



Effect of packaging materials and storage temperature on the physicochemical and microbial properties of ultrasonicated mature coconut water during storage

Anjitha Jacob^a, I.P. Sudagar^{b,*}, R. Pandiselvam^{c,*}, P. Rajkumar^b, M. Rajavel^d

^a Department of Food Process Engineering, Agricultural Engineering Collage and Research Institute, Tamil Nadu Agricultural University, Coimbatore, 641 003, India

^b Department of Processing and Food Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, 621712, Tiruchirappalli District, Tamil Nadu, India

^c Physiology, Biochemistry and Post-Harvest Technology Division, ICAR-Central Plantation Crops Research Institute, Kasaragod, 671 124, Kerala, India

^d Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, 641 003, Tamil Nadu, India

ARTICLE INFO

Keywords:

Preservation

Non-thermal technology

Beverage

Refrigerated storage

Reducing sugar

ABSTRACT

Preservation and shelf life extension of mature coconut water (MCW) is paramount importance for the production of flavored beverages. The present study aims to evaluate the effects of packaging materials (glass bottles, PET bottles and stand-up pouches) and storage temperatures such as atmospheric ($28 \pm 6^\circ\text{C}$) and cold storage ($5 \pm 1^\circ\text{C}$) temperatures on microbial growth and quality parameters (pH, Total Soluble Solids (TSS), total sugar, reducing sugar, and non-reducing sugar) of ultrasound treated MCW during storage. The results showed that pH, total soluble solids, total sugar, reducing sugar and non-reducing sugars decreased significantly ($p < 0.05$) during storage, irrespective of packaging materials. It was observed that the microbial load increased significantly ($p < 0.05$) during storage of ultrasonicated samples and control samples. The present study concluded that ultrasonication of MCW at 60% amplitude for 10 min treatment time increased their shelf life up to 12 days under cold storage condition ($5 \pm 2^\circ\text{C}$) with a safe limit of microbial load and maximum retention of nutrients. Even though all the packaging materials were found to be statistically on par ($p > 0.05$) in maintaining quality parameters and microbial load, glass bottles were observed to be most effective packaging followed by PET bottles and stand-up pouches.

1. Introduction

Coconut water (CW) is gaining popularity in the international market as a rehydrating drink with numerous nutritional and medicinal properties (Prithviraj et al., 2021). Compared to tender coconut water or young coconut water, mature coconut water (MCW) has loaded with higher proteins and organic ions, such as calcium, potassium, magnesium and phosphorous (Tan et al., 2014). During ripening, coconut water's flavor degrades due to decrease in water content and an increase in crude fat content (Zhang et al., 2018). For commercialising coconut water as a ready-to-drink beverage, manufacturers investigate and apply various treatments, such as thermal sterilisation, pasteurisation, filtration, and addition of additives in various combinations (Tan & Easa, 2021; Prades et al., 2012). Nevertheless, the proper handling and transportation of coconut water are of utmost importance, as air

exposure can accelerate rancidity, cloudiness, and discoloration caused by enzymes (Pandiselvam et al., 2022; Prithviraj et al., 2022).

Therefore, appropriate treatment is necessary for inactivating enzymes and spoilage microorganisms, as well as proper management and protocol during the processing and storage of coconut water. The canned coconut water that is available on the market is thermally treated at high temperatures for a short period. Although food commodities are subject to strict practices and thermal processing for ensuring their safety, consumer acceptance is low, especially when considering nutritional quality and natural flavors (Khandpur & Gogate, 2016). Consequently, proper processing method is necessary to ensure a product that is stable without altering its taste or nutritional value (Preetha et al., 2021).

In contrast to thermal treatments, non-thermal treatments provide food with the desired stability and microbial safety with minimum impact on sensory and nutritional properties. The emerging non-thermal

* Corresponding author.

** Corresponding author.

E-mail addresses: ips7@tnau.ac.in (I.P. Sudagar), r.pandiselvam@icar.gov.in, anbupandi1989@yahoo.co.in (R. Pandiselvam).

treatments such as cold plasma, ozone, ultrasound, high-pressure processing (HPP), and pulsed light have a less detrimental and/or no effect on the main components of the food matrix after processing in terms of sensor, flavor, and nutritional characteristics (Kaavya et al., 2021; Sruthi et al., 2022).

Ultrasound is one of the cutting-edge non-thermal techniques that has been generally used to improve food processing and fruit juice quality (Rahaman et al., 2019). The acoustic cavitation phenomenon is responsible for microbial destruction in ultrasonication (Aslam et al., 2022; Kutlu et al., 2022). There is a series of compressions created by ultrasound propagation in the medium. It would result in cavitation bubbles if the energy reached a certain point where rarefaction exceeds the attraction between molecules (Cheng et al., 2015). A violent collapse of unstable bubbles can destroy microorganisms and polymer chains. Tomadoni et al. (2016) reported that ultrasound treatment (at 40 kHz for 10 and 30 min) prevented sensory deterioration and extended the shelf-life of strawberry juice. In addition to retaining beneficial nutrients, ultrasonication can reduce microbial load while preserving taste and quality (Zou & Jiang, 2016).

The nutritional quality and shelf life of CW depend upon the storage conditions, packaging materials used and type of preservation treatment (Naik et al., 2022; Prithviraj et al., 2021). Packages play an important role since they protect food from chemical and physical damage, provide nutritional information, and inform the consumer of how to use the products (Anin et al., 2010). The quality of the stored food products is altered differently by various packing materials. It is, therefore, crucial to study the impact of packaging materials on quality parameters during storage.

To the best of our knowledge, this work is the first to investigate the individual and interactive effect of different packaging materials, storage temperature and ultrasonication treatment on the quality of MCW during storage. The purpose of the study was to examine the impact of three different packaging material and two type of storage temperature on the nutritional quality and microbial stability of ultrasonicated MCW during storage.

2. Materials and methods

2.1. MCW

The 12 months matured coconut (West Coast Tall variety) was obtained from coconut nursery, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, India. The surface of the mature coconut was cleaned with distilled water to minimize cross-contamination and then dried at room temperature. The coconut was split open with a sterilized stainless steel cutting tool, in a sterile environment maintained in an inside laminar flow chamber using autoclaved utensils to reduce risks of contamination and then the coconut water was extracted and filtered using a muslin cloth. The filtered coconut water was stored in a sterilized glass bottle kept temporary in an icebox stuffed with ice packs. The mature coconut water prepared was ultrasonicated on the same day of purchase and extraction.

2.2. Ultrasound treatment

A 1500 W ultrasonic processor (VCX1500, Sonics and Materials INC. 53 Church Hill RD. Newtown, CT. USA) at a frequency of 20 kHz was used to process MCW (80 ml) kept in a sterile glass beaker using a 25 mm ultrasonic probe. The probe was sanitized thoroughly before each run. The temperature of the sample was set at 28 °C and was monitored with a temperature sensor by submerging the glass beaker containing samples in an ice bath during the ultrasonication process. The MCW samples were treated for a treatment time of 10 min at amplitude of 60% (optimized in the preliminary study) with a pulse cycle of 5 s on and 5 s off. The control group consisted of untreated samples.

2.3. Total soluble solid and pH measurement

The TSS content of matured coconut water samples as °Brix was determined by using ERMA hand refractometer which had a range of 0–32 °Brix (Dubois et al., 1956). The pH of the samples was measured by using a digital pH meter (Digisun Electronics System, Model 2001).

2.4. Total sugar, reducing sugar and non-reducing sugar analyses

The estimation of total sugars (reducing and non-reducing) in the treated samples was done by the phenol sulphuric acid method described by Dubois (1956). The reducing sugar content of ultrasound treated and untreated matured coconut water was determined as per the Nelson-Somogyi method as described by Ranganna (1986). The non-reducing sugars were calculated using the following formula (Samreen et al., 2020).

$$\text{Non-reducing sugar (\%)} = \text{Total sugar (\%)} - \text{Reducing sugar (\%)}.$$

2.5. Microbial load measurement

Analyses for total plate count were conducted on replicate samples that were stored aseptically in glass bottles, PET bottles, and stand-up pouches after 0, 3, 6, 9, and 12 days of storage at 5 ± 1 °C and 28 ± 6 °C. The microbial load was evaluated by serial dilutions in sterile distilled water with samples taken from both control and ultrasonicated samples. The samples were pour-plated in plate count agar and dishes were incubated at atmospheric storage for 24–48 h to detect microbial load. After the incubation period, the colonies were counted and the number of organisms (total bacteria) per gram of sample was calculated.

2.6. Storage studies

MCW was ultrasonicated with optimized process parameters (60% ultrasound amplitude and 10 min treatment time) (Jacob et al., 2022). It was stored in glass bottles (1.5 mm thickness), PET bottles (0.25 mm thickness), and stand-up pouches (120 µm thickness) from M/S Safire Scientific Company, Coimbatore, India (30 ml in each packaging materials) under two different storage temperatures such as cold storage (5 ± 1 °C and $91 \pm 5\%$ RH) and atmospheric storage (stored at 28 ± 6 °C and $60 \pm 5\%$ RH). Control and sonicated samples were evaluated for the physicochemical and microbial properties on the 0th, 3rd, 6th, 9th and 12th day of storage. The packaging was done in a laminar airflow chamber to avoid any bacterial contamination during the package of samples. All storage studies were reported as means of three replicate measurements.

2.7. Statistical analysis

Data were presented as mean $\pm$ standard deviation, and all experiments were done in triplicate. Shelf life studies were carried out by using a factorial completely randomized design (FCRD) with two factors, including packaging materials (glass bottles, PET bottles and stand-up pouches) and storage days (0, 3, 6, 9, and 12) using the AGRES statistical tool.

3. Results and discussion

3.1. Biochemical profile of fresh MCW

Fresh MCW was collected from the selected mature coconuts and used for preservation studies. The optical, physical, biochemical, and microbial qualities of MCW were determined. A single mature coconut bears approximately 50–250 ml of coconut water. As compared to tender coconuts, mature coconuts contain less water (Pandiselvam et al., 2018). The turbidity value of fresh MCW was found to be 229 NTU. A mean turbidity value of 213 NTU was also obtained by Hosseini et al.

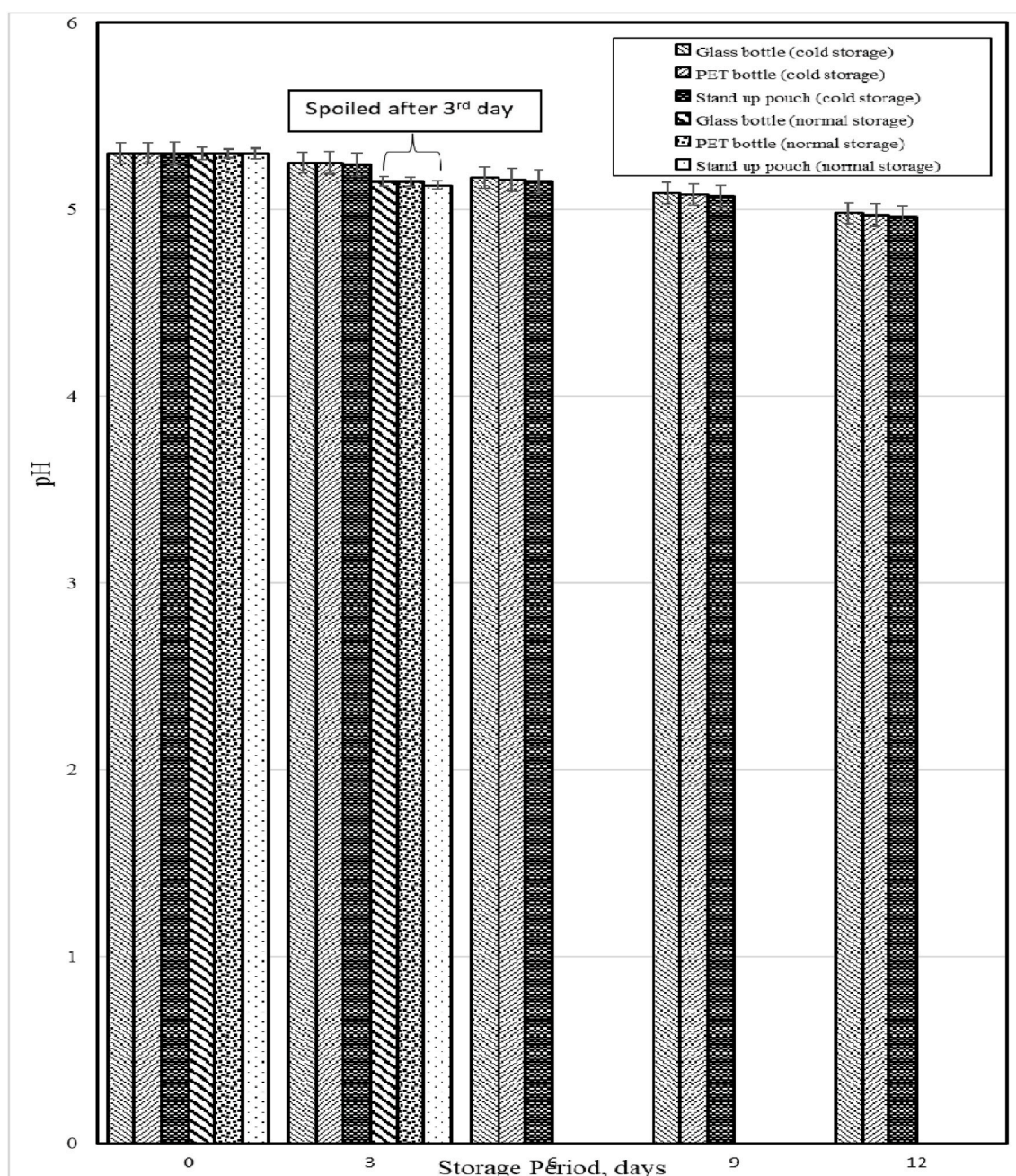


Fig. 1. pH of ultrasonicated MCW during storage under cold and atmospheric storage conditions.

Table 1

Analysis of variance for pH and TSS in ultrasound treated mature coconut water during cold storage period.

Effect	pH			TSS		
	ProbF	C.V. (%)	Significant	ProbF	C.V. (%)	Significant
Packaging material	0.955 ^b		NS	0.236 ^b		NS
Storage	p < 0.01 ^a		**	p < 0.01 ^a		**
Packaging material x Storage	1.000 ^b		NS	0.973 ^b		NS
Residual		2.66%			2.66%	

^aSignificant at p < 0.01.

^bNot Significant at p > 0.05.

(2019). This was due to the presence of suspended or dissolved particles present in MCW. The pH of MCW was 5.3 which are slightly acidic. The pH of the MCW could be useful to judge the consumers' acceptance and spoilage potential. The pH of coconut water can affects its flavor, consistency, and shelf life thereby affecting consumer's preferences. The suitable pH for microbial growth is 3.6–4 (Meng et al., 2001). In order to ensure quality control, mature coconut water should have pH values between 5.3 and 5.8 and TSS values between 3.9 and 5.5 °Brix (BIS 2010; Chan et al., 2016). Total soluble solids (TSS) content and density of MCW were found to be 5.0 °Brix and 1.011 g/cm³ respectively. The TSS value can indicate the sweetness of the coconut water, which affects its taste and flavor (Kusumiyati et al., 2020). It is required by Indian specifications for mature coconut water (BIS 2010) that the total solids (g/100 ml) should be within 3.9–5.5 g/100 ml. Total sugars, reducing sugars, and non-reducing sugars of the fresh sample were measured as 5.12, 2.40, and 2.72%, respectively. The total plate count value of the

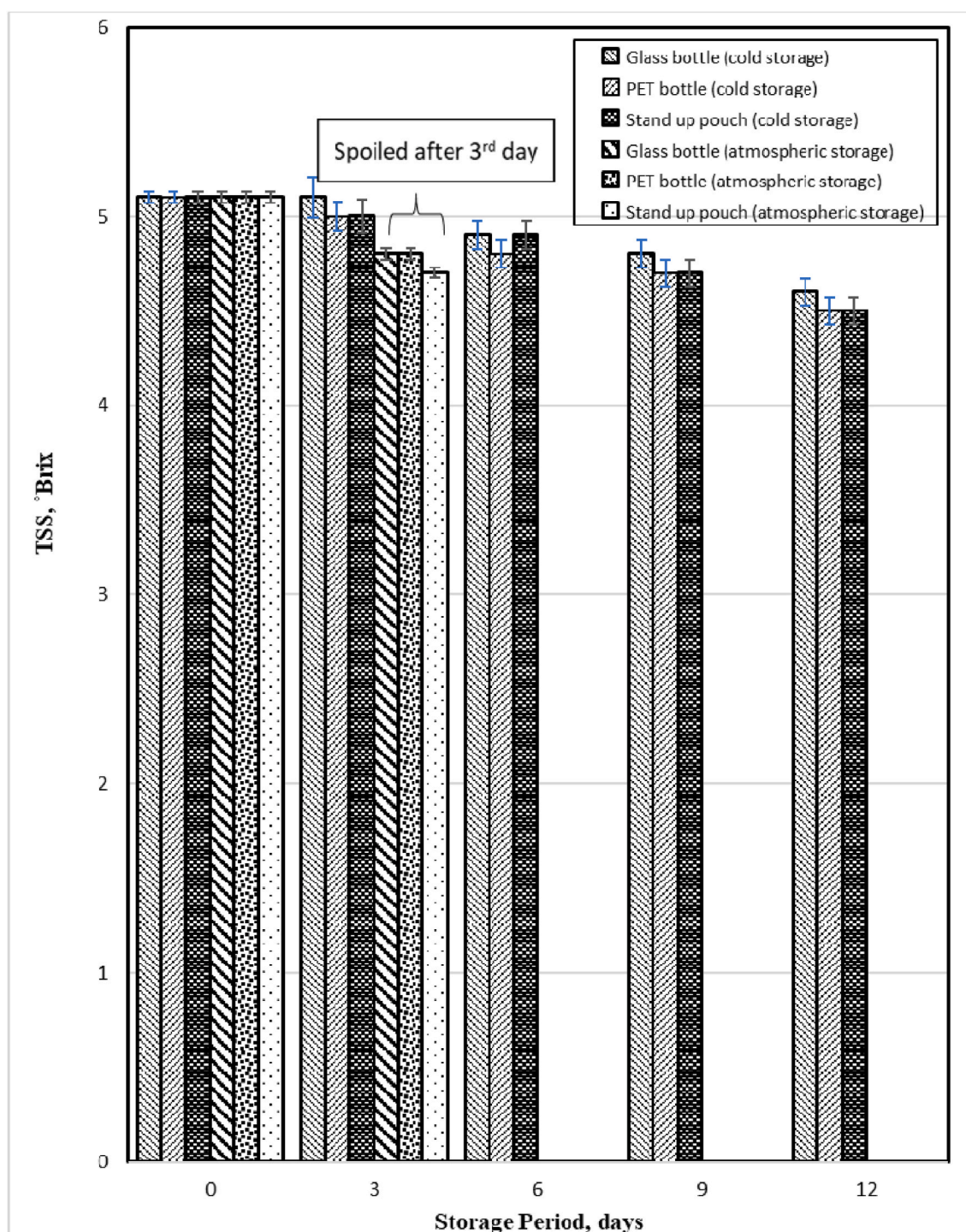


Fig. 2. TSS of ultrasonicated MCW during storage under cold and atmospheric storage conditions.

fresh sample was found to be 6.92 log cfu/ml. According to FSSAI (2019), the acceptable total plate count in fruit juices should be within 6.00 log cfu/ml. Microbial action is one of the major reasons behind the spoilage of coconut water (Iqbal et al., 2015). Based on preliminary studies, we found that the ultrasound treatment for 10 min at 60% amplitude with 5 s pulse and 20 kHz frequency proved to be the best for maintaining initial quality parameters (Jacob et al., 2022).

3.2. Effect of ultrasound treatment, packaging material and storage conditions on physicochemical properties of MCW during storage

3.2.1. pH

The change in pH for MCW with respect to different packaging materials (Glass bottles, PET bottles, and Stand-up pouch) and storage conditions (cold storage and atmospheric storage) was determined and presented in Fig. 1 and Table 1.

The initial pH of the control sample and sonicated MCW, packaged in glass bottles, PET bottles, and the stand-up pouch was 5.3. It was found that the pH of MCW decreased significantly ($p < 0.05$) during the

Table 2

Analysis of variance for total sugar, reducing sugar and non-reducing sugar in ultrasound treated mature coconut water during cold storage period.

Effect	Total sugar			Reducing sugar			Non-reducing sugar		
	ProbF	C.V. (%)	Significant	ProbF	C.V. (%)	Significant	ProbF	C.V. (%)	Significant
Packaging material	0.754 ^b		NS	0.971 ^b		NS	0.690 ^b		NS
Storage	p < 0.01 ^a		**	p < 0.05 ^a		*	p < 0.01 ^a		**
Packaging material x Storage	0.998 ^b		NS	1.000 ^b		NS	0.964 ^b		NS
Residual		2.61%			5.51%			3.98%	

^aSignificant at p < 0.01.^bNot Significant at p > 0.05.**Table 3**

Analysis of variance for total plate count in ultrasound treated mature coconut water during cold storage.

Effect	Total plate count		
	ProbF	C.V. (%)	Significant
Packaging material	0.325 ^b		NS
Storage	p < 0.01 ^a		**
Packaging material x Storage	0.960 ^b		NS
Residual		4.75%	

^aSignificant at p < 0.01.^bNot Significant at p > 0.05.

storage period. The sonicated MCW in glass bottles at cold storage condition showed a minimum reduction in pH from 5.3 to 4.98 from the 0th to 12th day of storage respectively. A percentage loss in pH of 0.94%, 2.45%, 3.96% and 6.04% increased over the intervals of 0–3 days, 0–6 days, 0–9 days and 0–12 days respectively when the treated samples were stored in glass bottles under cold storage. It was found that treated samples at atmospheric storage resulted in pH reductions of 2.83% for both glass and PET bottles, and 3.21% for stand-up pouches within 0–3 days and spoiled. While the control showed a rapid decrease in pH at atmospheric storage within 0–3 days (3.77%, 3.96%, and 4.34% reduction in pH for glass bottles, PET bottles and stand-up pouches, respectively) this makes it undesirable. Variations in physicochemical properties of control sample during storage are given in Table 7.

However, all the packaging materials were found to be statistically on par in maintaining the pH during storage. Revi et al. (2014) also observed there was no significant difference found in the pH of white wine when stored in different packaging materials such as glass bottles, bag with inner layer low density polyethylene and bag with inner layer ethylene vinyl acetate. A reduction of pH must be due to the microbial degradation of carbohydrates resulting in the production of acids during storage (Pandiselvam et al., 2020). Mala et al. (2021) reported that the pH of ultrasonicated (treatment time (2–10 min) and amplitude (30–70%)) pineapple juice was significantly decreased (p < 0.05) during the storage period.

3.2.2. Total soluble solids (TSS)

The change in TSS of MCW during storage is presented in Fig. 2 and Table 1 (for cold storage) and Table 4 (for atmospheric storage). The TSS content of MCW exhibited significant (p < 0.05) reduction during the

storage period. The initial TSS of control and sonicated MCW were 5.1 °Brix. After 12 days of storage, the TSS content of sonicated MCW stored in a glass bottle, PET bottle, and stand-up pouch at cold storage decreased to 4.6, 4.5, and 4.5 °Brix respectively. The TSS of the control sample at cold storage condition reduced from 5.1 °Brix to 4.5 °Brix after 3 days of storage. The undesirable decrease in total soluble solids is due to the microorganism's growth, which caused the conversion of the total soluble solids into acids (Tabikha et al., 2010). The reduction in TSS was observed to be higher in the samples stored in atmospheric storage than the samples stored in cold storage. It could be due to the rate of growth of microorganism is less in cold storage than atmospheric storage. Throughout the storage period, all packaging materials showed similar variations in TSS content.

Hashemi (2018) reported a significant decrease in the TSS content of ultrasonicated (30-kHz pulsed and continuous ultrasound at 20 °C for 0, 15, 30, 45 and 60 min) Mirabelle plum during refrigerated storage (4 °C). The decrease in °Brix for ultrasonicated samples had also been observed in green cactus pear juice (del Socorro Cruz-Cansino et al., 2015), carrot juice (Zou & Jiang, 2016), and passion fruit juice (Gómez-López et al., 2018).

3.2.3. Total sugar, reducing sugar and non-reducing sugar

The change in total sugar, reducing sugar, and non-reducing sugars of MCW during storage are presented in Figs. 3–5, respectively. During the storage period, the total sugar, reducing sugar and non-reducing sugar content of MCW showed significant reduction (p < 0.05) which is given in Table 2 (for cold storage) and Table 5 (for atmospheric storage).

The initial total sugar content of control and sonicated MCW was 5.5% and 5.3% respectively. The concentration of total sugars in sonicated samples stored in a glass bottle, PET bottle, and stand-up pouch at cold storage was reduced to 4.77, 4.75, and 4.72% respectively after 12 days of storage. However, the control samples spoiled within three days of storage as indicated by the count of microbial populations and organoleptic properties. Samples stored in stand-up pouches showed the maximum reduction of total sugars when compared to the other two packaging materials. The decrease in sugars during storage is due to the microbial action which converts sugars into acids (Alexandrakis et al., 2012). Glass bottles retained more total sugars in both storage conditions (at atmospheric storage and cold storage). However, all the packaging materials were found to be statistically on par in maintaining the total sugar during storage. Mala et al. (2021) also observed similar

Table 4

Analysis of variance for pH and TSS in ultrasound treated mature coconut water during atmospheric storage.

Effect	pH			TSS		
	ProbF	C.V. (%)	Significant	ProbF	C.V. (%)	Significant
Packaging material	0.966 ^b		NS	0.429 ^b		NS
Storage	p < 0.05 ^a		*	p < 0.01 ^a		**
Packaging material x Storage	0.966 ^b		NS	0.429 ^b		NS
Residual		1.25%			0.93%	

^aSignificant at p < 0.01.^bNot Significant at p > 0.05.

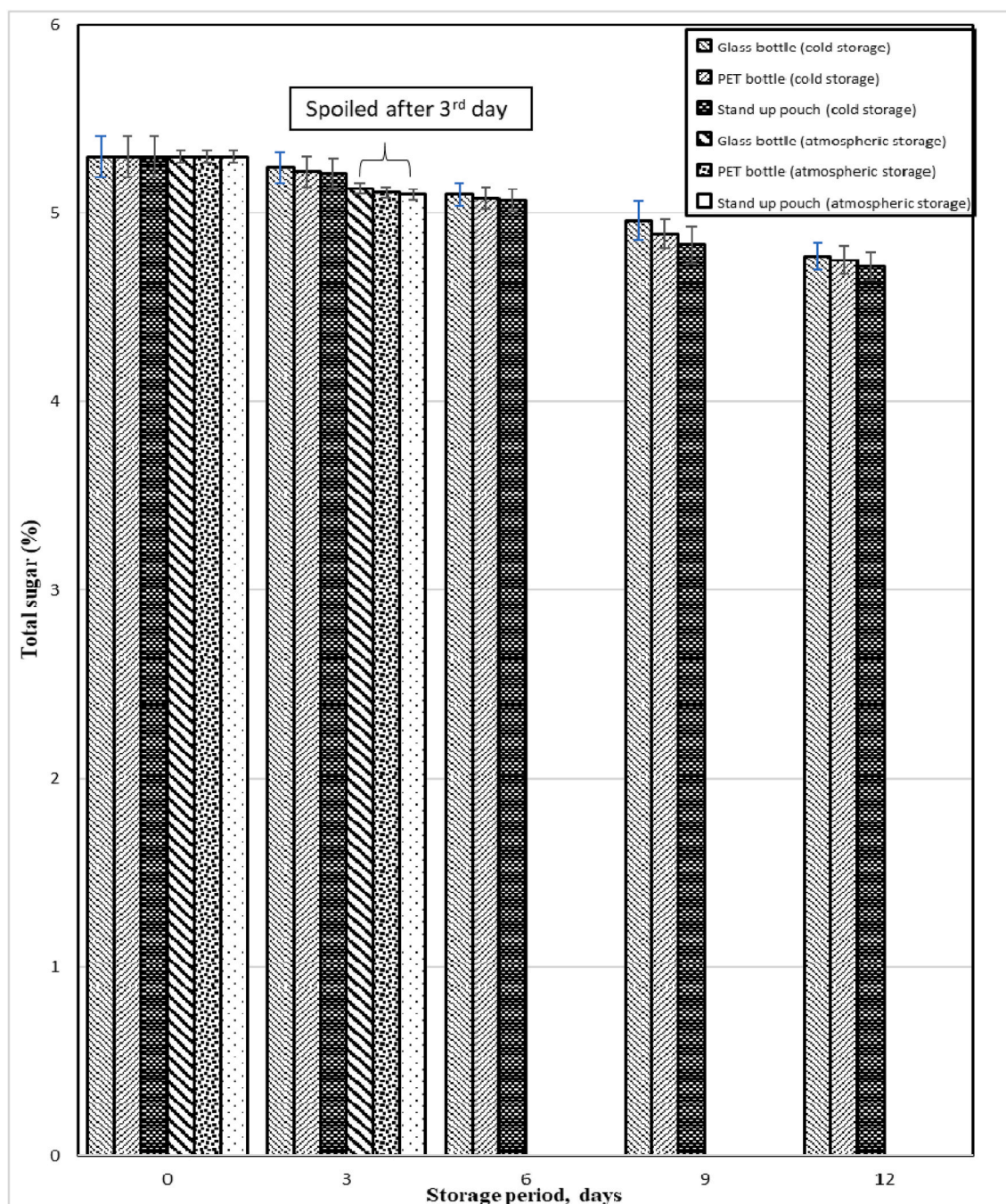


Fig. 3. Total sugar of ultrasonicated MCW during cold and atmospheric storage conditions.

results of the reduced total sugar content of ultrasonicated pineapple juice during storage.

The reducing sugar content of MCW decreased over the storage period in both sonicated and control samples. Reducing sugar content of the samples was reduced from 2.46 to 2.25%, 2.46 to 2.24%, and 2.46 to 2.24% during the storage period of 12 days for glass bottle, PET bottle, and stand-up pouch respectively, for the samples stored at 5 ± 1 °C. Similar results were reported for the drinks prepared from cucumber (*Cucumis sativus*) and muskmelon (*Cucumis melo*) (Kausar et al., 2012).

The non-reducing sugar content of the ultrasonicated samples stored at cold storage condition was reduced from 2.84 to 2.52% for glass bottles, 2.84 to 2.51% for PET bottles, and 2.84 to 2.48% for the stand-up pouch during a storage period of 12 days. While the ultrasonicated samples at atmospheric storage was reduced from 2.84 to 2.74% for

glass bottles, 2.84 to 2.72% for both PET bottles and stand-up pouch within 3 days and then spoiled. The Inversion of non-reducing sugars to reducing sugars through hydrolysis caused the decline in non-reducing sugar content (Chauhan et al., 2014). Patel et al. (2019) also reported a similar result on the non-reducing sugars content of thermally pasteurized tender coconut water during storage. They concluded that the best quality of coconut water was obtained after heating at 100 °C for 10 min and stored in glass bottles at room temperature for 3 months. Packaging material statistically showed no significant differences in the sugar content of MCW. Also, there was a slight variation in sugar content observed in the packaging materials. Glass bottles were observed to be best in maintaining the sugar content of MCW. When compared to the glass bottle, the other two packaging materials might have a faster rate of chemical reaction due to higher oxygen permeability and thermal

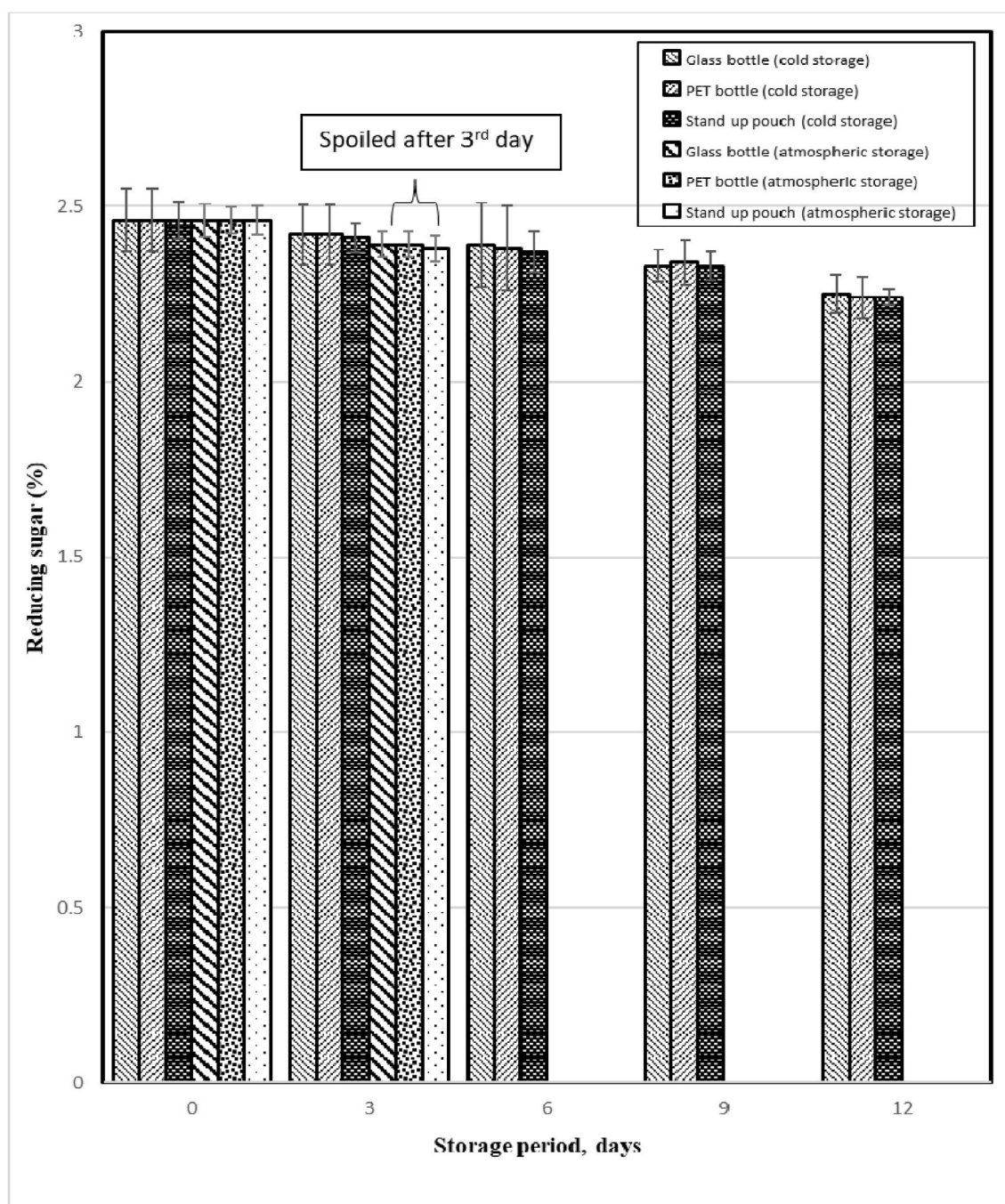


Fig. 4. Reducing sugar of ultrasonicated MCW during cold and atmospheric storage conditions.

conductance properties which leads to the degradation of nutrients (Kim et al., 2011).

3.2.4. Microbial load

The evolution of microbial populations during storage of MCW packed in different packaging materials (glass bottle, PET bottle and Stand-up pouch) under different storage conditions (atmospheric storage and cold storage) are shown in Fig. 6. During the storage period, the total plate count of MCW increased significantly ($p < 0.05$) and is given in Table 3 (for cold storage) and Table 6 (for atmospheric storage).

Ultrasound-treated samples showed reduced microbial growth during storage than the control samples. During storage of 12 days, the microbial count increased from 4.65 to 5.43, 4.65 to 5.49, and 4.65 to 5.68 log cfu/ml for different packaging materials such as glass bottles,

PET bottles, and stand-up pouches respectively, for the samples stored at cold storage condition. While the control samples showed rapid increase in microbial load such as 7.02 to 7.51, 7.02 to 7.55 and 7.02 to 7.58 cfu/ml for glass bottle, PET bottle and stand up pouch within 3 days of storage. All the packaging materials were statistically on par in terms of microbial growth during storage, but glass bottles had the least microbial growth compared to PET bottles and stand-up pouches. The glass bottle provides excellent barrier properties against moisture vapor, gases, and odors, as well as having high thermal resistance. Compared to other packaging materials, they can also prevent flavors and smells from migrating to food and, sometimes, preserve food for longer periods. Oxygen transmission rate (OTR) and water vapor transmission rate (WVTR) are key gas barrier properties that contribute to shelf life of food products (Sonar et al., 2019). PET and LDPE materials (stand-up pouch)

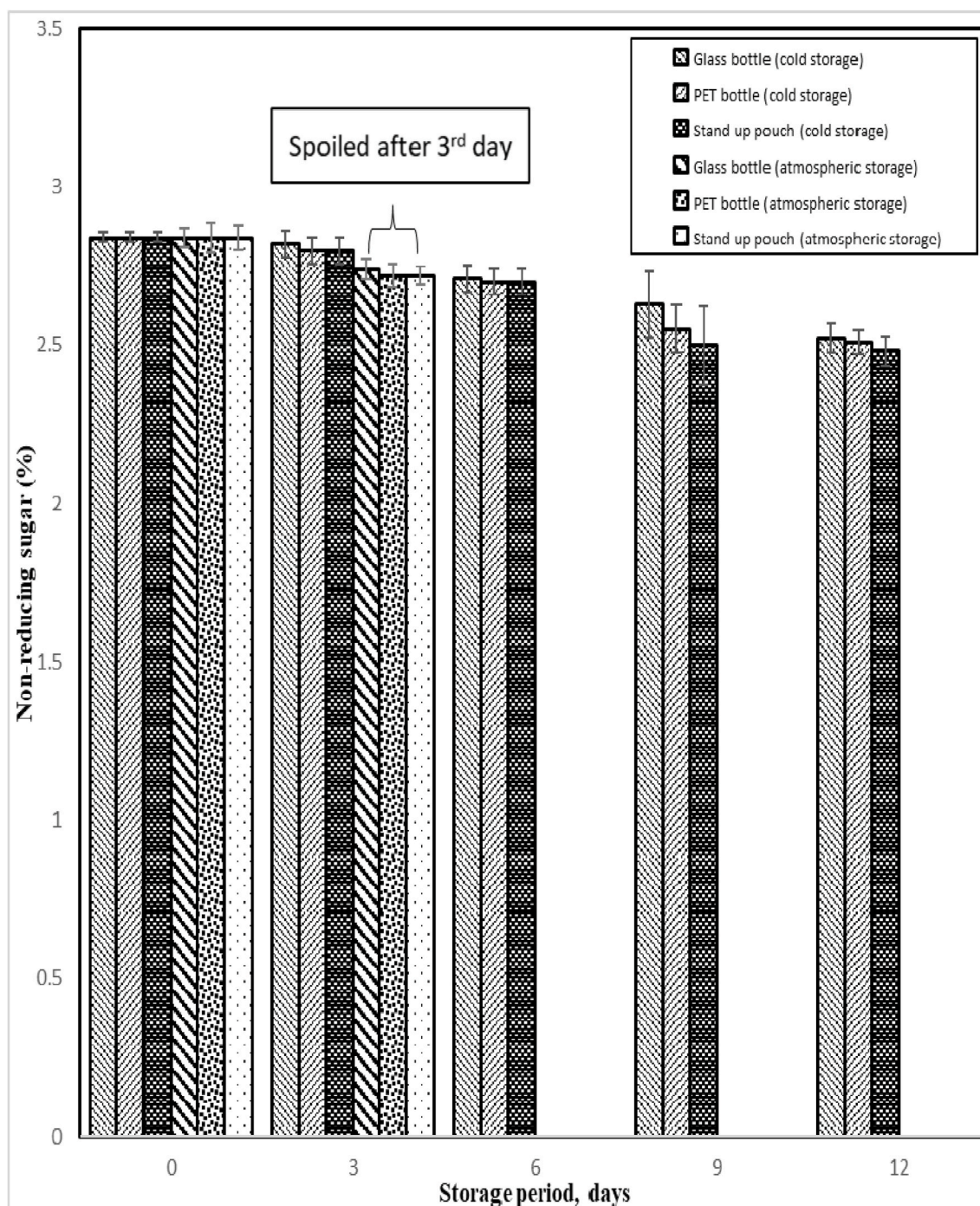


Fig. 5. Non-reducing sugar of ultrasonicated MCW during cold and atmospheric storage conditions.

Table 5

Analysis of variance for total sugar, reducing sugar and non-reducing sugar in ultrasound treated mature coconut water during atmospheric storage.

Effect	Total sugar			Reducing sugar			Non-reducing sugar		
	ProbF	C.V. (%)	Significant	ProbF	C.V. (%)	Significant	ProbF	C.V. (%)	Significant
Packaging material	0.980 ^b		NS	0.985 ^b		NS	0.947 ^b		NS
Storage	0.092 ^b		NS	0.174 ^b		NS	0.057 ^b		NS
Packaging material x Storage	0.988 ^b		NS	0.985 ^b		NS	0.947 ^b		NS
Residual		2.69%			2.41%			2.86%	

^aSignificant at $p < 0.01$.

^bNot Significant at $p > 0.05$.

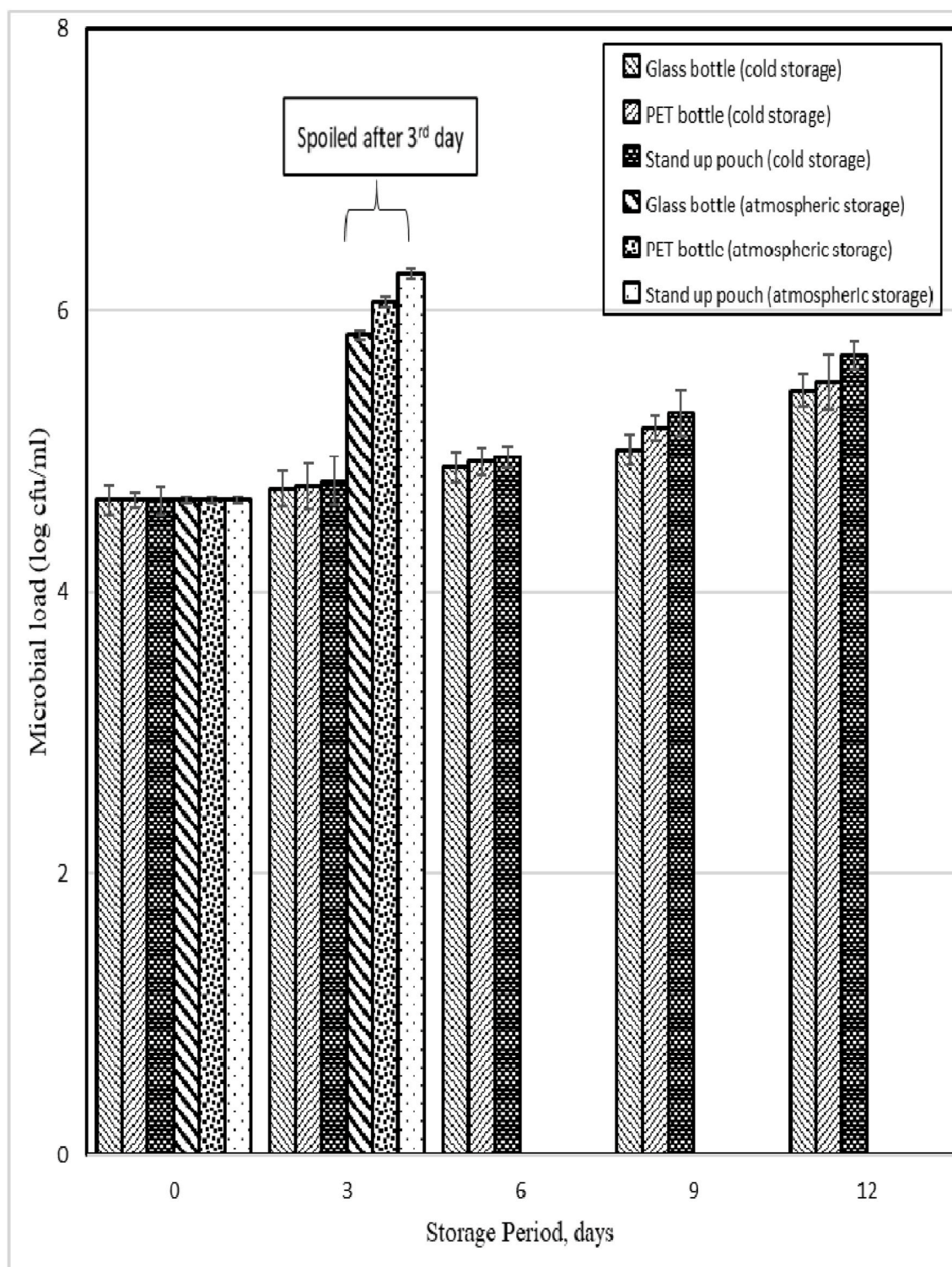


Fig. 6. Microbial load of ultrasonicated MCW during cold and atmospheric storage conditions.

will exhibit lower moisture barrier properties because moisture penetrates preferentially through walls of PET bottles and stand-up pouches which are influenced by their polymeric molecular structure and thickness. WVTR results obtained for the same bottle volume (30 cm^3) indicate that the material influences moisture barrier properties with average values of 0.07 and $9.9 \text{ mg.day}^{-1}.\text{bottle}^{-1}$ for glass and PET bottles respectively at $40^\circ\text{C}/75\% \text{ RH}$. The largest oxygen barrier is represented by the glass bottle ($\leq 0.005 \text{ ml.day}^{-1}.\text{bottle}^{-1}$) when considering the same volume of packaging material followed by PET

($0.012 \text{ ml.day}^{-1}.\text{bottle}^{-1}$) at 23°C and 21 atm partial pressure gradient (Jaime et al., 2022). Stand up pouches (LDPE) are transparent to translucent, highly flexible, but fairly permeable to oxygen ($6500\text{--}8500 [\text{cm}^3/(\text{m}^2/24 \text{ h atm})]$ at 38°C (RH 90%)), CO_2 , and odors. As a result, microbial growth was found to be more in stand-up pouch than other two packaging materials (Chaliha et al., 2013). Similar results on more effectiveness of the glass bottle in preventing microbial growth were reported by Nwafo and Ikenebomeh (2009). El-Sheikha et al. (2009) found that Physalis (Husk tomato) juice packaged in glass bottles was

Table 6

Analysis of variance for total plate count in ultrasound treated mature coconut water during atmospheric storage.

Effect	Total plate count		
	ProbF	C.V. (%)	Significant
Packaging material	0.244		NS
Storage	p < 0.01		**
Packaging material x Storage	0.244		NS
Residual		3.91%	

^aSignificant at p < 0.01, ^bNot Significant at p > 0.05.

Table 7

Variations in physicochemical properties of control sample during storage.

Storage period	pH					
	Normal storage			Cold storage		
	G	P	S	G	P	S
0	5.3	5.3	5.3	5.3	5.3	5.3
3	5.10	5.09	5.07	5.20	5.20	5.19
TSS						
	Normal storage			Cold storage		
	G	P	S	G	P	S
0	5.1	5.1	5.1	5.1	5.1	5.1
3	4.5	4.5	4.4	4.8	4.8	4.8
Total Sugar						
	Normal storage			Cold storage		
	G	P	S	G	P	S
0	5.48	5.48	5.48	5.48	5.48	5.48
3	5.1	5.1	5.1	5.31	5.31	5.31
Reducing sugar						
	Normal storage			Cold storage		
	G	P	S	G	P	S
0	2.25	2.25	2.25	2.25	2.25	2.25
3	2.15	2.15	2.13	2.2	2.19	2.19
Non-reducing sugar						
	Normal storage			Cold storage		
	G	P	S	G	P	S
0	3.23	3.23	3.23	3.23	3.23	3.23
3	2.97	2.97	2.95	3.16	3.15	3.15
Total plate count						
	Normal storage			Cold storage		
	G	P	S	G	P	S
0	7.02	7.02	7.02	7.02	7.02	7.02
3	8.28	8.35	8.39	7.51	7.55	7.58

more stable during storage than juice packaged in laminated flexible plastic packages.

Control samples spoiled within 24 h as determined by analyzing the change in physical properties of the samples. The sonicated samples stored at atmospheric storage spoiled within three days of storage. When compared to sonicated samples, the rate of microbial growth in the control samples stored under both storage conditions was much higher during three days storage. There were similar results observed by Gómez-López et al. (2017) on decreased microbial populations of sonicated passion-fruit juice than those of non-sonicated juice during refrigerated storage. According to FSSAI (2019), the acceptable total plate count in fruit juices should be within 6.00 log cfu/ml. In the present study, sonicated samples under cold storage conditions were within the safe limit of 6 log cfu/ml even after 12 days of storage.

4. Conclusion

The present study concluded that sonication of MCW at 60% amplitude for 10 min, increased their shelf life up to 12 days at the cold storage condition with minimum microbial load and maximum retention of nutrients. To maintain the benefits of ultrasound treatment on MCW during storage, it is essential to select a packaging material that is compatible with food. The pH, TSS, total sugar, reducing sugar and non-reducing sugar of coconut water decreased significantly (p < 0.05) while

total plate count of the sample increased significantly (p < 0.05) during the storage period. It was found that the samples stored in glass bottles under cold storage conditions had minimal changes in nutrients and minimal growth in microbial load when compared to the other two packaging materials. However, all the packaging materials were observed to be statistically on par in terms of microbial growth and maintaining nutritional quality during storage. The obtained results confirmed that ultrasound treatment can be an alternative to thermal treatment for MCW preservation.

CRedit authorship contribution statement

Anjitha Jacob: Conceptualization, Methodology, Investigation, Writing – original draft. **I.P. Sudagar:** Conceptualization, Methodology, Investigation, Writing – original draft. **R. Pandiselvam:** Conceptualization, Software, Formal analysis, Resources, Methodology, Writing – original draft, Writing – review & editing. **P. Rajkumar:** Formal analysis, Resources, Data curation, Writing – review & editing. **M. Rajavel:** Methodology, Investigation, Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

References

- Alexandrakis, D., Brunton, N. P., Downey, G., & Scannell, A. G. (2012). Identification of spoilage marker metabolites in Irish chicken breast muscle using HPLC, GC-MS coupled with SPME and traditional chemical techniques. *Food and Bioprocess Technology*, 5, 1917–1923.
- Anin, S. K., Ellis, W. O., & Adubofuor, J. (2010). Effects of two packaging materials and storage conditions on the quality of fresh taste, a natural and locally produced orange drink in Ghana. *African Journal of Food Science and Technology*, 1(6), 132–138.
- Aslam, R., Alam, M. S., Kaur, J., Panayampadan, A. S., Dar, O. I., Kothakota, A., & Pandiselvam, R. (2022). Understanding the effects of ultrasound processing on texture and rheological properties of food. *Journal of Texture Studies*, 53(6), 775–799.
- Chaliha, M., Cusack, A., Currie, M., Sultanbawa, Y., & Smyth, H. (2013). Effect of packaging materials and storage on major volatile compounds in three Australian native herbs. *Journal of Agricultural and Food Chemistry*, 61(24), 5738–5745.
- Chan, S. Y., Liu, S., Tanujaya, S., & Tan, S. Y. (2016). *Coconut handbook*. Tetra Pak South East Asia Pte Ltd, Coconut Knowledge Centre.
- Chauhan, O. P., Archana, B. S., Singh, A., Raju, P. S., & Bawa, A. S. (2014). A refreshing beverage from MCW blended with lemon juice. *Journal of Food Science & Technology*, 51(11), 3355–3361. <https://doi.org/10.1007/s13197-012-0825-6>
- Cheng, X., Zhang, M., Xu, B., Adhikari, B., & Sun, J. (2015). The principles of ultrasound and its application in freezing related processes of food materials: A review. *Ultrasonics Sonochemistry*, 27, 576–585. <https://doi.org/10.1016/j.ultrsonch.2015.04.015>
- Dubois, M., Gilles, K. A., Hamilton, J. K., Rabers, P. A., & Smith, F. (1956). Calorimetric method for determination of sugars and related substances. *Analytical Chemistry*, 28, 350–356.
- El-Sheikha, A., Ribeyre, F., Larroque, M., Reynes, M., & Montet, D. (2009). Quality of physalis (*Physalis pubescens* L.) juice packaged in glass bottles and flexible laminated packs during storage at 5° C. *African Journal of Food, Agriculture, Nutrition and Development*, 9(6). <https://doi.org/10.4314/ajfand.v9i6.46263>
- Gómez-López, V. M., Buitrago, M. E., & Martínez-Yépez, A. (2018). Effect of ultrasonication on sensory and chemical stability of passion fruit juice during refrigerated storage. *Emirates Journal of Food and Agriculture*, 30, 85–89. <https://doi.org/10.9755/ejfa.2018.v30.i1.1587>
- Gómez-López, V. M., Buitrago, M. E., Tapia, M. S., & Martínez-Yépez, A. (2017). Effect of ultrasonication on microbial quality, colour, and ascorbic acid content of passion-fruit juice during storage. *Acta Alimentaria*, 46(4), 470–480. <https://doi.org/10.1556/066.2017.46.4.10>
- Hashemi, S. M. B. (2018). Effect of pulsed ultrasound treatment compared to continuous mode on microbiological and quality of Mirabelle plum during postharvest storage. *International Journal of Food Science and Technology*, 53(3), 564–570. <https://doi.org/10.1111/ijfs.13629>
- Hosseini, S. S., Mahvi, A. H., & Tsunodac, M. (2019). Fluoride content of coconut water and its risk assessment. *Fluoride*, 52(4), 553–561.
- Iqbal, M. N., Anjum, A. A., Ali, M. A., Hussain, F., Ali, S., Muhammad, A., Irfan, M., Ahmad, A., & Shabbir, A. (2015). Assessment of microbial load of un-pasteurized

- fruit juices and in vitro antibacterial potential of honey against bacterial isolates. *The Open Microbiology Journal*, 9, 26–32.
- Jacob, A., Sudagar, I. P., Pandiselvam, R., Rajkumar, P., & Rajavel, M. (2022). Optimization of ultrasound processing parameters for preservation of matured coconut water using a central composite design. *Quality Assurance and Safety of Crops & Foods*, 14(SP1), 33–41.
- Jaime, S. B., Alves, R. M., & Bocoli, P. F. (2022). Moisture and oxygen barrier properties of glass, PET and HDPE bottles for pharmaceutical products. *Journal of Drug Delivery Science and Technology*, 71, Article 103330.
- Kaavya, R., Pandiselvam, R., Abdullah, S., Sruthi, N. U., Jayanath, Y., Ashokkumar, C., Khanashyam, A. C., Kothakota, A., & Ramesh, S. V. (2021). Emerging non-thermal technologies for decontamination of Salmonella in food. *Trends in Food Science & Technology*, 112, 400–418. <https://doi.org/10.1016/j.tifs.2021.04.011>
- Kausar, H., Saeed, S., Ahmad, M. M., & Salam, A. (2012). Studies on the development and storage stability of cucumber-melon functional drink. *Journal of Agricultural Research*, 50(2), 239–248. <https://doi.org/10.13140/RG.2.2.35674.18886>
- Khandpur, P., & Gogate, P. R. (2016). Evaluation of ultrasound based sterilization approaches in terms of shelf life and quality parameters of fruit and vegetable juices. *Ultrasonics Sonochemistry*, 29, 337–353. <https://doi.org/10.1016/j.ulsonch.2015.10.008>
- Kim, Y., Welt, B. A., & Talcott, S. T. (2011). The impact of packaging materials on the antioxidant phytochemical stability of aqueous infusions of green tea (*Camellia sinensis*) and yaupon holly (*Ilex vomitoria*) during cold storage. *Journal of Agricultural and Food Chemistry*, 59(9), 4676–4683. <https://doi.org/10.1021/jf104799y>
- Kusumiyati, Hadiwijaya, Y., Putri, I. E., Mubarak, S., & Hamdani, J. S. (2020). Rapid and non-destructive prediction of total soluble solids of guava fruits at various storage periods using handheld near-infrared instrument. *IOP Conference Series: Earth and Environmental Science*. <https://doi.org/10.1088/1755-1315/458/1/012022>
- Kutlu, N., Pandiselvam, R., Kamiloglu, A., Saka, I., Sruthi, N. U., Kothakota, A., Socol, A. T., & Maurescu, C. M. (2022). Impact of ultrasonication applications on color profile of foods. *Ultrasonics Sonochemistry*, 89, Article 106109. <https://doi.org/10.1016/j.ulsonch.2022.106109>
- Mala, T., Sadiq, M. B., & Anal, A. K. (2021). Optimization of thermosonication processing of pineapple juice to improve the quality attributes during storage. *Journal of Food Measurement and Characterization*, 15(5), 4325–4335. <https://doi.org/10.1007/s11694-021-01011-8>
- Meng, J., Doyle, M. P., Zhao, T., & Zhao, S. (2001). Enterohemorrhagic *Escherichia coli*. In M. P. Doyle, L. R. Beuchat, & T. J. Montville (Eds.), *Food microbiology. Fundamentals and frontiers* (2nd ed., pp. 193–214). Washington, DC: ASM Press.
- Naik, M., Ck, S., & Rawson, A. (2022). Tender coconut water: A review on recent advances in processing and preservation. *Food Reviews International*, 38(6), 1215–1236. <https://doi.org/10.1080/87559129.2020.1785489>
- Nwafo, O. E., & Ikenebomeh, M. J. (2009). Effects of different packaging materials on microbiological, physico-chemical and organoleptic quality of zobo drink storage at room temperature. *African Journal of Biotechnology*, 8(12).
- Pandiselvam, R., Hebbar, K. B., Manikantan, M. R., Prashanth, B. K., Beegum, S., & Ramesh, S. V. (2020). Microwave treatment of coconut inflorescence sap (Kalparasa®): A panacea to preserve quality attributes. *Sugar Tech*, 22(4), 718–726. <https://doi.org/10.1007/s12355-020-00828-9>
- Pandiselvam, R., Manikantan, M. R., Kothakota, A., Rajesh, G. K., Beegum, S., Ramesh, S. V., Niraj, V., & Hebbar, K. B. (2018). Engineering properties of five varieties of coconuts (*Cocos nucifera* L.) for efficient husk separation. *Journal of Natural Fibers*. <https://doi.org/10.1080/15440478.2018.1507863>
- Pandiselvam, R., Prithviraj, V., Manikantan, M. R., Beegum, P. S., Ramesh, S. V., Padmanabhan, S., Kothakota, A., Mathew, A. C., Hebbar, K. B., & Khaneghah, A. M. (2022). Central composite design, Pareto analysis, and artificial neural network for modeling of microwave processing parameters for tender coconut water. *Measurement: Food*, 5, Article 100015. <https://doi.org/10.1016/j.meafod.2021.100015>
- Patel, D., Sharma, H. G., Ramteke, V., & Xess, R. (2019). Processing and preservation of green coconut water. *International Journal of Communication Systems*, 7(6), 1260–1263.
- Prades, A., Dornier, M., Diop, N., & Pain, J. P. (2012). Coconut water uses, composition and properties: a review. *Fruits*, 67(2), 87–107.
- Preetha, P., Pandiselvam, R., Varadharaju, N., Kennedy, Z. J., Balakrishnan, M., & Kothakota, A. (2021). Effect of pulsed light treatment on inactivation kinetics of *Escherichia coli* (MTCC 433) in fruit juices. *Food Control*, 121, Article 107547. <https://doi.org/10.1016/j.foodcont.2020.107547>
- Prithviraj, V., Pandiselvam, R., Babu, A. C., Kothakota, A., Manikantan, M. R., Ramesh, S. V., Beegum, P. S., Mathew, A. C., & Hebbar, K. B. (2021). Emerging non-thermal processing techniques for preservation of tender coconut water. *Lebensmittel-Wissenschaft & Technologie*, 149, Article 111850. <https://doi.org/10.1016/j.lwt.2021.111850>
- Prithviraj, V., Pandiselvam, R., Manikantan, M. R., Ramesh, S. V., Shameena Beegum, P. P., Kothakota, A., & Mousavi Khaneghah, A. (2022). Transient computer simulation of the temperature profile in different packaging materials: An optimization of thermal treatment of tender coconut water. *Journal of Food Process Engineering*, Article e13958. <https://doi.org/10.1111/jfpe.13958>
- Rahaman, A., Zeng, X.-A., Kumari, A., Rafiq, M., Siddeeq, A., Manzoor, M. F., Baloch, Z., & Ahmed, Z. (2019). Influence of ultrasound-assisted osmotic dehydration on texture, bioactive compounds and metabolites analysis of plum. *Ultrasonics Sonochemistry*, 58, Article 104643. <https://doi.org/10.1016/j.ulsonch.2019.104643>
- Ranganna, S. (1986). *Handbook of analysis and quality control for fruit and vegetable products*. Tata McGraw-Hill Education.
- Revi, M., Badeka, A., Kontakos, S., & Kontominas, M. G. (2014). Effect of packaging material on enological parameters and volatile compounds of dry white wine. *Food Chemistry*, 152, 331–339. <https://doi.org/10.1016/j.foodchem.2013.11.136>
- Samreen, C. V., Edukondalu, L., Beera, V., & Rao, V. S. (2020). Physicochemical characteristics of pomegranate and pineapple juice. *Indian Journal of Ecology*, 43, 60–63.
- del Socorro Cruz-Cansino, N., Ramírez-Moreno, E., Leon-Rivera, J. E., Delgado-Olivares, L., Alanís-García, E., Ariza-Ortega, J. A., de Jesús Manríquez-Torres, J., & Jaramillo-Bustos, D. P. (2015). Shelf life, physicochemical, microbiological and antioxidant properties of purple cactus pear (*Opuntia ficus indica*) juice after thermoultrasound treatment. *Ultrasonics Sonochemistry*, 27, 277–286. <https://doi.org/10.1016/j.ulsonch.2015.05.040>
- Sonar, C. R., Paccola, C. S., Al-Ghamdi, S., Rasco, B., Tang, J., & Sablani, S. S. (2019). Stability of color, β -carotene, and ascorbic acid in thermally pasteurized carrot puree to the storage temperature and gas barrier properties of selected packaging films. *Journal of Food Process Engineering*, 42(4), Article e13074.
- Sruthi, N. U., Josna, K., Pandiselvam, R., Kothakota, A., Gavahian, M., & Khaneghah, A. M. (2022). Impacts of cold plasma treatment on physicochemical, functional, bioactive, textural, and sensory attributes of food: A comprehensive review. *Food Chemistry*, 368, Article 130809. <https://doi.org/10.1016/j.foodchem.2021.130809>
- Tabikha, M., El-Shehawey, S. M., & Helal, D. M. A. (2010). Changes in chemical and nutritional quality during cold storage of some fruit and vegetable juice blends. *Journal of Food and Dairy Sciences*, 1(4), 181–191. <https://doi.org/10.21608/jfds.2010.82107>
- Tan, T. C., Cheng, L. H., Bhat, R., Rusul, G., & Easa, A. M. (2014). Composition, physicochemical properties and thermal inactivation kinetics of polyphenol oxidase and peroxidase from coconut (*Cocos nucifera*) water obtained from immature, mature and overly-mature coconut. *Food Chemistry*, 142, 121–128.
- Tan, T. C., & Easa, A. M. (2021). The evolution of physicochemical and microbiological properties of green and mature coconut water (*Cocos nucifera*) under different storage conditions. *Journal of Food Measurement and Characterization*, 15(4), 3523–3530.
- Tomadoni, B., Cassani, L., Ponce, A., Moreira, M. R., & Agüero, M. V. (2016). Optimization of ultrasound, vanillin and pomegranate extract treatment for shelf-stable unpasteurized strawberry juice. *LWT—Food Science and Technology*, 72, 475–484. <https://doi.org/10.1016/j.lwt.2016.05.024>
- Zhang, G., Li, X., Chen, W., Chen, P., Jin, X., Chen, W., & Chen, H. (2018). Organic acid content, antioxidant capacity, and fermentation kinetics of matured coconut (*Cocos nucifera*) water fermented by *Saccharomyces cerevisiae* D254. *International Journal of Food Engineering*, 14(3). <https://doi.org/10.1515/ijfe-2017-0331>
- Zou, Y., & Jiang, A. (2016). Effect of ultrasound treatment on quality and microbial load of carrot juice. *Food Science and Technology*, 36, 111–115. <https://doi.org/10.1590/1678-457X.0061>