H. Qari[12]

[1]National Institute of Food Science and Technology, University of Agriculture Faisalabad, Faisalabad, Pakistan; [2]Department of Food and Nutrition Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia; [3]Department of Food Science and Nutrition, College of Sciences, Taif University, Taif, Saudi Arabia; [4]Department of Biology, College of Sciences, Taif University, Taif, Saudi Arabia; [5]Department of Food Science and Nutrition, Alkhurmah University College, Taif University, Taif, Saudi Arabia; [6]Department of Clinical Nutrition, Taibah University, Medina, Saudi Arabia; [7]Department of Agricultural Engineering, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia; [8]Department of Mechanical Engineering, Faculty of Engineering, Taif University, Taif, Saudi Arabia; [9]Food and Nutrition Department, Faculty of Human Sciences and Design, King Abdulaziz University, Jeddah, Saudi Arabia; [10]Department of Early Childhood, College of Education, Qassim University, Buraydah, Saudi Arabia; [11]Biology Department, College of Science, Umm Al-Qura University, Makkah, Saudi Arabia; [12]Department of Biology, Al-Jumum University College, Umm Al-Qura University, Makkah, Saudi Arabia

***Corresponding Author:** Rokayya Sami, Department of Food Science and Nutrition, College of Sciences, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia. Email: rokayya.d@tu.edu.sa

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PAPER

Abstract

Cantaloupe (*Cucumis melo L.*) is a nutrient-rich, seasonal fruit with limited availability and short shelf life. This study evaluated the effects of conventional pasteurization (72°C, 2 min) and ohmic heating (60–72°C, 5–25 min at constant voltage 220V) on the physicochemical, phytochemical, microbial, and sensory properties of the cantaloupe pulp. Physicochemical and sensory analyses were performed over a period of 28 days at a refrigerator temperature (4°C). Ohmic heating significantly enhanced the retention of bioactive compounds and shelf life of the cantaloupe pulp. Total phenolic content increased by up to 2.07 times with time and 1.82 times with temperature, retaining 1.18 times more than conventional heating. Flavonoid content increased by 1.20 times with optimal ohmic conditions, preserving 0.77 times more than traditional methods. Antioxidant activity increased significantly by 53.7% with time, and 46.3% with temperature, yielding 1.19 times higher activity overall, and 1.15 times more than conventional heating. Vitamin C contents significantly increased by 1.37 times because of enhanced cell permeability. Microbial load was reduced by 1.25 times, with ohmic heating achieving 1.17 times greater microbial reduction than conventional treatment. Sensory analysis has higher scores for ohmic-treated samples, especially T_9 (66°C, 5 min), which maintained better acceptability and quality of pulp throughout storage. Ohmic heating demonstrated significant potential for the cantaloupe pulp preservation, by assuring uniform heating, preserving sensorial attributes, and enhancing microbial safety and shelf life. These results demonstrated that ohmic heating is an effective, minimally destructive thermal technique with strong potential for application in fruit processing industries.

Keywords: Cantaloupe pulp; Ohmic heating; Physicochemical; Food safety; Microbiology; Bioactive compounds

Introduction

Cantaloupe (*Cucumis melo L.*) belongs to the *Cucurbitaceae* family. Forty million tons of cantaloupe are produced globally, and Asia accounts for 74% of the total production (Silva *et al.*, 2020). However, perishable fruits, such as cantaloupe, are greatly affected by worldwide postharvest losses ranging from 28% to 55% per year, with low- to middle-income countries (including those in Asia) suffering the most related to insufficient infrastructure and preservation measures (Karoney *et al.*, 2024). It is rich in dietary fiber, vitamins (B_1, B_3, B_6, B_9, and K), copper, and magnesium. The cantaloupe is a good source of polyphenols, antioxidants, organic acids, and lignans, which impart nutritive value as well as decrease the risk of chronic diseases (Fundo *et al.*, 2019). Cantaloupe melon with pleasant organoleptic characteristics, nutritional properties, and sweet taste is a suitable raw material for the food industry to utilize the cantaloupe pulp in immense quantities for making natural, nutritious drinks and ready-to-eat desserts (Miller *et al.*, 2018). However, the perishability of the cantaloupe melon makes it unsuitable for commercialization in distant markets unless appropriate technology is employed to extend its short shelf life (Tan *et al.,* 2021).

Fresh cantaloupe pulp is spoiled easily as high moisture levels and nutrients make it food for microorganisms if not handled properly during or after processing. Mechanical, chemical, physical, and microbial processes occurring in fresh food commodities are major reasons for the food spoilage (Hashemi and Jafarpour, 2022). Thermal sterilization is one of the high-temperature treatments that can damage cantaloupe melon and its products. Heat treatment of melon juice results in color changes, breakdown of aromatic components, and off-flavor generation (Fonteles *et al.*, 2012). For the agro-industries, preserving the physical, nutritional, and sensory qualities of highly perishable fruits is particularly difficult (Orqueda *et al.*, 2021).

The most basic and widespread practice in the food industry is thermal processing, which is used for preservation of the food by enhancing its microbiological safety. Preservation of food through heating is one of the most commonly used methods of pasteurization. Depending on the fruit type and processing conditions, pasteurization can have a negative impact on the color of the fruit, antioxidant activity, polyphenols, and vitamin C contents (Mandha *et al.*, 2023). Innovative technologies are being employed as a substitute for conventional thermal processing to tackle these issues. Two main types of thermal processing that are now being developed in innovative technologies: novel thermal processing and novel non-thermal processing (Hashemi *et al.*, 2019).

Ohmic heating can address the limitations of traditional heat transfer techniques, which cause liquids and solids to heat up at different rates and with significant nonuniformity (Rinaldi *et al.*, 2020). Ohmic heating, which heats materials uniformly, seems to be an effective method than the thermal method and causes less thermal damage to labile compounds. It may facilitate better preservation of vitamins, pigments, and minerals (Sarkis *et al.*, 2013). During ohmic heating, an electric current is applied, and heat is produced through resistance of food toward electric current (Alizadeh and Aliakbarlu, 2020). In this way, heat is produced by applying current for a shorter time causing less harm to the bioactive compounds in food (Ferreira *et al.*, 2019). Ohmic heating also has additional benefits, such as increased efficiency, reduced maintenance costs, and a shorter processing time. Ohmic heating is suggested as a time- and energy-saving technique as compared to conventional techniques (Hashemi *et al.*, 2019). Hence, ohmic heating is a process that generates internal thermal energy (Torgbo *et al.*, 2022).

Ohmic heating is employed in food processing industries, as it is an innovative processing method with better economic outcomes in comparison to conventional heating methods (Alkanan *et al.*, 2021). Water retention and apparent viscosity were increased by ohmic heating treatment as a result of enhanced release of insoluble dietary fibers. Polyphenol-oxidase was inactivated 1.5 times quicker than by conventional heating at 20 V/cm, highlighting its industrial potential (Barrón-García *et al.*, 2021). The use of ohmic heating has been increased for the concentration of tomato juice (Fadavi *et al.*, 2018) and orange juice (Darvishi *et al.*, 2019).

The main focus of this study is to examine how the physicochemical and bioactive compounds of the cantaloupe pulp are influenced through ohmic heating processing. Physicochemical and sensory properties were studied during 28 days of storage to determine the best condition for pulp quality and shelf life through ohmic heating.

Materials and Methods

Procurement of raw materials

Fresh cantaloupe was purchased from the local market of Faisalabad. The study was conducted in the laboratory of the University of Agriculture Faisalabad, Pakistan. Analytical grade chemicals and reagents were all used (Merck, Germany).

Preparation of sample

The cantaloupe was washed thoroughly with water to remove contaminants. Then, it was peeled and chopped

Table 1. Treatment plan for the pasteurization of pulp.

Treatments	Temperature (°C)	Time (min)
T_0	Conventional Pasteurization (72°C, 2–3 min)	
T_1	60	15
T_2	63	10
T_3	63	20
T_4	66	5
T_5	66	15
T_6	66	25
T_7	69	10
T_8	69	20
T_9	72	5
T_{10}	72	15
T_{11}	72	2

into small pieces. Pulp was prepared by using an electric blender and then pasteurized through ohmic heating as shown in Table 1.

A total of 11 treatments were carried out on the cantaloupe pulp. One treatment served as the control and was pasteurized (72°C, 2–3 min) using a water bath as a traditional heat treatment. The remaining 10 samples were treated through ohmic heating at different temperatures (60°C–72°C) and time intervals of (5–25 min) while keeping the voltage constant at 220 V.

Conventional heating

In the traditional heating experiment, the influence of heating on the cantaloupe pulp was investigated. A 20 mL sample of the cantaloupe pulp was prepared in a conical flask. A water bath was used to ensure constant and controlled heating; the temperature was set to 72°C ± 2 for 2–3 min. The sample was cooled down at 4°C in an ice bath after heating (Achir *et al*., 2016).

Physicochemical analysis

pH

A digital pH meter was used to estimate the pH of the Cantaloupe pulp. The probe was cleaned with distilled water, followed by calibration with buffer solution of pH 4.7 and 7 before measuring the pH of each sample. The values were noted down, and the measurements were conducted in triplicate (Barrón-García *et al*., 2021).

Total soluble solids (TSS)

The TSS of the cantaloupe pulp was analyzed by using a digital refractometer, as specified by Rios *et al.* (2021). A drop of the cantaloupe pulp sample was placed on the mirror of the refractometer, and the measurements were taken after a while. The light passed through the mirror, gave the readings.

Titratable acidity (TA)

The acidity of the sample was measured with slight modification in the protocol given by Stadlmayr *et al*. (2020). A pulp sample of 10 mL was taken, and phenolphthalein was added as an indicator. Later, 0.1 N NaOH was added drop by drop, and the mixture was consistently shaken until a pink color appeared. Burette reading was noted down to calculate the amount of NaOH used. At last, the acidity % was measured by using the following formula:

$$\text{Acidity \%}=\frac{0.006\times\text{Volume of NaOH used (mL)}}{\text{Weight of sample}}\times 100$$

Phytochemical analysis

Total phenolic content

Total phenolic content of the cantaloupe pulp were measured by using the Folin–Ciocalteu reagent. In an aliquot, 0.5 mL of pulp extract was taken, and 0.5 mL of Folin reagent was added. The liquid was placed in a dark place for half an hour after careful mixing. After that, 10 mL of a 75 g/L Na_2CO_3 solution was added. After stirring, the mixture was set in the dark for an hour. The absorbance was measured at 750 nm. The standard curve of gallic acid was used to express the total amount of polyphenols in proportions (Mallek-Ayadi *et al*., 2017).

Determination of total flavonoid contents

TFC has been carried out by using the method of Arshad *et al*. (2025). The pulp sample of 0.25 mL was mixed with 1.25 mL of water, and then after 6 min, 50 µl 5% $NaNO_2$ was added, followed by 100 µl (10%) $AlCl_3$. In the next step, 0.5 mL of 1 M NaOH was added, followed by 2.5 mL of distilled water. The absorbance was measured by using a spectro-photometer (U2020, IRMECO, Germany) at a wavelength of 415 nm.

Antioxidant activity

Antioxidant activity of the cantaloupe pulp was evaluated according to Baliyan *et al*. (2022). The DPPH solution was made in methanol. Later, it was supplemented with the cantaloupe pulp extract in various concentrations. Spectro-photometer was used to measure the absorbance of the mixture at 517 nm. DPPH radical scavenging activity percentage was calculated by using the formula below:

$$\text{DPPH radical scavenging activity (\%)} = 100\times\frac{A_0 - A_1}{A_0}.$$

A_0 is the absorbance of control, and A_1 is the absorbance of the pulp.

Vitamin C

Vitamin C contents in the cantaloupe pulp were analyzed using the method outlined by Jaeschke *et al.* (2016). The titration approach was utilized to evaluate the Vitamin C contents. Ascorbic acid standard solution (2 mL) was mixed with 5 mL of metaphosphoric acetic acid solution. It was then titrated against indophenol dye solution until a noticeable rose–pink color was seen.

Microbial evaluation

The total plate count of the cantaloupe pulp samples was determined by pursuing the standard method of Singla *et al.* (2022). The media was prepared by mixing nutritional agar in distilled water and autoclaving it at 121°C for 1 h. Aliquots (1 mL) of the dilutions were prepared and plated on plates with a sterile pipette. After being prepared, the Petri plates were incubated at 37°C for 24 h. After the incubation period was completed, the plates with colony numbers 30–300 CFU/ mL were selected for counting. The CFU/mL formula was used to calculate the total bacterial count in the sample:

$$\text{Total plate count} = \text{Average no. of colonies} \times \frac{\text{Dilution factor}}{\text{Volume factor}} \times 100$$

Sensory analysis

The color, aroma, taste, and overall acceptability of the cantaloupe pulp were evaluated using a 0–9 point hedonic scale, as outlined by Rodrigues *et al.* (2021).

Storage study

Pulp was kept in the refrigerator for 28 days to examine the influence of storage on physicochemical attributes (pH, TSS, and TA) and sensory analysis (color, aroma, taste, and overall acceptability) (Arshad *et al.*, 2025).

Statistical analysis

In this study, the D-optimal design (two-factor, five-level) was chosen for the modelling of processing variables (time, temperature, and voltage). After experimentation, data were collected and statistically analyzed through Statistic 8.1 software to optimize the cantaloupe pulp processing. Cubic model adequacy was assessed by analysis of variance (ANOVA), lack of fit tests ($p > 0.05$), coefficient of determination ($R^2 > 0.90$), and adequate precision (>4), ensuring reliable prediction of optimal processing conditions. Response surface methodology (RSM) was applied to assess the impact of time and temperature on physicochemical, microbial, and sensory properties of the cantaloupe pulp.

Results and Discussion

Physicochemical analysis

pH

Food pH has a direct impact on factors including microbial growth, eating behavior, and palatability (Deshpande *et al.*, 2015). Ohmic heating treatments significantly increased the pH of the cantaloupe pulp (Figure 1). The pH of conventionally treated pulp T_0 (72°C, 2 min) was 5.33 at day 0, which shows an increasing trend at different time and temperature during ohmic processing. The highest value of pH processed through ohmic heating was observed in T_1 (6.6; 66°C, 25 min), followed by T_3 (6.48; 63°C, 20 min) and T_8 (6.3; 66°C, 15 min). The lowest value of pH was observed in T_{11} (5.5), where the ohmic processing conditions were set the same as conventional conditions at 72°C ± 2 for 2 min at day 0.

With increasing time and temperature, ohmic heating raised the pH of the cantaloupe pulp by up to 1.29 times and 1.46 times, respectively. Time, temperature, and voltage gradient were shown to be the most contributing elements, as the pH increased 1.23 times overall when compared to traditional heating. This study is supported by Ishita and Athmaselvi (2017), where pH of fresh watermelon juice increased from 5.2 to 5.36 when processed with ohmic heating. pH may increase because of the corrosion of electrodes or the electrolysis of juices or pulp that occur during the process of ohmic heating (Athmaselvi *et al.*, 2017). Furthermore, similar results were observed when watermelon juice treated with OH

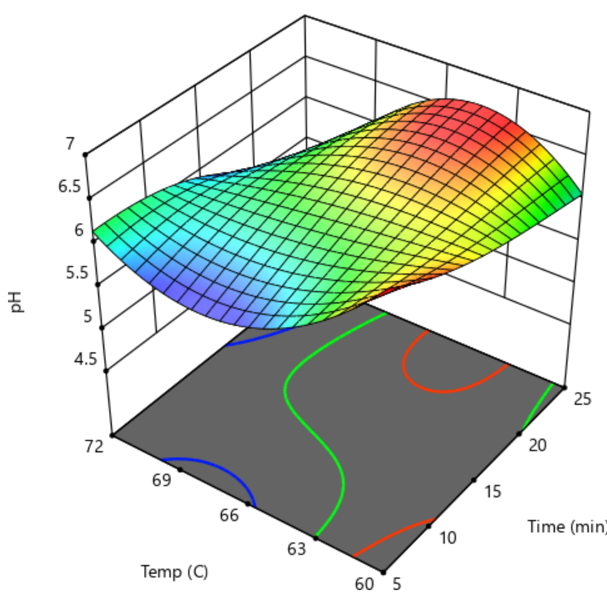

Figure 1. pH influenced by the ohmic heating of the cantaloupe pulp.

had a maximum and highly significant pH shift from 5.59 to 5.86 (Makroo *et al*., 2016).

TSS

Ohmic heating had significantly increased the TSS of the cantaloupe pulp (Figure 2). The brix of conventionally treated pulp T_0 (72°C, 2 min) was 6.9, which shows an increasing trend for all the ohmic processed treatments. The highest value of brix processed through ohmic heating was observed in T_{10} (7.4; 66°C, 25 min), followed by T_6 (7.3; 72°C, 15 min) and T_8 (7.2; 66°C, 15 min). The lowest value of brix was observed in T_5 (6.9) at 63°C for 10 min at day 0.

TSS of the cantaloupe pulp increased by 1.38 and 1.48 times, after ohmic processing because of temperature and time, respectively. Temperature, voltage gradient, and processing time all affected better sugar retention, resulting in a brix that was up to 0.93 times higher than conventional heating. Similar research outcomes were noticed by Akhtar *et al*. (2010). The rise in TSS may potentially be the result of organic acids being converted to sugars or the loss of water during heating. In addition, when the banana pulp was treated at 26.7 V/cm, the maximum value of brix was achieved because of solubilization of sugar facilitated by ohmic heating (Pushparaj and Athmaselvi, 2016).

TA

The acidity of conventionally treated pulp T_0 (72°C, 2 min) was 0.205 at day 0. Ohmic heating significantly increases the acidity value in the cantaloupe pulp as shown in Figure 3. The highest value of acidity processed through ohmic heating was observed in T_{10} (0.832) at 66°C for 25 min, followed by T_4 (0.795; 69°C, 10 min) and T_6 (0.768; 72°C, 15 min). The minimum value of pH was observed in T_{11} (0.309) at 72°C ± 2 for 2 min at day 0.

The acidity of the cantaloupe pulp was greatly enhanced by ohmic heating; the temperature (60–72°C) and time (5–25 min) raised the acidity by 1.61 and 2.77 times, respectively. Overall, acidity rose up to 4.05 times as compared to traditional heating, indicating that temperature, time span, and voltage gradient were important determinants. Similar findings were noticed by Gomathy *et al.* (2015) where acidity of papaya pulp increased with higher temperatures and longer treatment times. The increase in acidity was linked to the degradation of complex molecules into simpler acidic chemicals because of the thermal energy produced during ohmic heating (Makroo *et al*., 2019). Ohmic heating processing of plaque enhanced the flavor and increased its palatability (Hashemi and Jafarpour, 2022).

Phytochemical analysis

Total phenolic contents

Phenolic compounds and antioxidants are capable of protecting cellular constituents from free radical damage (Mallek-Ayadi *et al*., 2017). The total phenolic contents of conventionally treated unnecessary cantaloupe pulp T_0 (72°C, 2 min) were 70.42 mg GAE/100g. The peak value of phenolic contents processed through ohmic heating was observed in T_9 (83.08 mg GAE/ 100 g) at 66°C for 5 min followed by T_5 (82.02 mg GAE/100 g, 63°C for 10 min) and T_4 (80.86 mg GAE/100 g, 69°C for 10 min),

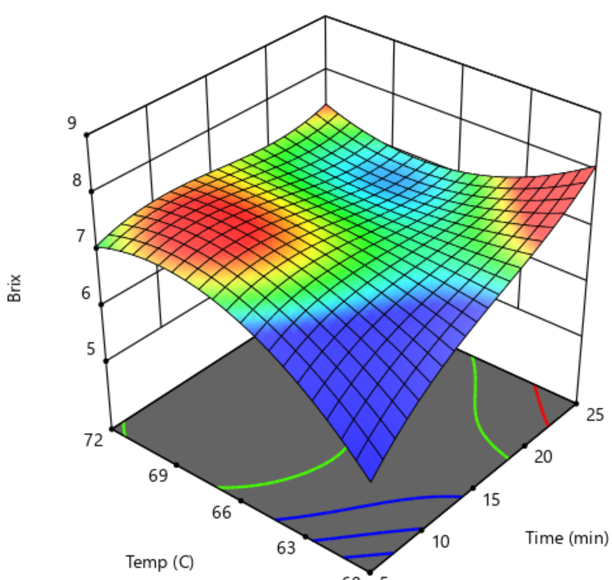

Figure 2. TSS influenced by the ohmic heating of the cantaloupe pulp.

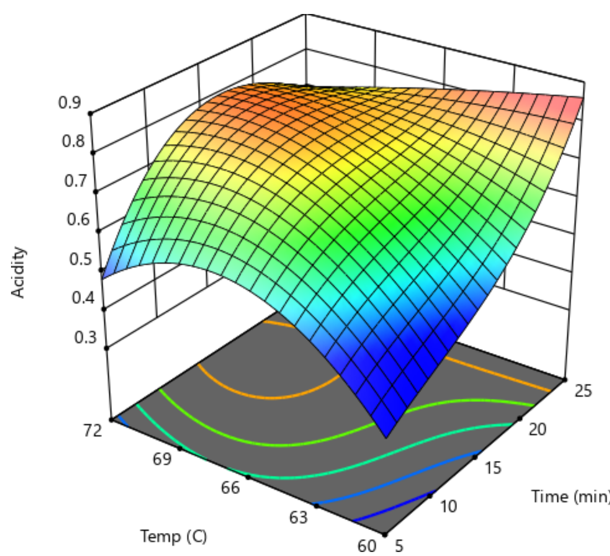

Figure 3. Acidity influenced by the ohmic heating of the cantaloupe pulp.

as shown in Figure 4. The least value was observed in T_2 (72.80 mg GAE/100 g) at 63°C for 20 min. This loss may be because of prolonged thermal exposure that leads to significant degradation of polyphenols because of oxidation and structural breakdown (Narra *et al*., 2024).

The total phenolic contents of the cantaloupe pulp were significantly increased by ohmic heating; it increased by 1.82 times with temperature (60–72°C) and 2.07 times with time (5–25 min). Although excessive time and temperature led to some degradation, ohmic-treated pulp retained 1.18 times more phenolic compounds than the conventionally heated sample. Similar observations were found when black mulberry juice treated with ohmic heating had a 3.0–4.5 fold greater total phenol concentration than those treated conventionally (Darvishi *et al*., 2020b). In addition, the processing of apple juice through ohmic heat increases the total phenolic content from 30.56 mg GAE/ 100 g to 32.22 mg GAE/100 g. This may be because of increased cell wall permeability and efficient heat transfer during ohmic processing (Abedelmaksoud *et al*., 2018).

Total flavonoid contents

The total flavonoid contents of the conventionally treated pulp T_0 (72°C, 2 min) were 13.78 mg/g. The highest value of flavonoid contents processed through ohmic heating was observed in T_9 (17.79 mg/g) at 66°C for 5 min, followed by T_5 (16.48 mg/g, 63°C for 10 min) and T_1 (15.57 mg/g; 66°C, 25 min). The lowest contents value was observed in T_3 (13.51 mg/g) at 63°C for 20 min (Figure 5).

Ohmic heating substantially increased the total flavonoid contents of the cantaloupe pulp, increasing it by up to 1.20 times as a result of the synergistic effects of temperature and time. In contrast to traditional heating, 0.77 times more flavonoids were preserved after ohmic treatment. However, excessive heating (over 63°C for 20 min) degrades flavonoids, demonstrating the need for optimal processing conditions. Similarly, the mango pulp of fresh samples, heated both conventionally and with ohmic heating, had maximum total flavonoid contents of 76.61 mg QE/100 g dm, compared to 48.88 mg QE/100g dm in the conventionally processed pulp. Another study found that ohmic-heated orange juice at 50-90°C had higher nutrient content than other nonthermal methods (microwave and infrared) and conventional heating (Priyadarshini *et al*., 2023).

Antioxidant activity

The processing conditions related to ohmic heating had a significant impact on the antioxidant activity of the cantaloupe pulp (Figure 6). The antioxidant activity of conventionally treated pulp T_0 (72°C, 2 min) was 64.50%. The highest value of antioxidant activity of pulp was observed in T_9 (73.73%) at 66°C for 5 min, followed by T_1 (72.76%, 66°C for 25 min) and T_5 (71.98%, 63°C for 10 min). The least antioxidant activity was noticed in T_6 (56.10%) at 72°C for 15 min.

Ohmic heating remarkably surged the antioxidant activity of the cantaloupe pulp by 46.3% when the temperature was raised from 60 to 72°C and by 53.7% when the time

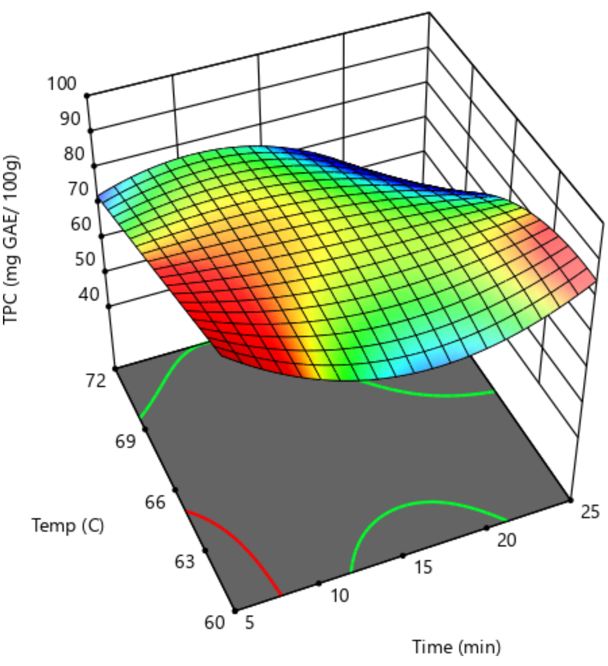

Figure 4. TPC influenced by the ohmic heating of the cantaloupe pulp.

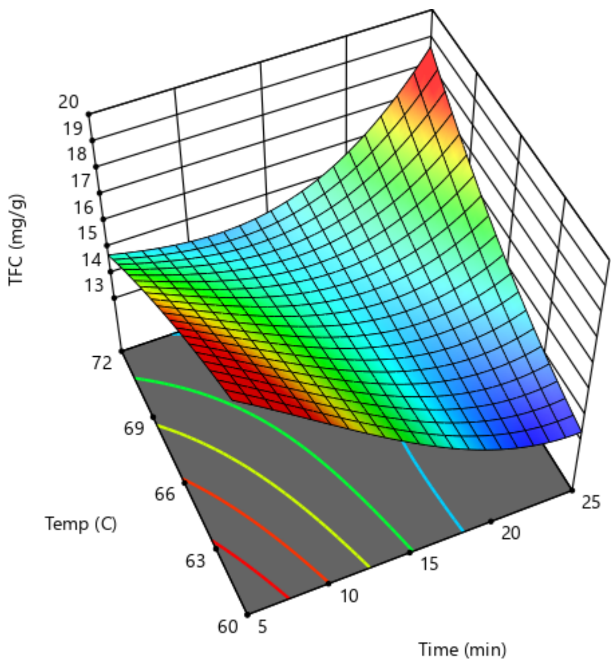

Figure 5. TFC influenced by the ohmic heating of the cantaloupe pulp.

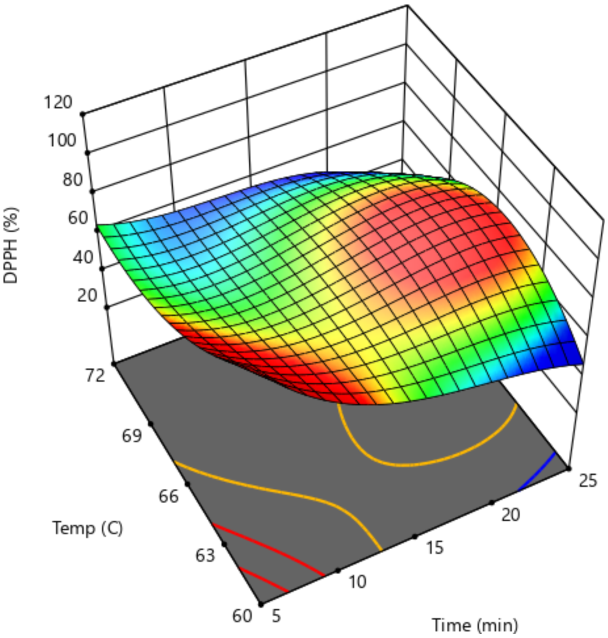

Figure 6. Antioxidant activity influenced by the ohmic heating of the cantaloupe pulp.

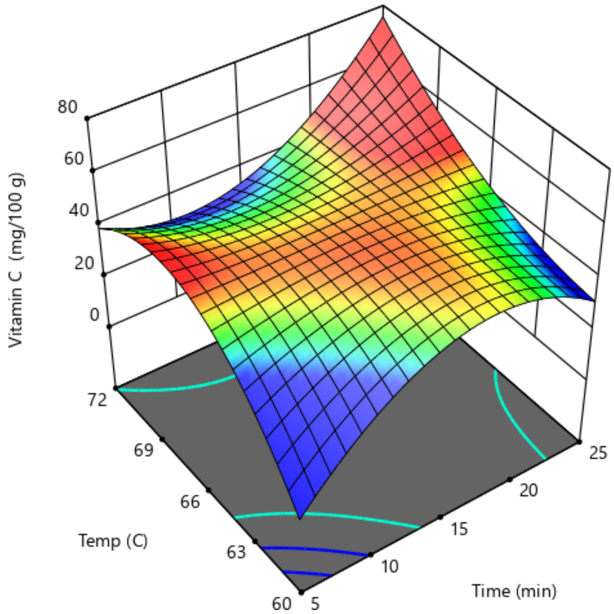

Figure 7. Vitamin C influenced by the ohmic heating of the cantaloupe pulp.

was extended from 5 to 25 min. This resulted in a 1.19-fold increase, which is 1.15 times more than that of conventional pasteurization. The antioxidant content started to drop after 15 min at 72°C, below that of conventional heating. Similar studies reported that the antioxidant activity was greatly increased by ohmic heating at 80°C in comparison to the control, but it was decreased by treatments at 40°C and 60°C. Both the electrical permeabilization that promotes the release of antioxidant molecules and the thermal inactivation of oxidative enzymes are probably responsible for this increase in effectiveness (Mannozzi *et al.*, 2019). Compared to samples that were cooked conventionally at the same temperature, whey-raspberry drinks that were ohmically heated at 45, 60, and 80 V showed greater antioxidant capacity (DPPH and FRAP) at 65°C (Ferreira *et al.*, 2019).

Vitamin C

Ohmic heating treatments significantly retained the vitamin C contents of the cantaloupe pulp than conventional heating (Figure 7). The highest value for vitamin C contents was found in T_9 (49.4 mg/ 100 g) followed by T_8 (48.8 mg/100 g) and T_{10} (46.7 mg/100g) at 66°C for 5 min. The lowest values were observed in T_0 (28.93mg/100g) at 72°C for 2 min, where the pulp was treated by conventional heating. A similar range of vitamin C from 31.97 mg/100 g to 37.21 mg/100 g was found in different cultivars of melon (Manchali *et al.*, 2021). Increasing the temperature (60–72°C) and time (5–25 min) enhanced vitamin C content up to 1.37 times because of improved cell penetrability that leads to easier discharge of cell components to the liquid part of pulp (Abedelmaksoud *et al.*, 2018). As found by Athmaselvi *et al.* (2017), better retention of Vitamin C was observed in ohmic processed fruit pulps (sapota, papaya, and guava). In addition, Ohmic heating at 69°C preserved 45.2 mg/100 mL of ascorbic acid, while conventional heating at 95°C preserved 42.9 mg/100 mL (Demirdöven and Baysal, 2014).

Microbial evaluation

Ohmic heating resulted in greater microbial (TPC) inactivation, reaching 72°C in 2 min compared to nearly 15 min with conventional heating. This indicates significant efficacy and a clear trend of enhanced microbial reduction (Figure 8). The pulp treated with ohmic heating (T_9) had the lowest microbial count (5.71%, 4 log CFU/mL), while pulp treated conventionally (T_0) had the highest microbiological count (6.65%, 4.71 log CFU/mL), demonstrating the improved microbial decline provided by ohmic heating. After T_9, treatments T_8 to T_{11} and T_1 to T_7 showed reduced microbial counts, with values ranging from 4.04 to 4.69 log CFU/mL under ohmic conditions between 60 and 72°C for 5–25 min. In comparison to conventional heating, ohmic heating demonstrated a 1.17 times higher microbial decrease. The microbial load was decreased by 1.11 times and 1.125 times, respectively, by raising the temperature (60–72°C) and duration (5–25 min), with an overall effect of 1.25 times. Thermal action, as well as nonthermal processes, like membrane permeability modifications and electroporation, contributes to ohmic heating's antibacterial impact (Hashemi *et al.*, 2019). Similarly, in cantaloupe juice, pathogens were considerably decreased by ohmic, microwave, and conventional heating ($P \leq 0.05$). Spores were decreased by up to 5 log when orange juice was heated ohmically for 30 min at 90°C (Indiarto and Rezaharsamto, 2020).

Sensory evaluation

Sensory analysis revealed that T_9, processed at 66°C for 5 min, had the highest scores for color, 7.25; aroma, 8.04; taste, 7.77; and overall acceptance, 7.8 (Figure 9). In every treatment, pulp treated with ohmic heating performed better than pulp treated conventionally. While taste remained mostly unaltered by the constant processing, slight color alterations were seen under extreme processing conditions.

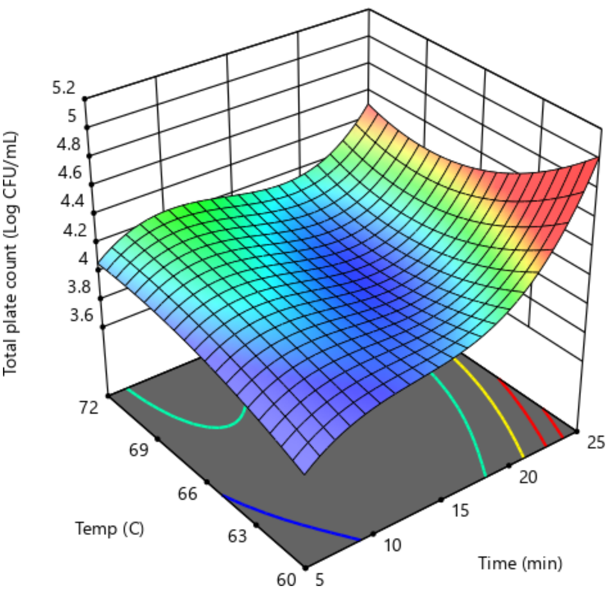

Figure 8. Total plate count influenced by the ohmic heating of the cantaloupe pulp.

Storage study

Physicochemical Parameters

pH

pH of cantaloupe depicts a declining trend during storage period of 28 days. From day 0 to day 28, the pH trended downward throughout storage, impacted by temperature, time, and storage days (Figures 10–12). By day 28, the maximum pH of 6.6 on day 0 had fallen to 3.98 in T_1. The pH decreased by a total of 1.33 times. This may be because of ongoing microbial metabolism and fermentation (Alcántara-Zavala *et al.*, 2019). A comparable decrease was seen when mango pulp was heated ohmically (Barrón-García *et al.*, 2021).

TSS

TSS of melon pulp considerably increased over the preservation period (Figure. 13–15), most likely because of polysaccharide breakdown into sugars or membrane degradation (Ahmad *et al.*, 2014). The highest °Brix was noted in T_6 (7.4, 72 °C, 15 min) on day 7, while T_{10} (69°C, 20 min) showed the highest values at days 14, 21, and 28, reaching up to 7.62. In contrast, lower °Brix values were seen in T_7 (7; 60°C, 15 min), T5 (7; 63°C, 10 min), and T8 (7.1; 66°C, 15 min). Overall, TSS increased with longer

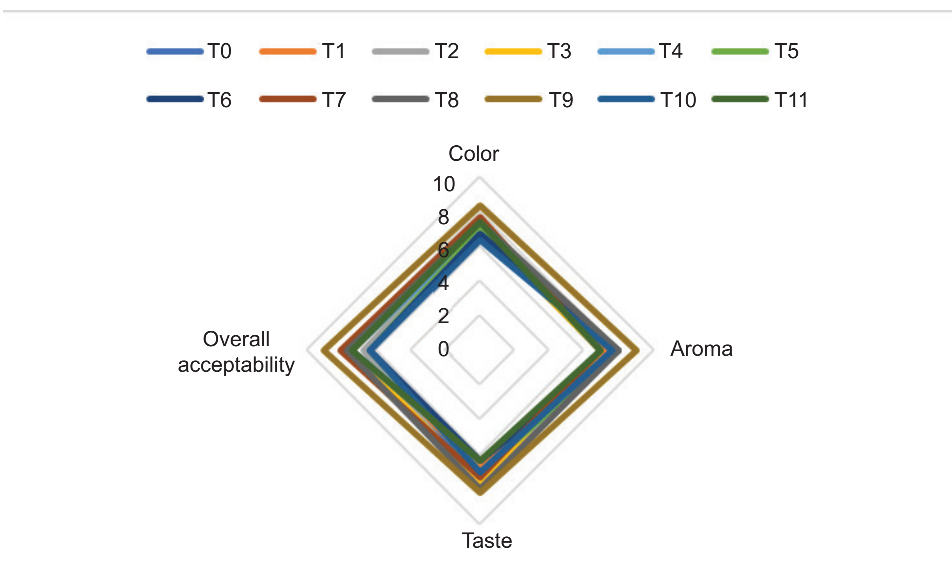

Figure 9. Impact of treatments on sensory analysis of the cantaloupe pulp.

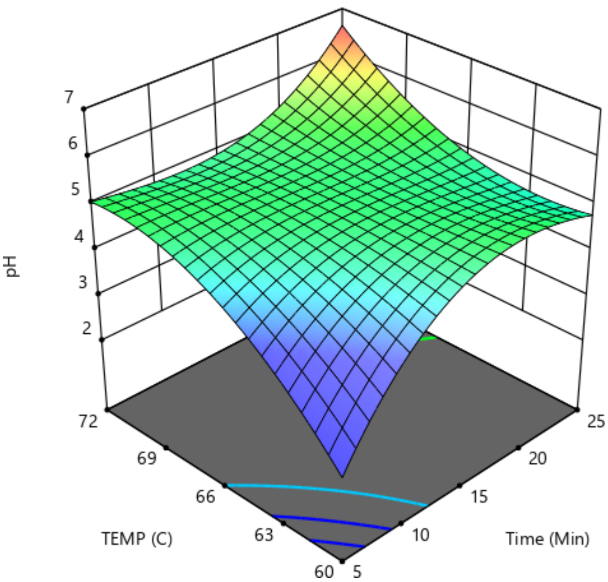

Figure 10. pH (a) influenced by time and temperature during storage.

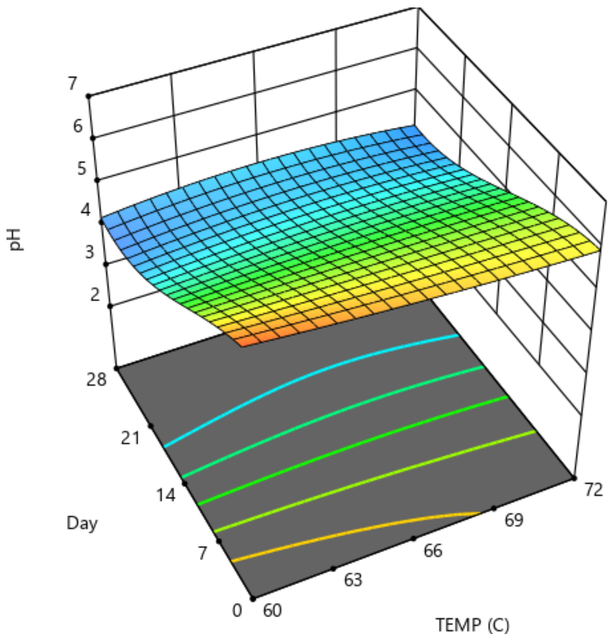

Figure 12. pH (c) influenced by temperature and day during storage.

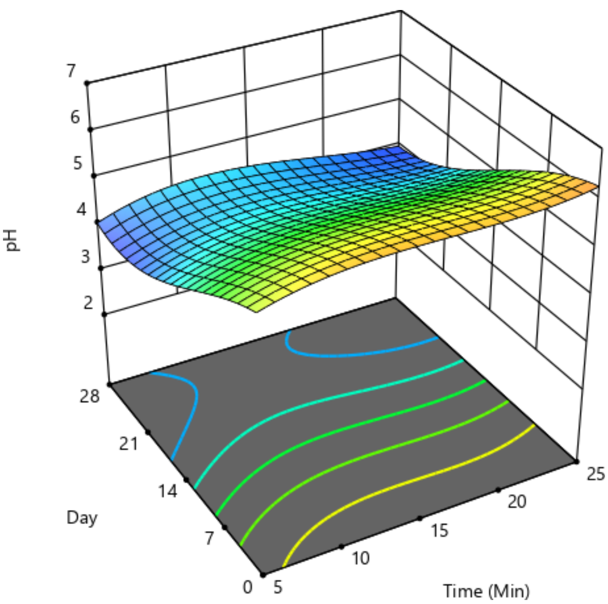

Figure 11. pH (b) influenced by time and day during storage.

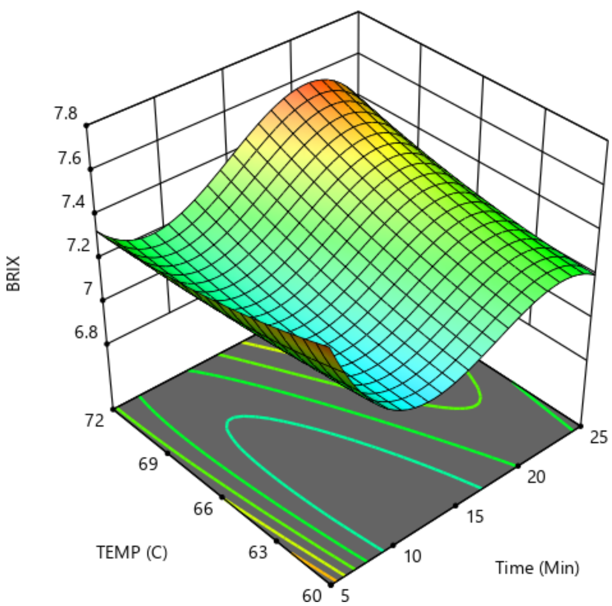

Figure 13. Brix (a) influenced by temperature and time during storage.

storage duration, higher processing temperatures, and extended heating times. The significance of ohmic heating in TSS retention was highlighted by similar findings in roselle-mango juice (Priyadarshini *et al.*, 2023) and banana pulp (Pushparaj and Athmaselvi, 2016).

TA

The acidity of the cantaloupe pulp shows an increasing trend during storage (Figures 16–18). During the 28-day storage period, the pulp of the cantaloupe became more acidic. On average, T_8 (66°C, 15 min) had the highest acidity, reaching 0.874 by day 21, while T_2 (72°C, 5 min) had the lowest, reaching 0.441 by day 28. This trend indicates that lower acidity was maintained during storage by using higher processing temperatures for shorter periods (as in T_2). The upward trend in TA may be linked to the production of acid via the breakdown of polysaccharides and the oxidation of reducing sugars (Imtiaz *et al.*, 2008).

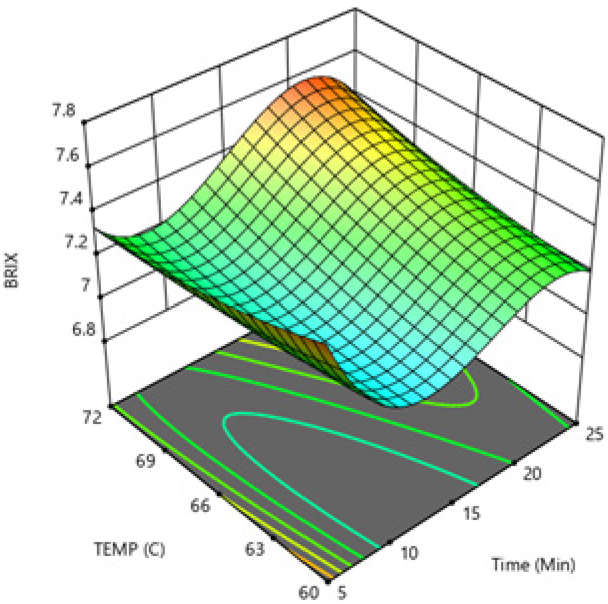

Figure 14. Brix (b) influenced by time and day during storage.

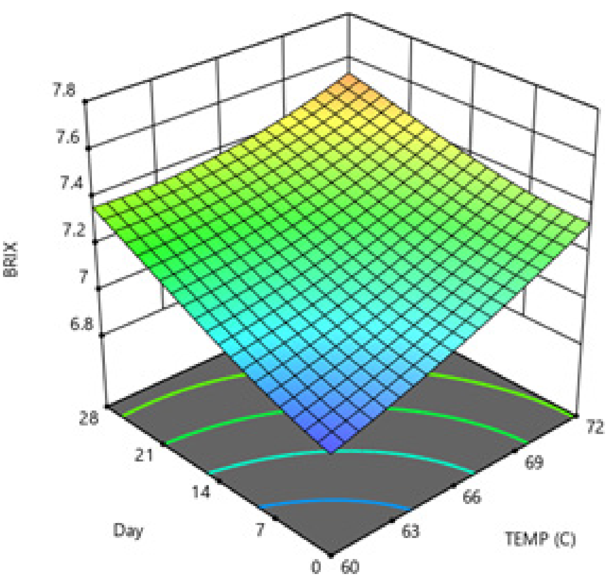

Figure 15. Brix (c) influenced by temperature and day during storage.

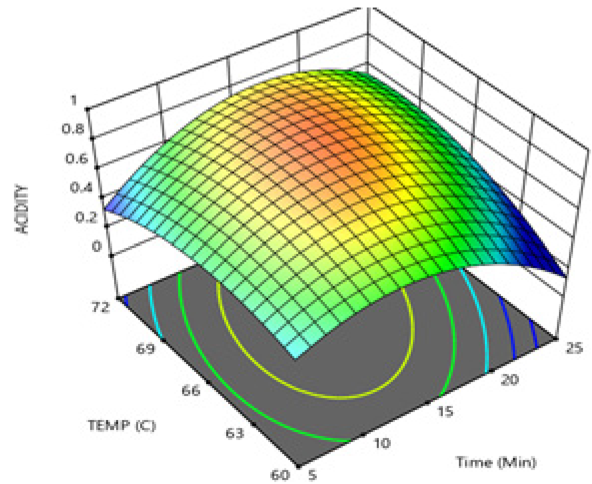

Figure 16. Acidity (a) influenced by time and temperature during storage.

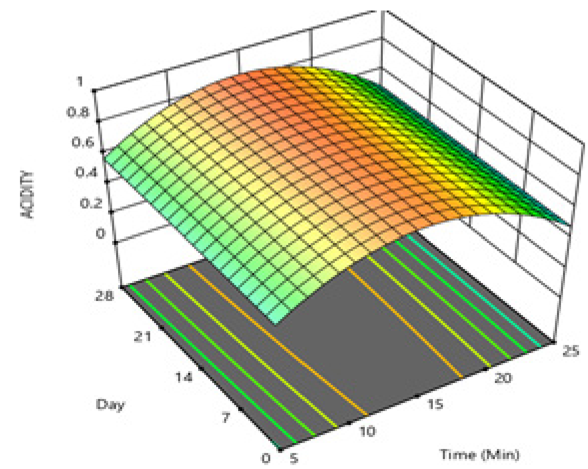

Figure 17. Acidity (b) influenced by time and day during storage.

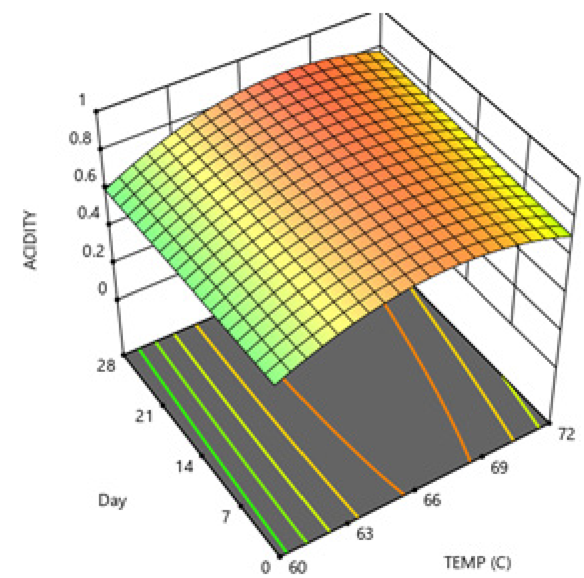

Figure 18. Acidity (c) influenced by temp and day during storage.

Findings from this study are consistent with studies on grape juice concentrate made by ohmic heating (Darvishi *et al*., 2020a). Similarly, white grape juice and peach pulp over a 120-day storage period showed comparable trends (Malik *et al*., 2016).

Sensory analysis

A nine-point hedonic scale was used (Rodríguez *et al*., 2021), and sensory panelists evaluated the color, aroma, taste, and overall acceptability of the cantaloupe pulp that had been heated both conventionally and ohmically at 0, 7, 14, 21, and 28 days of storage.

Color

On day 0, T_8 had the highest color score (8.367; 66°C, 15 min), followed by T_9 (8.35; 66°C, 5 min) and T_3 (8.1; 63°C, 20 min). At the end of day 28, T_0 (4.12; 72°C, 2 min), T_4 (4.23; 69°C, 10 min), and T_5 (4.3; 63°C, 10 min) had the lowest color scores (Figures 19–21). Over the period of storage, T_8 continuously obtained the highest scores. From 8.367 on day 0 to 6.33 on day 28 for T_8, color scores decreased with time, demonstrating that color is adversely affected by higher temperatures and longer processing times. Ohmically treated pulp significantly retained its color better than the conventionally treated sample during storage. Color changes are associated with enzyme activity and pigment breakdown during storage, as observed in comparable products such as watermelon juice (Makroo *et al.*, 2016).

Aroma

On the first day, T_9 had the highest aroma scores (8.667; 66°C, 5 min), followed by T_8 (8.15; 66°C, 15 min) and T_7 (7.61; 60°C, 15 min) (Figures 22–24). The 28th day was when T_{10}, T_3, and T_0 showed the least amount of aroma (5.52; 69°C, 20 min), (5.33; 63°C, 20 min), and (4.6; 72°C, 2 min). Scores for odor decreased throughout storage, with T_9 indicating the best overall consistency. The scores decreased from 8.667 on day 0 of T_9 to 5.33 on day 28. Treatment T_9 (66°C, 5 min) continued to be the best result. Ohmic heating significantly retained the aroma during the storage period. Ohmic-treated grape juice concentrate consistently maintained its aroma better than conventionally treated pulp (Darvishi *et al.*, 2020a).

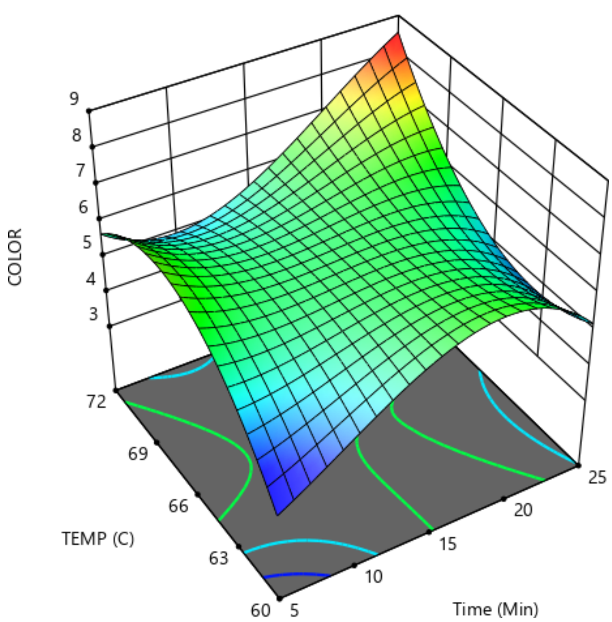

Figure 19. Color (a) influenced by temperature and time during storage.

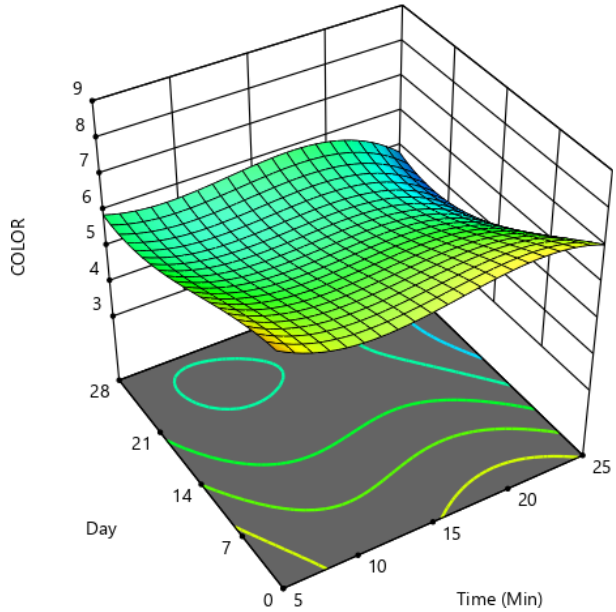

Figure 20. Color (b) influenced by day and time during storage.

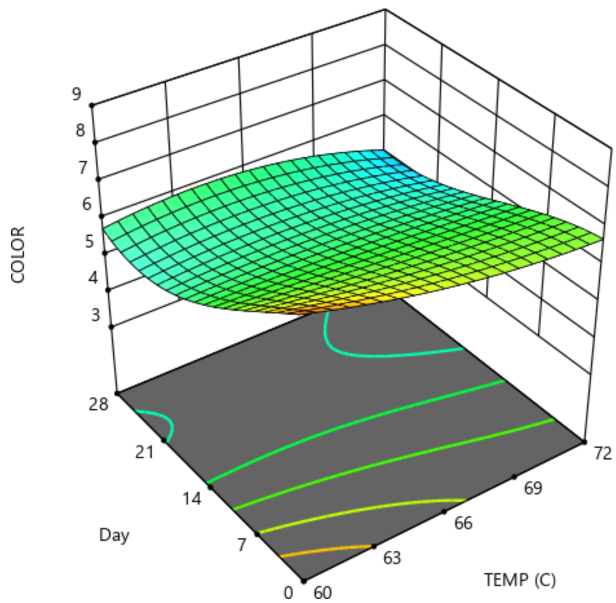

Figure 21. Color (c) influenced by temperature and day during storage.

Taste

Taste, which is affected by food composition, texture, and aroma, was scored lowest in T_3 (6.6; 63°C, 20 min), T_5 (6.3; 63°C, 10 min), and T_0 (5.6; 72°C, 2 min), and highest in T_9 at day 0 (8.23; 66°C, 5 min), followed by T_8 (8; 60°C, 15 min) and T_{10} (7.33; 9°C, 20 min) (Figures 25–27). T_9 continuously scored highest on days 14, 21, and 28 while taste scores decreased during storage. T_9 shows values from 8.23 on day 0 to 6.63 on day 28, indicating a decrease in the taste score. Taste acceptance

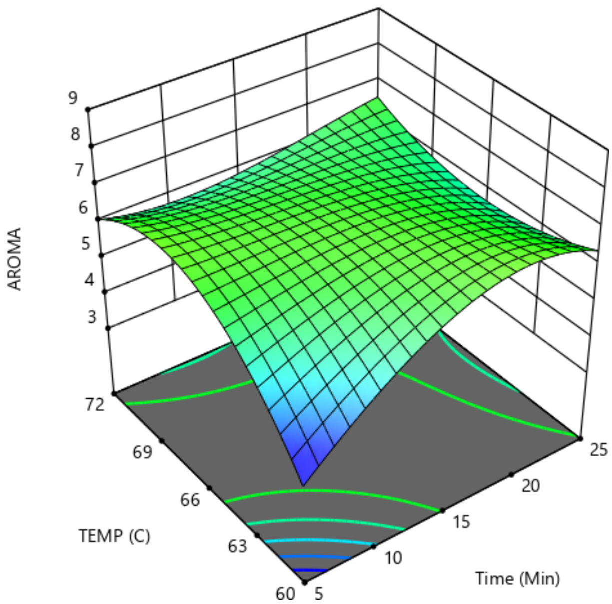

Figure 22. Aroma (a) influenced by time and temperature during storage.

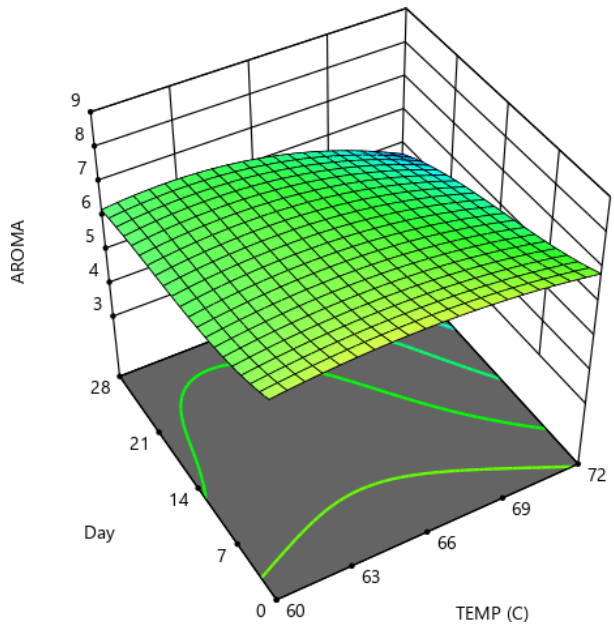

Figure 24. Aroma (c) influenced by temperature and day during storage.

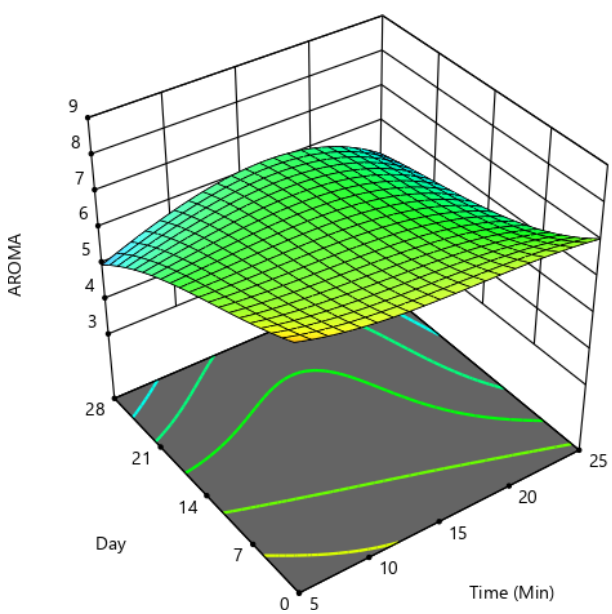

Figure 23. Aroma (b) influenced by time and day during storage.

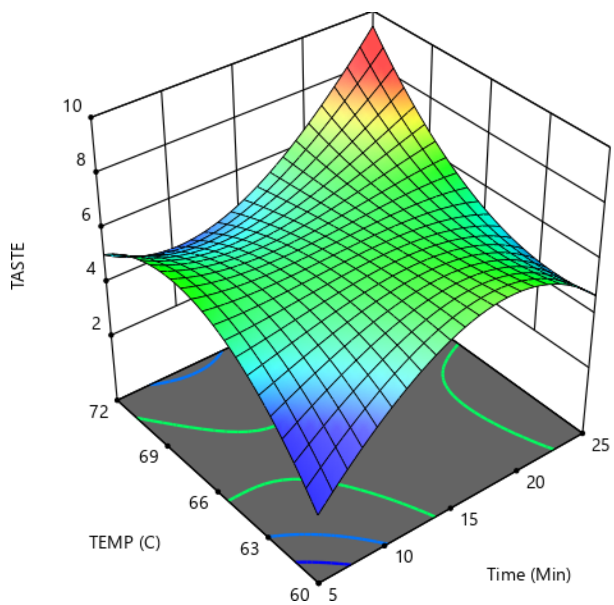

Figure 25. Taste (a) influenced by time and temperature during storage.

declined as temperature and duration increased. Ohmic-treated samples taste significantly better than conventional ones during the duration of storage.

Overall acceptability

Sample T_9 had the highest overall acceptance (8.367; 66°C, 5 min), followed by T_7 (8.35; 66°C, 5 min) and T_8 (8.1; 63°C, 20 min) on the first day (Figures 28–30). At the end of day 28, T_0 (4.32; 72°C, 2 min), T_4 (4.63; 69°C, 10 min), and T_{10} (4.3; 69°C, 20 min) had the lowest scores. A better sensory score was shown by T_9 over storage. The highest score decreased with time, from 8.667 on day 0 to 6.11 on day 28. Acceptability decreased with increasing duration and temperature of processing (from 60 to 72°C and 5 to 25 min). After 2 days of storage, conventionally treated carrot juice exhibited limited acceptability, but ohmic-treated juice retained better overall scores (Rodríguez *et al.*, 2021).

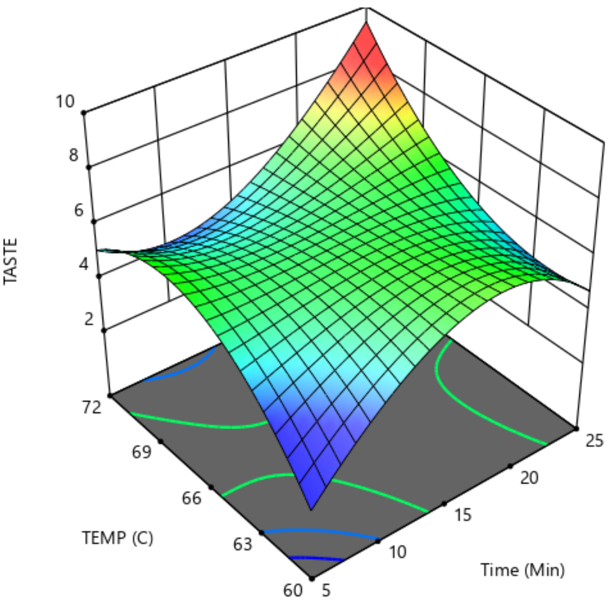

Figure 26. Taste (b) influenced by time and day during storage.

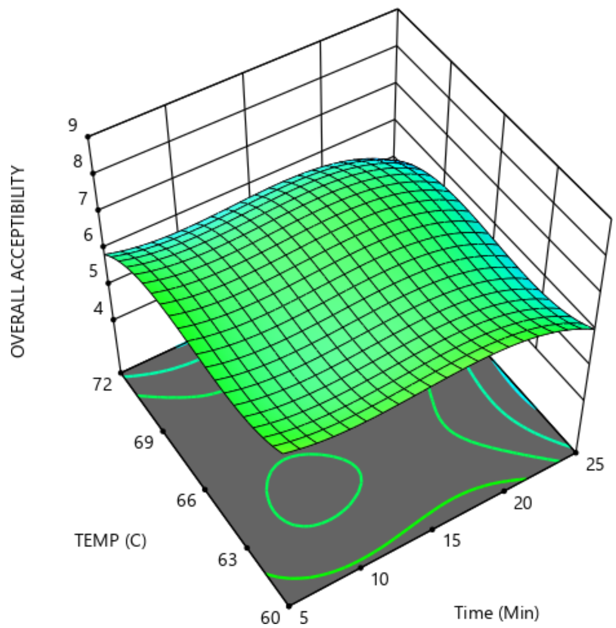

Figure 28. Overall acceptability (a) influenced by temperature and time during storage.

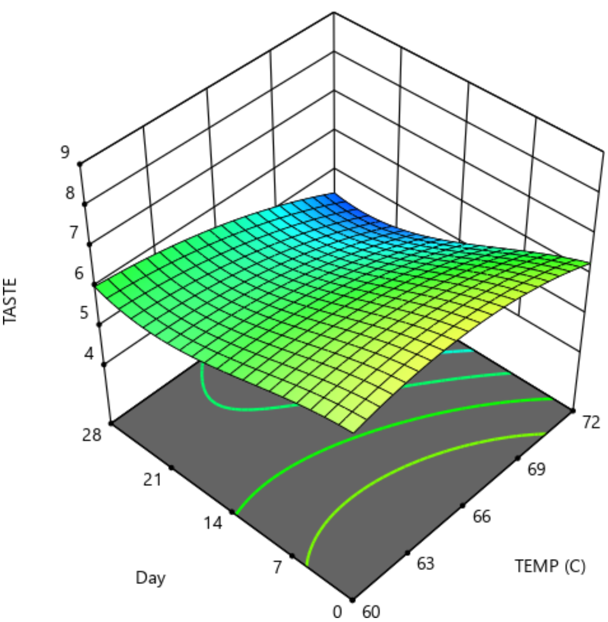

Figure 27. Taste (c) influenced by temperature and day during storage.

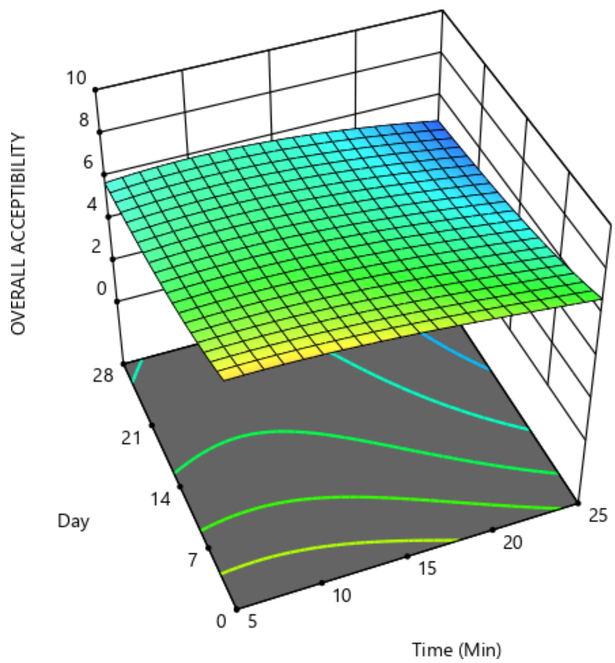

Figure 29. Overall acceptability (b) influenced by time and day during storage.

Conclusions

Results indicated that the pH of the cantaloupe pulp from T_1 to T_{11} ranged from 5.55 to 6.6 on day 0, which significantly decreased on the 28th day, respectively, during storage. The acidity of pulp ranged from 0.384 to 0.832 on day 0, which increased during storage, ranging from 0.441 to 0.881 on day 28. TSS contents of the pulp ranged from 6.9 to 7.3 on day 0, while they increased significantly from 7.4 to 7.63 at 28 days, during storage. Vitamin C (28.93–49.4 mg/100 g), total phenolic contents (70.42 mg GAE/100 g–83.03 mg GAE/100 g), total flavonoid contents (13.78 mg QE/g–17.79 mg QE/g), and activity of antioxidants (64.50%–73.73%) showed that these are heat sensitive and decreased with the increase in temperature but retained maximum contents in pulp

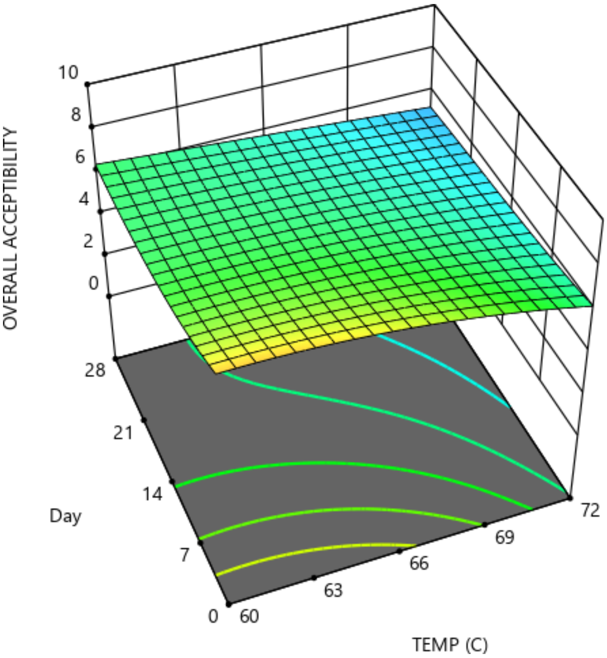

Figure 30. Overall acceptability (c) influenced by temperature and day during storage.

processed through ohmic heating as compared to conventional heating. The shelf life of conventionally treated pulp was 3–4 days; after that, the aroma gets pungent, and the microbial load starts to increase during storage days. However, the shelf life of ohmic-treated pulp was 5.25 times greater than conventionally treated pulp, indicating improvements in microbial growth and sensory quality. Future research should assess the method's applicability across a variety of cantaloupe matrices and optimize electrical parameters (voltage gradient, frequency, and treatment time), conduct techno-economic and energy-consumption assessments at a large industrial scale, and conduct nutritional profiling to ensure consumer acceptance. Our research results demonstrated that ohmic heating can be implemented in fruit and vegetable processing industries to produce minimal processed food products that fulfill consumer demands. Ohmic heating inhibits microbial proliferation in the cantaloupe pulp and extends its shelf life by up to 1 month without decay. Future studies should focus on combining ohmic heating with other nonthermal processing methods to attain enhanced product stability over longer durations.

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Authors Contributions

Farah Jameel, Zunaira Arshad, Nabeel Ashraf, and Rokayya Sami designed the study; Nashi K. Alqahtani, Fatin Alsalmi, Abeer A. Abu-zaid, Norah E. Aljohani, Bandar Alfaifi, Mahmoud Helal, Alanood A. Alfaleh, Ebtihaj O. Alnasri, Shatha Alaoufi, Tasahil S. Albishi, Farah Jameel, Zunaira Arshad, and Nabeel Ashraf were concerned with the methodology; Bandar Alfaifi, Mahmoud Helal, and Sameer H. Qari were responsible for writing and editing the draft. All authors conducted a critical review and endorsed the final version of the manuscript.

Conflicts of Interest

None.

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