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Synergistic effect of microwave heating and thermosonication on the physicochemical and nutritional quality of muskmelon and sugarcane juice blend

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ABSTRACT

Melons (Cucumis melo L.) are highly popular due to its delicate and delightful flavor in the worldwide. However, the flavor of the melon juice was easily affected by thermal treatments and unpleasant cooking smell during production process. Sugarcane (Saccharum officinarum) juice is a proven nutritious beverage with high levels of antioxidants, polyphenols, and other beneficial nutrients. Due to its low sugar content, combined with sugarcane, muskmelon-sugarcane blend juice gives an appealing and exotic drink. The research was planned to evaluate the effect of thermo-sonication (20 kHz, 70% amplitude, 5, 10 and 15 min) and microwave (90 °C, 400 W, 120 *sec*) on physicochemical parameters including pH, titratable acidity, total soluble solids (TSS), total phenolic contents (TPC), total flavonoid contents (TFC) and antioxidant capacity of muskmelon and sugarcane juice blend, during storage of 90 days at refrigeration (4±1 °C). The statistical results showed that synergism of sonication and microwave treatments had a significant ($p \leq 0.05$) influence on pH, TSS, titratable acidity, TPC, TFC and antioxidant capacity. T_3 (15 min of sonication and 120 s of microwave) showed the maximum TSS (12.00±0.40 °B), pH (5.07±0.02), TPC (484.33±10.41 mg GAE/100 mL), TFC (261.73±11.32 mg CE/100 mL), and antioxidant activity (381.62±17.72 μg AAE/100 mL), as compared to untreated samples. Thermosonication for 15 min caused maximum retention of TPC, TFC and antioxidant capacity of blend juice during 90 days of storage, whereas in untreated samples these parameters were found highly decreased during storage. Thus, sonication and microwave can be recommended as an alternative to both conventional pasteurization processes and chemical preservatives.

1. Introduction

The name of the melon variety known as the muskmelon (*Cucumis melo*), which belongs to the *Cucurbitaceae* family, comes from the Latin term melopepo, which denotes an apple-shaped melon, and the Persian word musk, which indicates perfume. It is indigenous to Persia (Iran) and its eastern and western neighbors. The melon is enjoyed as table fruit and has a netted rind with creamy, pale yellow-orange flesh that tastes bland and has a musky flavour. Melons *(Cucumis melo* L.) are very well-liked all around the world for their exquisite flavour. Unfortunately, during the production process, the flavour of the melon juice was easily impacted by thermal treatments and foul cooking odors (Liu et al., 2023). The climacteric melon known as the “muskmelon” is prized for its peculiar musky flavour and perfume. It became well-known for being a

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fruit that is both hydrating and energizing. One of the commercially significant fruits grown around the world in temperate, tropical, and subtropical zones is the muskmelon (Sangamithra & Ragavi, 2020).

Muskmelon is the 4th most essential fruit of the world regarding production after orange, banana, and grape. The global consumption of this muskmelon is more than any other cucurbit (Aguayo, Escalona, & Rtes, 2004). Production of *Cucurbits* including melons, in 2019 was estimated above 23 million tons cultivated all over the world comprising an area of 1.54 million hectare and in Pakistan 2.7 lac tons on 26515-hectare area (Hussain et al., 2022). Melons generally possess a huge amount of water, about 90–97%. These are known for their hydrating and excellent thirst-quenching properties. These fruits have abundant antioxidant capacities due to presence of various bioactive compounds. Muskmelon is nutritious fruit due to presence of vitamins (C, B and K), minerals (K, Fe, Cu, Fe and Mg), carotenoids, phenolics and fiber (Kudri et al., 2022).

The sugar concentration, volatile content, and texture of harvested melon fruit are more influenced by maturity than by other factors. The fruit has a wealth of beneficial nutritional and therapeutic qualities. It is a good supply of potassium, vitamin B6, vitamin C, and vitamins A and C. (Sangamithra & Ragavi, 2020). Muskmelon is full of dietary fiber, beta-carotene, minerals, and ascorbic acid. Muskmelon possesses medicinal properties. It consists of anti-oxidant, anti-ulcer, free radical scavenging, and anti-diabetic properties (Milind & Kulwant, 2011).

High quantities of polyphenols, antioxidants, and other healthy elements can be found in sugarcane juice (*Saccharum officinarum*), a beverage with a demonstrated track record for being nutritious. As a result of its strong nutritional profile and alkaline makeup, it has recently attracted more consumer interest. Yet, juice begins enzymatic degradation and microbial fermentation, because of its high polyphenolic and sugar content, which gives it dark colour (Panigrahi, Shaikh, Bag, Mishra, & De, 2021). Recently, certain cutting-edge methods have been developed to increase sugarcane juice's nutritional content and shelf life. The adoption of such processing methods is advantageous over current procedures and necessary for the production of chemical-free, premium, fresh juices (Mukhtar et al., 2022). Sugarcane is a persistent grass related to the family *Poaceae*, and it is grown throughout the world in about greater than 90 countries for the reason of its low cost and good yield. It's the cheapest crop providing high energy through higher glucose and fructose contents (Yadav & Solomon, 2006). It has been well known for its therapeutic properties. It exhibits antioxidant properties due to phenolic compounds, such as phenolic acids, flavonoids, etc. (Payet, Sing, & A., & Smadja, J., 2006). Sugarcane juice has wide medicinal applications, and especially its stem and roots are used to treat several diseases such as anuria, jaundice, dysuria, cough, hemorrhage, anemia, constipation, bronchitis, and other urinary diseases (Akber et al., 2011).

The muskmelon fruits are seasonal and grow in different areas for a very short time, but in huge numbers in a specific season, becoming a reason for scanty production in the next season (Aruna, Promod, & Jayamma, 2017). A good alternative solution for muskmelon fruits is to produce ready-to-serve drinks by mixing 2 or more than 2 fruit and vegetable juices. A blending of fruit juices helps to improve taste and flavor, and becomes a source of low-cost production. Many fruits have high nutrients, but are still not used commercially, because of high acidity or bad taste and flavor; this can be solved by blending different fruits, to use their nutrients (Fatima et al., 2023).

In contrast to traditional heat treatment, non-thermal food processing technology known as sonication has attracted a lot of interest for its ability to preserve food's nutritional value and original freshness, while using less energy and having a higher level of sensory appeal (Salehi, 2020). One of the non-thermal food processing techniques that can be employed in place of thermal food processing is ultrasound. The energy generated by sound waves of different frequencies that is too high for the human ear to detect, or above 16 Kz, is referred to as ultrasound. It is a cutting-edge technology that shortens processing times and lowers costs, while increasing and guaranteeing product quality. It has many benefits when paired with microwave technology. Food quality has been effectively impacted by factors like texture, color, antioxidants and polyphenolic characteristics (Nehra, Duhan, Khan, Sandhu, & Ansariee, 2023).

Improper hygienic and storage condition of fresh juice stalls leads towards unsafe provision of fruit juices towards consumers, due to microbial food contamination. That's why processing of muskmelons is crucial, which includes frozen, canned, desserts, beverages, fresh juices and dehydrated (Leon, Priya, & Somasundaram, 2023). Pang et al. (2019) developed muskmelon juice and used different advanced techniques to study the effect of heating on aroma and odorants of the juice.

Thermal processing alone, produce strong cooked off odors in melon juice, leading to serious quality and nutritional deterioration. Treatment of melon juice with glucose oxidase along with heating produced good quality melon juice with quality characteristics near to the non-processed juice (Luo, Pan, Zhang, Bi, & Wu, 2022). Heating of muskmelon juices led to sulfurous and fermented off-note active odorants decreasing the fresh aroma of natural juice, therefore non-thermal technologies are advocated for processing and preservation of naturally occurring bioactives in the melon juices (Yu et al., 2021). In experiments performed by Suo, Zhou, Su, and Hu (2022), pumpkin juice was treated with ultrasonic waves with different powers, but same frequency, to compare the storage analysis of treated juice with non-treated juice samples.

Ultrasound treatment has been found useful in enhancing total phenolics, flavonoids and antioxidant capacity of fresh fruit juices with minimum quality deterioration (Wang, Vanga, & Raghavan, 2019). Ultrasonic waves were used to prepare melon juice, which resulted in improvements to the juice's microbiological purity, bioactive chemical content and physical appearance (Rodriguez-Rico et al., 2022). Sonication treatment appeared to be effective for increasing many quality characteristics as well as microbial decontamination (Rawson *et al.,* 2010; Bhat, Kamaruddin, Min-Tze, & Karim, 2011). As a green processing technologies, ultrasound and microwave processing have great potential in food applications (Taha et al., 2022).

Microwave technique is a type of dielectric warming utilized for mechanical food handling and used locally to prepare or defrost the food (Song & Kang, 2016). Electromagnetic waves with varying frequencies of 300 MHz – GHz are called microwaves. It takes a short heating time and gives a better product (Shaheen, El-Massry, El-Ghorab, & Anjum, 2012). Microwaves applications were proved useful in retention of maximum phenolic compounds and destruction of microorganisms present in traditional sugarcane juice product (Patel, Dhar, & Chakraborty, 2023).

The nutritional value of food is crucial since it can greatly influence the product's health benefits and determine whether consumers would accept it or not. Utilizing ultrasound treatments in conjunction with the thermal sterilization method, it is possible to create fruit and vegetable juices with excellent nutritional qualities. The implementation of ultrasound technology in the food business has a substantial potential, according to a number of prior findings. According to scale-up research, non-thermal procedures could be useful for the food business in producing fruit juice with excellent nutritional content and opening the door for widespread commercialization of the technology (Golmohamadi, Moller, Powers, & Nindo, 2013; Khandpur & Gogate, 2015; Odriozola-Serrano, Soliva-Fortuny, & Martín-Belloso, 2008). Synergism of ultrasound and microwaves was found beneficial in maintaining the nutritional and antioxidant quality of sugarcane juice (Zia, Khan, Zeng, Shabbir, & Aadil, 2019).

Due to its ongoing respiration, muskmelon, a climacteric fruit, cannot be kept in storage for an extended period of time. Thus, muskmelon's value addition is essential for keeping the fruit in a variety of shapes, especially juices, and further addition of sugarcane juice can produce delicate taste and more sweetness in blend juice by increasing the Brix. In recent past, several experiments have been conducted upon muskmelon and sugarcane juices by application of microwaves and sonication individually, but fewer research are present about synergistic effect of microwave and sonication upon muskmelon and sugarcane blend juice samples. Keeping in view the above stated facts and figures the present research work was designed to assess the effect of combined application of microwaves at 90 °C for 120 *sec* and sonication at a frequency of 20 kHz for 5, 10 and 15 min, on phytochemical and antioxidant quality of blend juices samples for 90 days of storage.

2. Materials and methods

2.1. Purchasing of raw materials

All the reagents and chemicals were purchased from Fluka Chemical Co. (Buch's, Switzerland) and Merck (Darmstadt, Germany). Good quality, fresh, and completely ripened muskmelons (variety golden) were obtained from the Sargodha local market. Fresh sugarcanes (CoL-54 variety) were also purchased from local market of Sargodha, Pakistan and juice was extracted using common crusher. The study was conducted at Institute of Food Science and Nutrition, University of Sargodha, Pakistan.

2.2. Pre-treatment of raw materials

Muskmelon fruits were cleaned to remove dirt, dust, and other foreign substances. The seeds were removed. Similarly, sugarcanes were removed from attached green plant materials and any foreign substances, then washed and used to extract juice.

2.3. Preparation of juice

After deseeding the muskmelons, the juice was extracted using a blender (Model No. MJ-J176, Panasonic Industry, Berhad, Malaysia). Sugarcane juice after crushing the sugarcanes was checked for its Brix with hand refractometer (3840- PAL (alpha) Atago, Japan) and Brix was noted 21 before addition in muskmelon juice. Both the juices were filtered over a 0.8 mm pore size sieve to remove any foreign particles. Sugarcane juice (30 mL) with high Brix was then added to the muskmelon juice (70 mL) having Brix 8, and this 30:70 ratio increased the overall brix of blend juice up to 12%, which was used for further analyses. The juices were then kept in an aseptic environment and given additional thermal and non-thermal treatments. The processed juices were utilized periodically for various analyses while being kept in the refrigerator at 4 °C.

Juices that had been filtered out of the solids were utilized in all trials involving the ultrasonic and microwave. According to preliminary investigations, when the test juice samples were not filtered and contained particle matter, the effectiveness of ultrasound was dramatically diminished. The bacteria were protected by the presence of soluble solids, and the extended sonication process had a detrimental effect on the juices' nutritional content. For whole processes of juice preparation and storage protocols were adopted from the methodology given by Khandpur and Gogate (2015), with required modifications. Treatment plan for processing of blend juice before analyses has been presented in Table 1.

Table 1
Treatment plan.

Treatments	Sonication	Microwave
T_0	–	–
T_1	5 min	120 s
T_2	10 min	120 s
T_3	15 min	120 s

2.4. Ultrasound processing of juice

The juice extracted from each type was ultrasonically processed. Sonication was performed using an ultrasonic processor (UP400S, Ultrasonics GmnH Hielscher USA, Inc.) equipped with a 0.5-inch probe. Sonication of blended samples (200 mL in a 500 mL beaker) was performed at 70% amplitude for 5–15 min with a pulse length of 5 s on and 5 s off, at a frequency of 20 kHz, as previous literatures have provided promising results regarding phytochemicals retention with same parameters. The ultrasonic parameters for this investigation were chosen in accordance with Yikmiş (2019) earlier findings on the use of ultrasonography in fruit juices. The energy of ultrasound in the 20–1000 kHz range can break down fruit matrices to make it easier to extract valuable bioactive chemicals. It also exhibits unique propagation characteristics in fluid media. Up to 30 min, each measured parameter responded significantly and favorably to ultrasound treatment in every case (Golmohamadi et al., 2013). Use of 50–90% amplitude was experimented earlier and promising results were found with 70% amplitude were present in the studies of Bhat and Sharma (2016). Sonication was conducted immediately following juice extraction.

2.5. Microwave processing of juice

Microwave treatment of blended samples (200 mL in a 500 mL beaker) was done in a microwave oven (MRO-AV200E, Hitachi, Japan) at 90 °C and 400 W for 120 *sec*. Due to its unique features, including thermostatic control, temperature resistance up to 120 °C, and operating temperature range of 25 °C to 100 °C with an accuracy of 0.3 °C, and a 220 Volt/50 Hz electric supply, the mentioned microwave was used to pasteurize juices. The drink was then poured into 200 mL plastic bottles already placed in ice-cold water before pouring juice to avoid shrinkage due to heat. The fresh samples without any treatments were taken as control. All the samples were kept at refrigerated temperature 4±1 °C for further analysis.

2.6. Storage of juices

Juices that had not been treated, thermally pasteurized and treated with ultrasound were kept cold at 4 °C for three months, following processing. Juice samples were taken at regular intervals for study of the processed juice's shelf life.

2.7. Physicochemical analysis

pH was determined using a digital pH meter (CE 1040 Benchtop meter, Adwa, Hungary) according to method 981.12 of AOAC (Association of Official Agricultural Chemists) (2016). Titratable acidity was calculated using method 942.15 of AOAC (Association of Official Agricultural Chemists) (2016). Degree Brix was determined using a hand refractometer (3840- PAL (alpha) Atago, Japan) under method 932.12 of AOAC (Association of Official Agricultural Chemists) (2016).

2.8. Phytochemical analysis

2.8.1. Total phenolic content

The total phenolic content of the muskmelon-sugarcane juice blend was determined using a modified Folin–Ciocaltue reagent assay as described by Nadeem, Ubaid, Qureshi, Munir, and Mehmood (2018). At 760 nm, the absorbance was determined using a spectrophotometer (U 2900 Hitachi, Japan). Gallic acid was used as a reference, and total phenolic contents were expressed as mg gallic acid equivalents (GAE) per 100 mL juice.

2.8.2. Total flavonoid content

The total flavonoid content of the muskmelon-sugarcane juice blend was determined using aluminum chloride, as described by Munir, Khan, Qureshi, Murtaza, and Munazir (2020). At 695 nm, the absorbance was determined using a spectrophotometer (U 2900 Hitachi, Japan). Catechin was used as a reference, and total flavonoid contents were expressed as mg catechin acid equivalents (CE) per 100 mL juice.

2.8.3. Total antioxidant capacity

The procedure used to evaluate the total antioxidant capacity of the muskmelon-sugarcane juice blend was adopted from the guidelines of Prieto, Pineda, and Aguilar (1999), with some modifications. Ascorbic acid was applied as standard calibration curves, and the data were represented as microgram ascorbic acid equivalent (AAE)/100 mL juice, respectively.

2.9. Statistical analysis

The recorded data were analyzed statistically with Minitab 16 software. Significant differences among mean values were demonstrated by two-way ANOVA test at a significance level of $P < 0.05$, by following the procedures described by Steel and Torrie (1980).

3. Results and discussion

3.1. Physicochemical analysis

3.1.1. pH analysis

Effect of all treatments on pH has been presented in Table 2. The pH increased with the increase in treatment time and storage days, the highest pH was observed in T_3 with the mean value of 5.41±0.02 and the lowest pH was observed in T_0 with the mean values of 5.01±0.02, after 90 days. After studying, it was revealed that the pH of the muskmelon-sugarcane juice blend increased over time. The lowest value was presented at 0 day of storage period by T_0 with the value of 4.55±0.03. However, consequently, the maximum value was seen at 90 days of storing time by T_3, as shown in Table 2.

Ultrasonic treatment has been widely used as an alternative technology to thermal techniques for fruit juices preservation and processing. Due to low frequencies and high pressure, this technique causes minimum degradation, and increases functionalities of the juices. Ultrasounds (15 min, 40 kHz and 240 W) have been proved useful in inactivation of various kind of microbes without any significant changes in the pH of sugarcane juice (Mukhtar et al., 2022). In another study, Adulvitayakorn, Azhari, and Hasan (2020) compared conventional thermal processing with microwave and thermosonication for sugarcane juice processing and reported slight decrease in pH of sugarcane juice processed at 700 W through microwave technology and thermosonicated at 80 °C. Further they linked this variation in pH with variation in temperature of the juice samples under treatment. Previous studies by Khandpur and Gogate (2015) unequivocally demonstrated that pH is crucial to the quality and safety of juices. Low pH or acidic conditions increase the anti-microbial effectiveness of sonication, which may be related to increased hydroxyl radical generation. Juices with lower pH values are therefore more sensitive to ultrasonic therapy.

Liu *et el.* (2023) used ultrasonic treatment to preserve aromatic compounds of melon juice and observed minor change in pH of ultrasonic treated, control and ultrahigh temperature treated melon juice, with values 6.51, 6.47 and 6.62, respectively, validating the results of present study that ultrasound waves for different time periods had minor pH change effect. Yikmis (2020) prepared juice from red and yellow water melon and processed with different techniques to assess physicochemical parameters of the processed and unprocessed juices. Unprocessed control juice samples of red and yellow water lemon exhibited pH values 5.6 and 5.37, respectively. Pasteurized and ultrasonic treated samples at lower time periods had not any variations on pH of the juice samples as results has been presented for current findings, in Table 2, but ultrasonic treatment for longer time period (16 min) caused slight reduction in pH, possibly due to the increase in organic acids liberated due to high cavitation effect of longer ultrasonication.

In some earlier studies that are still relevant, there was no discernible difference in the pH values and titration acidity, in the studies with ultrasound applied to banana juice (sonication treatments; treatment frequency 40 kHz, 50 W, 0–30 min) (Bora, Handique, & Sit, 2017), strawberry juice (sonication treatments; 0, 15, and 30 min at 20 °C, 25 kHz frequency) (Bhat & Goh, 2017), and carrot-grape juice (sonication treatments; 20 kHz frequency, 70% amplitude level, 525 W power, and pulse duration 5 s on and 5 s off, 5 min at 15 °C) (Nadeem et al., 2018).

Bhat et al. (2011) applied the sonication technique on kasturi lime for different time intervals. His results showed an increase in pH from 2.66±0.02 to 2.68±0.01, with the increase in sonication time, showing close resemblance to current study outcomes. An increase in pH might be attributed to extracting mineral elements or vitamins from fruit tissues, possibly due to the microwave application used in combination with ultrasound. Synergistic effect of these treatments might assist the liberation of such substances while trapped into colloidal particles or vegetal cells, possibly due to rise of temperature (Abid et al., 2015; Liu et al., 2023). Malik et al. (2022) investigated the impact of microwave treatments and storage on pH of lemon cordial, and observed significant increase in pH of lemon cordial as a result of microwave treatment for 120 *sec* as compared to untreated samples, while during storage period of 90 days they observed a gradual reduction in pH of lemon cordial, which they linked with the reduction in the contents of organic acids as a result of microwave treatment.

The small letter used in the table is to indicate a significant difference between samples by column (effect of treatment) or by row (effect of storage time), T_0 = Muskmelon-sugarcane juice blend (no technique), T_1 = muskmelon-sugarcane juice blend with microwave at 90°C for 120 *sec* and 5 min ultrasound treatment, T_2 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 10 min ultrasound treatment, T_3 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 15 min ultrasound treatment.

3.1.2. Titratable acidity

Titratable acidity of all the treated samples reduced significantly from 0 to 90 days of storage period and decreased within the treatment, as shown in Table 3. The maximum acidity was noticed in T_0 (0.28 ±0.001%) followed by T_1 (0.25±0.11%), and the lowest acidity was found in T_3 (0.21±0.01%), at start of study. The influence of storage duration on the acidity of muskmelon-sugarcane juice blend exhibited that it declined with the passage of storage time. The maximum mean value was seen at 0 day of storage, and the lowermost acidity was calculated at 90 days of storage with the mean value of 0.19±0.003 % in

Table 2
The effects of microwave heating and sonication time treatment and storage time on the pH of muskmelon and sugarcane juice blend.

Treatments	Days			
	0	30	60	90
T_0	4.55±0.03d	4.74±0.03 h	4.86±0.03efg	5.01±0.02 cd
T_1	4.65±0.03i	4.85±0.03 fg	4.93±0.02ef	5.09±0.02c
T_2	4.79±0.02gh	4.94±0.04de	5.03±0.02c	5.24±0.02b
T_3	5.07±0.02c	5.17±0.05b	5.34±0.02a	5.41±0.02a

Table 3
The effects of microwave heating and sonication time treatment and storage time on the titratable acidity (%) of muskmelon and sugarcane juice blend.

Treatments	Days			
	0	30	60	90
T_0	0.28±0.001a	0.27±0.003b	0.26±0.002c	0.25±0.002d
T_1	0.25±0.01 cd	0.25±0.01d	0.24±0.11e	0.22±0.13f
T_2	0.23±0.001e	0.23±0.001ef	0.22±0.001 g	0.21±0.002 g
T_3	0.21±0.01 g	0.21±0.001 g	0.19±0.002 h	0.19±0.003 h

T_3, as displayed in Table 3. On the other hand, acidity of untreated juice blend was increased during storage.

Kudri et al. (2022) calculated titratable acidity of fresh muskmelon and found value 0.026 g/100 g of muskmelon and observed non-significant effect on titratable acidity as a result of osmotic dehydration and application of different preserving coatings including molasses, honey and sugar.

Yikmis (2020) prepared juice from red and yellow water melon and processed with different techniques to assess physicochemical parameters of the processed and unprocessed juices and observed non-significant results for titratable acidity as affected by pasteurization and sonication at different time lengths, with values 0.094% for red melon juice and 0.087% for yellow melon juice. These results were found closely related with our findings as decrease in titratable acidity with increase in sonication time was minute, which was attributed to minor increase in pH as stated in earlier section. Yikmiş (2019) after their experiments stated that non-thermal treatments like sonication, generally have non-significant effect on pH and titratable acidity of processed juices.

Abid et al. (2015) observed sonication influence on acidity of apple juice. There was a continuous decrease in acidity from 0 days to 21 days of storage from 0.22±0.06 to 0.19±0.03%, respectively. The acidic hydrolysis of polysaccharides utilizes the acid for the conversion of non-reducing sugars into reducing sugars, due to which there is a significant decrease in titratable acidity (Bhardwaj & Pandey, 2011).

Aadil, Zeng, Han, and Sun (2013) found that even after treatments lasting 60 and 90 min, sonication had no effect on the pH, titratable acidity, or °Brix of grapefruit juice. Instead, these parameters remained steady. They stated that to optimize sonication treatments by varying the time, frequency, and temperature, as well as to assess the effects on juices nutritional quality, further experiments will be helpful.

Mukhtar et al. (2022) used ultrasonic waves treatment to preserve sugarcane juice and observed non-significant results for titratable acidity of sugarcane juice samples, which might be due to different parameters adopted during processing. Adulvitayakorn et al. (2020) reported a significant increase in titratable acidity (40.62%) of sugarcane juice processed at 700 W, and this effect on titratable acidity was found linked with loss of temperature. Adulvitayakorn et al. (2020) compared conventionally heat-treated sugarcane juice with microwave and thermosonicated juice samples and calculated their titratable acidity. Thermosonication resulted non-significant effect on sugarcane juice samples, while microwave heating exhibited significant increase in titratable acidity. The effects of the treatments on the juice's look and quality might be better understood if you are aware of how the pH and titratable acidity alter. Aconitic acid, which is present in sugarcane juice, affects the pH and titratable acidity, and Thai and Doherty (2011) claim that sonication over longer time periods in this study, which led to a decrease in titratable acidity, may be caused by this acid's breakdown.

Malik et al. (2022) investigated the impact of microwave treatments and storage on titratable acidity of lemon cordial and observed a gradual reduction on titratable acidity of lemon cordial during storage. During microwave treatments increased time and temperature resulted in destruction of fermenting microorganism due to which reduction in production of organic acids might have been occurred.

The small letter used in the table is to indicate a significant difference between samples by column (effect of treatment) or by row (effect of storage time), T_0 = Muskmelon-sugarcane juice blend (no technique), T_1 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 5 min ultrasound treatment, T_2 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 10 min ultrasound treatment, T_3 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 15 min ultrasound treatment.

3.1.3. Total soluble solids (Brix)

The effect of microwave and thermo-sonication were highly significant on the total soluble content of muskmelon and sugarcane juice blends, as shown in Table 4. Statistical results showed that the highest °Brix was found in T_3 followed by T_2, and the lowest brix was observed in T_0 (Table 3). The effect of storage period on °Brix of muskmelon-sugarcane juice demonstrated that the total soluble solids decreased with time during 90 days, with maximum reduction in untreated samples and minimum reduction in T_3. The maximum values were seen at 0 and 30 days of storage period and the lowest °Brix was seen at 90 days of storage as shown in Table 4.

Pulela, Maboko, Soundy, and Amoo (2022) calculated total soluble solids of different varieties of melons and values were found from 10.1 to 11.8. Kudri et al. (2022) provided value of Brix of fresh muskmelon as 6%, before osmotic dehydration and this lower value might be due to absence of sugarcane juice, which have been added in current experiments. Liu *et el.* (2023) compared ultrasonic and ultra-high temperature treatments with control in melon juice processing and non-significant difference was recorded in TSS of the juice. Brix of control, ultrasonic treated and ultrahigh temperature treated melon juice was found 8.53, 8.47 and 9.60, respectively. Synergism of ultrasonics and microwave as reported by Zia et al. (2019) exhibited no change effect on TSS of the sugarcane juice samples, when compared to individual microwave, sonication and untreated treatments.

Mukhtar et al. (2022) used ultrasonic waves at 15 min, 40 kHz and 240 W for sugarcane juice processing and observed slight increase in TSS, total sugars and reducing sugars. Further they explained this increase linked with greater extraction ability of ultrasounds due to which conversion of disaccharides to monosaccharides may have taken place. In a study conducted on sugarcane juice, microwave heating of sugarcane juice enhanced the shelf life up to 56 days and also caused significant increase in TSS (106.5%) at 700 W, which was found associated with loss of moisture through evaporation. Thermosonication at 30 60 and 80 °C also caused significant increase in TSS of sugarcane juice as compared to untreated and conventionally heat-treated juice samples, but in microwave heating at higher temperature and powers the TSS were recorded much higher than ultrasound treated samples (Adulvitayakorn et al., 2020). These results can be corelated to the present study outcomes as microwave parameters were constant for all treatments and sonication was applied for three different time periods and TSS remained unchanged, which concluded that sonication time did not affect TSS.

Yikmis (2020) compared unprocessed melon juice of red and yellow varieties, with pasteurized and ultrasonicated and observed non-significant results for total soluble solids of the juice, providing similar findings as has been reported in current study. Similar findings were also present in the experiments of Bora et al. (2017) as sonication time had non-significant effect on TSS of banana juice. Nadeem et al. (2018) applied ultrasound on carrot-grape blend. They noticed that total soluble solids increased slightly, with the increase in sonication time. The control sample was found to have total soluble solids of 12.5±0.1. TSS increased with sonication time from 12.7±0.1 to 13.0±0, which might be due to different parameters applied by them as compared to ours, as in current study synergism of sonication and microwave have provided different results. The TSS in the carrot-grape blend decreased with an increase in the storage period from 12.7±0.1 to 10.8±0.1 °B, just as has been found in present study results. Reduction in TSS during storage time was possibly due to the fermentation of sugars into the water, ethyl

Table 4
The effects of microwave heating and sonication time treatment and storage time on the TSS (Brix) of muskmelon and sugarcane juice blend.

Treatments	Days			
	0	30	60	90
T_0	12.00±0.20a	6.20±0.10 g	5.37±0.15 h	4.47±0.15i
T_1	12.00±0.10a	10.60±0.44d	9.80±0.10ef	9.37±0.25f
T_2	12.00±0.30a	11.77±0.15ab	10.77±0.15 cd	10.33±0.15de
T_3	12.00±0.40a	12.30±0.10a	11.70±0.10ab	11.30±0.10bc

alcohol, and carbon dioxide. Bhat and Sharma (2016), sonicated bottle gourd juice at 70% amplitude for 20 min and observed maximum TSS, validating the use of ultrasound waves at 70% amplitude as applied in current investigations.

Malik et al. (2022) studied the impact of microwave treatments and storage on TSS of lemon cordial and observed similar results as decrease in TSS was significant during storage periods, both in control and microwave treated samples, while there was slight increase in TSS of microwaved cordial samples as compared to untreated samples before storage for longer period of time. They linked this increase in TSS due to microwave treatment with increase in internal temperature of treated samples resulting in evaporation of water. During storage of both treated and untreated juices, conversion of sugars into their respective acids and alcohols by yeast and lactic acid bacteria cause decrease in TSS of juices. Whereas, this decrease in TSS was highly decreasing in untreated control blend juice, which was due to greater microbial activities, which were significantly controlled by synergism of microwave and sonication (Zia et al., 2019), as applied in present research.

The small letter used in the table is to indicate a significant difference between samples by column (effect of treatment) or by row (effect of storage time), T_0 = Muskmelon-sugarcane juice blend (no technique), T_1 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 5 min ultrasound treatment, T_2 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 10 min ultrasound treatment, T_3 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 15 min ultrasound treatment.

3.2. Phytochemical analysis

3.2.1. Total phenolic contents

Statistical analysis revealed a highly significant effect of thermosonication and microwave on total phenolic contents of muskmelon-sugarcane juice blend treatments, as depicted in Table 5. The highest TPC were calculated in T_3, while the minimum was recorded in T_0. TPC of untreated samples were decreased significantly during storage, whereas application of sonication lowered down this decreasing trend of TPC during storage, with maximum retention in samples treated with 15 min ultrasound as can be seen from Table 5.

Ultrasound and microwave known as green processing techniques for juices have become a study consideration in the field of different processing patterns to preserve functional constituents of the juices. The combined technologies have been proved effective in optimum retention of total phenolic contents of juices (Farmani, Mohammadkhani, & Andabjadid, 2023). Phenolic compounds are secondary metabolites in plants known to play an important role in color and flavour development, antioxidant and antimicrobial activities in fruit juices (Rawson et al., 2011).

Pulela et al. (2022) provided total phenolic contents of different melon varieties during different post-harvest storage duration and observed that during storage without any processing, total phenolic contents were decreased significantly, acknowledging the current findings as maximum reduction of TPC in untreated samples was occurred. Yikmis (2020) compared TPC of control, pasteurized and ultrasonic treated lemon juices red and yellow varieties, and significant reduction in total phenolic contents of pasteurized juice samples was noticed as compared to control juice samples, whereas sonicated juice samples exhibited results closer to current findings as sonication for 16 min resulted increase in TPC to 101.86 mg GAE/L from 97.39 mg GAE/L (sonication for 4 min). Demirok and Yıkmış (2022) provided similar findings for TPC of tangerine juice samples treated with ultrasound and microwave power, as these processing technologies proved helpful in reducing loss of phenolics. Patel et al. (2023) observed maximum improvement in TPC of jaggery processed at 700 W for 60 *sec* by microwaves, during storage days, strengthening the fact of positive impacts of microwaves on fruit products.

In a similar fashion study earlier, Golmohamadi et al. (2013) investigated the impact of ultrasonic frequency on red raspberry puree's antioxidant activity, total phenolic content, and anthocyanin content. Their findings were consistent with recent findings, as they showed that TPC for 20 kHz increased by 9.5% after 30 min compared to the control. After 10 min, the anthocyanin concentration and antioxidant activity at 20 kHz increased by 17.3% and 12.6%, respectively. In comparison to 490 and 986 kHz, it was shown that 20 kHz ultrasound therapy, limited to 10 min, was the most effective for extracting bioactive chemicals from red raspberry. However, the result may be similar at higher frequencies if various amplitudes are utilized.

Bhat et al. (2011) sonicated kasturi lime for 30 and 60 mins, and he also found similar results that the total phenolic content increased with the sonication treatment time from 263.08±to 336.0±1.3 mg GAE/g. The reason could be the addition of OH– radical in the aromatic ring of phenolic compound. The collapse of cell walls, which releases bound phenolic substances, may also be the cause of the rise. Fresh watermelon juice had a total phenolic content of 13.89 mg GAE/100 mL as provided in the experiments by Rawson et al. (2011). During the analysis of synergistic effect of thermosonication, for shorter processing intervals of 0 to 6 min, total phenolic content was not significantly impacted; however, at longer processing times of 10 min, total phenolic content significantly degraded as compared to the unprocessed sample. The levels of total phenolic content were significantly influenced by temperature; from 25 to 45 °C, as phenolic content was shown to decrease.

Liu *et el.* (2023) identified total 34 volatile components in ultrasonic treated melon juice and the composition of these volatile components were consistent with those present in control juice samples, which explored that sonication did not have any negative effect on juices quality. While there was no flavor change effect of ultrasonic treated juice as compared to control juice, as changes in phenolics and flavonoids may cause changes in flavor. On the other hand, they detected newly generated volatile components in ultrahigh temperature treated melon juices, which possibly would cause off flavor, a drawback for thermal treatments. Wang et al. (2019) reported 108.65% increase in total phenolic contents of kiwifruit juice processed with high intensity ultrasound (16 min, 400 W and 25 kHz) as compared to control group. Results similar to ours were also discovered when the total phenolic content in fruit and vegetable juices treated with ultrasound increased immediately following the treatment compared to the control but marginally decreased in all samples after 10 weeks of storage (Khandpur & Gogate, 2015).

Rodriguez-Rico et al. (2022) observed reduction in total phenolic contents of melon juice treated with ultrasound waves with longer time periods as compared to those treated for short period of times. Degradation of total phenolic contents as a result of high intensity ultrasound treatment has been linked with production of free radicals, extended exposition of unbound polyphenols, release of bound phenolic compounds due to cell disruption. Further they observed increase in gallic acid and syringic acid contents of thermosonicated juice samples as compared to non-treated juice samples. Aydar (2020) investigated the impact of microwave power level (180, 450, and 800 W) and ultrasonic

Table 5
The effects of microwave heating and sonication time treatment and storage time on the total phenolic contents (mg GAE/100 mL) of muskmelon and sugarcane juice blend.

Treatments	Days			
	0	30	60	90
T_0	397.67 ±8.08d-f	370.33 ±11.59 fg	333.33 ±18.23gh	320.00±8.54 h
T_1	468.67 ±21.73ab	378.33 ±9.07e-g	343.00 ±5.29gh	330.67 ±5.51gh
T_2	495.33 ±9.50a	445.33 ±47.86a-d	403.00 ±13.11d-f	395.67 ±17.39d-f
T_3	484.33 ±10.41a	459.67 ±8.33a-c	427.00 ±11.53b-e	410.67 ±5.13c-f

pretreatment time (5 and 10 min; 32 kHz) on the drying and rehydration kinetics of green olives. The total drying time of green olives was shortened by 42.5% by increasing the microwave level and ultrasonic time. Olive slices' TPC decreased while drying in all treatments, however it was substantially higher in ultrasonic-pretreated samples than in untreated ones dried in the same microwave. Results of current study found close relation with the earlier investigations by Adulvitayakorn et al. (2020), when thermosonication of sugarcane juice decreased TPC significantly, with increasing the temperature from 30 to 80 °C similarly microwave heating at higher powers also exhibited similar trend. The effect of the low temperature microwave mixed with the cavitation effect of sonication, which caused the breakdown of macromolecules and released the bound form of the phenolic contents, may have contributed to the increase in TPC in T_1 and T_2. Sonication has the capacity to generate hydroxyl groups, which can be added to the aromatic ring of phenolic compounds to raise the TPC, claim Aadil et al. (2013).

Luo et al. (2022) used glucose oxidase to preserve aromatic and volatile components of melon juice and observed reduced contents of off odor compounds in melon juice treated with glucose oxidase as compared to thermal processing, witnessing the use of non-thermal treatments, helpful than thermal ones for juices treatment. Pang et al. (2019) used two compatible extraction methods jointly to capture volatile bioactives from muskmelon juice and found many heat-induced odorants from the muskmelon juice, which exhibited extremely low odor threshold and unpleasant smells, a potential drawback of conventional heat treatments of juices, which can be prevented by use of green processing techniques. De Medeiros, Sarkis, Jaeschke, and Mercali (2021) observed lower degradation of phenolic compounds of sugarcane juice samples stored under refrigerator conditions treated with different ultrasound powers.

Sugarcane juice have been found rich in phenolics and flavonoids, which have been reported as natural antioxidants capable of scavenging free radicals. Adulvitayakorn et al. (2020) analyzed sugarcane juice samples treated with different processing techniques and observed significant increase in TPC of thermosonicated juice samples at lower temperatures, whereas microwave heating at lower powers caused decrease while high power and high temperature microwave heating also caused increase in TPC, similarly conventional heat treatments also resulted increase in TPC of juice samples. Ferulic acid was found dominant phenolic acid in sugarcane juice samples, which is found naturally bound with hemicellulose and lignin of sugarcane juice, and high powers of microwave and thermosonication might have caused the release of ferulic acid. Mukhtar et al. (2022) observed significant increase in TPC of sugarcane juice samples preserved by ultrasound treatments at 15 min, 40 kHz and 240 W power. This increase in TPC may be a result of phenolic liberation from cell wall particles that remained in the non-filtered juice. In conclusion, US treatment is an efficient way to enhance the nutritional value of sugarcane juice.

Numerous studies have also shown that increasing the ultrasonic power improved the efficacy of extracting sugars, organic acids, and phenolic compounds. Because there is more contact between the solute and the solvent due to the mechanical action of ultrasound, the solute particles diffuse easily in the water. Additionally, it was found that prolonged ultrasonic treatment lasting more than 15 min with an ultrasonic power of at least 100 W reduced the ascorbic acid and phenolic content while only slightly degrading the sensory attributes. The quality and sensory qualities are based on very sensitive chemicals, which are significantly impacted when exposed to hostile environments such cavitating circumstances, which can be the cause of the observed trends (Khandpur & Gogate, 2015).

The small letter used in the table is to indicate a significant difference between samples by column (effect of treatment) or by row (effect of storage time), T_0 = Muskmelon-sugarcane juice blend (no technique), T_1 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 5 min ultrasound treatment, T_2 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 10 min ultrasound treatment, T_3 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 15 min ultrasound treatment.

3.2.2. *Total flavonoids contents*

The synergistic effect of microwave and sonication treatment on the total flavonoids content of muskmelon-sugarcane juice blend is discussed in detail in Table 6. The total flavonoid content of the muskmelon-sugarcane juice blend different treatments ranged from 83.15±4.42 to 192.28±2.98 mg CE/100 mL. At the start of experiments, highest flavonoid content was calculated in T_3 was 261.73±11.32 mg CE/100 mL, followed by T_2 that was 193.83±9.33 mg CE/100 mL, while the minimum flavonoids content was observed in T_0 that was 131.36 ±13.01 mg CE/100 mL. The flavonoid contents decreased significantly during the storage of 90 days, and decrease was high in untreated samples, whereas synergism of microwaves and sonication for 15 min caused maximum retention of flavonoids.

Abid et al. (2013) studied the impact of sonication on apple juice. Their results demonstrated that the flavonoid content increased with the sonication time. The control sample had a flavonoid content of 466.82 ±4.55 μg/g. They sonicated the juice for 30, 60 and 90 min and found TF of 486.52±2.62, 600.15±2.62, and 607.73±4.55 μg/g, respectively. The study revealed that the bioactive compound also increases with the increase in sonication time. Demirok and Yıkmış (2022) used microwave and ultrasound treatments to process and preserve tangerine juice samples and provided similar results for TFC. Patel et al. (2023) observed maximum improvement in TFC of jaggery, a traditional nutritional product made from sugarcane juice, treated with microwaves at 700 W for 60 *sec*.

Pulela et al. (2022) evaluated total flavonoid contents of different melon varieties during postharvest storage and observed decrease in total flavonoid contents during normal storage conditions. Yikmis (2020) prepared lemon juice of red and yellow varieties and treated these juice samples with pasteurization and sonication to compare with non-processed samples. Results revealed that pasteurization caused significant reduction in total flavonoid contents of juice samples whereas, sonication provided values of total flavonoid contents similar to those present in control juice samples, whereas increase in sonication time from 4 to 8, 12 and then 16 min caused increase in TFC, as has been reported in our results. Sonication treatments (25 kHz, 20 °C and 30 min), showed significant enhancement in bioactive compounds especially phenolics and flavonoids of strawberry juice, as reported earlier by (Bhat & Goh, 2017), has been found strongly corelated with current findings.

Wang et al. (2019) reported 105.56% increase in total flavonoid contents of kiwifruit juice processed with high intensity ultrasound (16 min, 400 W and 25 kHz) as compared to control group. Mukhtar et al. (2022) observed significant increase in TFC of sugarcane juice samples preserved by ultrasound treatments at 15 min, 40 kHz and 240 W power. Malik et al. (2022) treated lemon cordial with microwave processing at 60, 90 and 120 *sec* to compare their TFC with untreated samples and chemical based preserved samples. They recorded a gradual decrease in

Table 6
The effects of microwave heating and sonication time treatment and storage time on the total flavonoid contents (mg CE/100 mL) of muskmelon and sugarcane juice blend.

Treatments	Days			
	0	30	60	90
T_0	131.36 ±13.01e	97.53±5.66f	62.96±3.70gf	40.74±3.70 h
T_1	171.51±7.71 cd	133.33±3.70e	100.00±3.70f	80.25±5.66 fg
T_2	193.83 ±9.33bc	170.37±3.70 cd	130.86±7.71e	95.06±5.56f
T_3	261.73 ±11.32a	206.17±7.71b	166.67 ±13.35d	134.57 ±7.71e

TFC of cordial samples during 30, 60 and 90 days of storage, while TFC contents in microwave treated samples were higher than in control. The sonication parameters used in the present study were also supported by an earlier study by Khandpur and Gogate (2015), which investigated the use of ultrasound sterilization parameters maintained at ultrasound frequency of 20 kHz and power of 100 W with treatment time of 15 min for ultrasound processed juice retained most of the nutrient components to a greater extent than pasteurization and ultraviolet irradiations. Sonication at 70% amplitude for 20 min has been found involved in retaining maximum TPC of bottle gourd juice was reported earlier by Bhat and Sharma (2016).

Sugarcane juice has been found a good source of total flavonoid contents. Flavonoids in sugarcane juice aid the body's defense mechanisms against cancerous cells, particularly those that cause breast and prostate cancer. Alkaline environments aid in preserving the body's electrolyte equilibrium. It has benefits on our bodies that are anti-allergic, hepatoprotective, anti-inflammatory, and cardioprotective (Mukhtar et al., 2022). In a study conducted by De Medeiros et al. (2021) higher retention of TFC in ultrasonic treated sugarcane juice samples was observed during 36 days of refrigerator storage, which was attributed as a result of inactivation of peroxidase enzyme.

The TPC and TFC of mix juice that had undergone 15 min of ultrasound treatment were higher than those attained by juice that had undergone 5 min of heat pasteurization during the 90 days of storage. The outcomes demonstrated that the total phenolic, flavonoid, and antioxidant levels of blend juices were maintained throughout storage by applying ultrasound therapy for 10 and 15 min. Whereas, the inclined decrement in polyphenols during 90 days of storge of all treated juices could be due to effect of ultrasonic waves on structure of phenolics, residual activity of polyphenol oxidase and peroxidase and deterioration in the quality of fruits due to browning (Khandpur & Gogate, 2015; Odriozola-Serrano et al., 2008)).

The small letter used in the table is to indicate a significant difference between samples by column (effect of treatment) or by row (effect of storage time), T_0 = Muskmelon-sugarcane juice blend (no technique), T_1 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 5 min ultrasound treatment, T_2 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 10 min ultrasound treatment, T_3 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 15 min ultrasound treatment.

3.2.3. Total antioxidant capacity

Data presented in Table 7 showed the effect of microwave and thermosonication on the total antioxidant activity of muskmelon-sugarcane juice blend, that the maximum retention of antioxidant activity was observed in T_3 even after 90 days of storage, when compared to untreated samples, and the lowest antioxidant activity was calculated in T_0, which was also significantly decreased during 90 days storage. From Table 7 it was also clear that during synergism of microwaves and ultrasounds as the time of sonication was increased from 5 to 15 min, there was a significant rise in the antioxidant activity of blend juice.

Table 7
The effects of microwave heating and sonication time treatment and storage time on the total antioxidant capacity (mg ascorbic acid equivalent/100 mL) of muskmelon and sugarcane juice blend.

Treatments	Days			
	0	30	60	90
T_0	150.99 ±22.99f	133.87±8.26 fg	106.85±8.26 fg	95.14±27.43 g
T_1	215.86 ±17.58e	160.00 ±10.81f	134.77 ±21.68 fg	110.45 ±16.51 fg
T_2	281.62 ±21.45 cd	228.47 ±34.55de	143.78±2.70 fg	131.16 ±12.77 fg
T_3	381.62 ±17.72a	345.59 ±6.80ab	327.57 ±9.74bc	288.83 ±13.60c

Due to their link to health benefits against a range of oxidative stress-related disorders, dietary antioxidants' role has attracted more attention. Obtaining healthier and safer food products is made possible by the development of revolutionary thermal and nonthermal food processing methods. In order to accomplish these objectives, it has been discovered that high pressure processing, pulsed electric field, and ultrasound are suitable non-thermal processing methods, and ohmic, microwave, and infrared heating are useful thermal processing methods. Use of sonication as non-thermal processing was found effective technique in retaining maximum antioxidant compounds in natural fruits and their uses (Ozkan, Guldiken, & Capanoglu, 2019). The study of green processing technologies (microwave and ultrasound) has gained attraction in the industry of processing various juices. The integrated technologies manifest their effects through chemical (free radicals) and mechanical (cavitation and shock waves) methods. When processing juices, using ultrasound and microwaves together produces better outcomes because juices have stronger antioxidant capabilities and retain more bioactive chemicals (Farmani et al., 2023).

Yikmis (2020) prepared lemon juice of red and yellow varieties and treated these juice samples with pasteurization and sonication, to compare their DPPH free radical scavenging activities, and from results it was obvious that sonicated juice samples presented significantly higher antioxidant activities as compared to fresh non-treated and pasteurized juice samples. On the other hand, pasteurized juice samples of both varieties presented significantly lower antioxidant activities as compared to control and sonicated juice samples. These improvements in overall antioxidant capacity are explained by the rise in phenolic and flavonoid compounds linked to cavitation in processed fruit juices following prolonged ultrasound exposure, as have been investigated in current experiments. Demirok and Yıkmış (2022) used microwave and ultrasound treatments to process and preserve tangerine juice samples and provided similar results for antioxidant activities. Supporting the findings of current work for decrement of nutritional potential of blend juices during storage, in a similar study, antioxidant capacity of untreated, pasteurized and high intensity pulsed electric filed processed juices was reported in decreasing trend during storage, following a first order kinetics (Odriozola-Serrano et al., 2008).

Superiority shifts, according to research done on freshly made hand-pressed strawberry juice, prolonged (30 min.) sonication treatments greatly increased the release of specific bioactive components, increasing the juice's antioxidant activity (Bhat & Goh, 2017), as in current study increasing the sonication time has provided similar results. Nayak, Chandrasekar, and Kesavan (2018) applied thermosonication on star fruit juice. The raw juice was found to have antioxidants of 37.82±1.42%, and then thermosonication was done for 15, 30, 45, and 60 min, and he found that the total antioxidant activity significantly increased 38.25±2.18, 40.15±1.58, 53.30±1.78, and 64.11±1.97%. The reason was that with the increase of temperature, the phenolic compound was increased due to the cavitation effect that increased the antioxidant activity.

Suo et al. (2022) took freshly squeezed pumpkin juice and sonicated at various power levels keeping same frequency (25 kHz) for treatment time of 10 min and upon analysis results revealed that ultrasonic treatment had little effect on carotenoids and other antioxidants during storage of juice, as compared to untreated juice samples. The fact that ultrasonic facilitates the release of chemicals from cell matrix can be used to explain why there is a rise in antioxidant activity when it is applied. In addition, it possibly inactivates enzymes such polyphenol oxidases to lessen enzymatic browning. Additionally, a positive correlation between polyphenols including phenolics and flavonoids and antioxidant capacity of ultrasonically treated blend juice samples strengthens current outcomes (Khandpur & Gogate, 2015).

Wang et al. (2019) reported 65.67% increase in total antioxidant activity of kiwifruit juice processed with high intensity ultrasound (16 min, 400 W and 25 kHz), as compared to control group. They reported that high intensity ultrasonic treatment of fruit juices has high potential of increasing bioactive components of fresh juices, which have been found due to the changes in microstructures of the juice components as a result of ultrasonic processing. Supportive results were also present in the findings of Bhat and Sharma (2016), when sonication at 70% amplitude for 20 min exhibited highest antioxidant activity of bottle gourd juice.

Rodriguez-Rico et al. (2022) reported that total antioxidant capacity of melon juice was enhanced due to sonication treatment. In control juice samples DPPH free radical scavenging activity was found 29%, which was increased to 46% in sonication treated juice samples. Researchers have attributed the increase of antioxidant capacity to the addition of a second hydroxyl group to the ortho- or *para*-positions to the aromatic ring of phenolic compounds during sonochemical reactions. Further, increase in individual phenolic compounds and their possible interaction with carotenoids have been found related to increase in free radical scavenging activities of the sonicated melon juices. Because of the mechanical effects of cavitations and bubble implosions during sonication, the increased antioxidant capacity of fruit juices as a result of ultrasonic treatments may be attributed to the enhanced extraction of antioxidant compounds (ascorbic acids and phenolic compounds) in the product (Abid et al., 2013, 2015; Bhat et al., 2011).

Adulvitayakorn et al. (2020) calculated total antioxidant activity (% inhibition) of sugarcane juice samples treated with processing techniques. Antioxidant activity of untreated juice samples was 20.37%, which was raised to 21.30 in conventional heat-treated juice samples, and microwave heating caused increase in antioxidant activity up to 24.03%. On the other hand, thermosonication at 30 °C caused highly significant increase in total antioxidant activity and value was recorded 34.71%. Increase in antioxidant compounds especially phenolics and flavonoids, and lesser loss of vitamin C during thermosonication might be the reason of high total antioxidant activity of sugarcane juice samples. When it came to keeping the sugarcane juice color characteristics, total phenolic and flavonoid content, ascorbic acid concentration, and antioxidant capabilities during storage, synergism of both treatments outperformed as compared to individual ultrasonics or microwaves, was reported earlier by Zia et al. (2019).

Malik et al. (2022) investigated the effect of microwave treatments and storage on total antioxidant activity of lemon cordial samples and noted an increasing trend of antioxidant activity of samples as result of microwave treatments for longer time periods, whereas in control sample this antioxidant activity was recorded significantly low. On the other hand, they observed a significant decrease in antioxidant activity of both untreated and microwave treated lemon cordial samples during storage periods. Inhibition of oxidation promoting enzymes and greater extraction of antioxidant compounds from product under treatment were the major reasons behind the increased antioxidant activity of microwave treated juice samples.

The small letter used in the table is to indicate a significant difference between samples by column (effect of treatment) or by row (effect of storage time), T_0 = Muskmelon-sugarcane juice blend (no technique), T_1 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 5 min ultrasound treatment, T_2 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 10 min ultrasound treatment, T_3 = muskmelon-sugarcane juice blend with microwave at 90 °C for 120 *sec* and 15 min ultrasound treatment.

4. Conclusion

Muskmelon could also be processed for squash preparation and many other value-added products as it is a nutritious fruit, and sugarcane can be processed as a beverage. These can be processed and preserved by different preservation techniques, like thermosonication and ultrasound waves application, as these techniques enhances physicochemical attributes and sensory properties of the muskmelon-sugarcane juice blend. Thermosonication is an innovative technique for extending the shelf stability of muskmelon-sugarcane juice blend and other value-added products. T_3 treatment (15 min of sonication and 120 of microwave) produced superior physicochemical properties and antioxidant capacity outcomes. Microwave and thermo-sonication should be used at both the laboratory and industrial scales to alternative chemical preservatives and thermal treatments because of their cost efficiency and simplicity of processing. Further, it produces minimally processed foods with great shelf life and nutritive quality.

In conclusion, in terms of the types of natural bioactive components in muskmelon juice, ultrasound had a good retention effect on total phenolic and total flavonoid contents, and the enhancement effect on the antioxidant capacity of melon juice was better than that of high temperature treatment. This provided more useful information for muskmelon juice flavor enhancement technology and non-thermal processing methods. The targeted foodstuffs' physical, chemical, and technological features were enhanced by the ultrasound method, which also lengthened their shelf life without significantly affecting their nutritional value. The key benefits of ultrasound use include reduced energy and solvent consumption, simple operation, and little to no emission during ultrasound processing.

5. Recommendations

Ultrasound is a green technology that has numerous potentials uses in the food industry. Ultrasound devices will be widely used in the food business due to the growing interest in employing green and energy-efficient methods. Numerous food applications, including extraction, emulsification, gelation, tenderization, microbial and enzyme inactivation, modification of the structural and functional properties of biological macromolecules, freezing, cooking, foaming, food waste valorization, and others, can benefit from the use of ultrasound. There is still an impending need for development in hygienic and working conditions of fresh fruit stalls, since the juices seem to have high microbial load, which may pose a major health threat to consumers. New applications are needed to develop, preserve and store these fresh juices for their safe and healthy consumption. When the results are examined, it is clear that ultrasonic therapy is beneficial to the consumer's health since it encourages an overall improvement in terms of consumer enjoyment and bioactive properties. To build models like surface response methodology and to optimize process variables during ultrasound operations, new research is required. It is also advised to look into combining ultrasound technology with other non-thermal food processing techniques to enhance the quality of fresh juice samples and juice samples that have been preserved.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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