Journal of Tropical Agriculture 58 (1): 44-52, 2020

Mild thermal processing of cashew apple juice using ohmic heating

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Received 15 April 2020; received in revised form 24 May 2020; accepted 4 June 2020

Abstract
Cashew apple is an under exploited fruit crop due to its seasonal and highly perishable nature. Ohmic heating is adopted for processing and preservation of cashew apple juice. Ohmic heating is widely accepted for the inactivation of enzymes and microorganisms. The optimization of ohmic heating process parameters such as voltage gradient, holding time and temperature was done based on the microbial inactivation and the variation in physico-chemical qualities of cashew apple juice. The cashew apple juice was ohmic heated at different voltage gradients (10-15 V/cm) temperatures (50-60°C) and holding times (1-5 min). Maximum microbial reduction was obtained in treatment with higher voltage gradients, temperature, and time. A treatment with a voltage gradient of 12.5 V/cm, temperature of 60°C and a holding time of 5 min resulted in highest microbial reduction. A significant change in ascorbic acid content and total colour difference was observed with the increase in temperature and treatment time. A voltage gradient of 14.21 V/cm, process temperature of 55.47°C and holding time of 2.43 min was found to be the optimum conditions for ohmic heating conditions.

Key words: Holding time, Ohmic heating, Temperature,Voltage gradient.

Introduction

Cashew (*Anacardium occidentale* L.) is well known as 'Gold Mine' of the wasteland as its cultivation is highly economical (Attri, 2009). Cashew apple is a good source of vitamins reducing sugars, minerals, carotenoids, amino acids, phenolics, antioxidants and organic acids (Trevisan et al., 2006; De-Carvalho et al., 2008; Honorato and Rodrigues, 2010). Cashew apple also contains 6-10 times more vitamin C content than orange (Azoubel et al., 2005). However, the processing and value addition of cashew apple is limited due to its perishable nature. The cashew apple juice is one of the important value added product from cashew apple. The seasonal nature and high susceptibility to spoilage limits the storage of product and its marketing. The processing methods currently adopted for juice preservation include addition of chemical preservatives and thermal processing. The conventional thermal processing may lead to visible changes in colour and loss of some bioactive compounds like ascorbic acid, carotenoids, flavonoids and polyphenols. The positive transformations of consumer preferences have developed a negative perception on the addition of chemical preservatives in products. Hence, novel technologies are adopted in processing of cashew to improve the safety and quality of characteristics.

Ohmic heating is novel thermal processing technology, which provides uniform and volumetric heating of food materials sandwiched between two electrodes by supplying alternating current (AC) through it. The heat generated in the foods is based on their inherent characteristics of electrical resistance (De-Alwis and Fryer, 1990). Ohmic heating also reduces the treatment time and leads to reduced thermal damage to pigments, vitamins and other elements due to uniform and rapid heating

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(Salengke and Sastry, 2007). The microbial reduction is achieved through the thermal effect developed inherently and non thermal effects due to electroporation imposed by electric fields. During ohmic heating working at low frequency (50–60 Hz), a mild electroporation mechanism may occur which allows the build up of electrical charges and formation of pores across cell walls (Ruan et al., 2004). Hence the effect of ohmic heating process parameters *viz*., as voltage gradient, temperature, and holding time, on the physiochemical and microbiological characteristics were studied towards the preservation of cashew apple juice.

Material and Methods

Cashew apple juice

Cashew apples for the study were procured from Cashew Research Station Madakkathara, KAU. The cashew apple was separated from nuts and washed with water for removing external dirt and debris. The cashew apple juice was extracted by using a juice extractor (screw press model). The astringency of the fruit juice was removed by adding cassava starch at 2g/L of fruit juice which is referred to as clarification (Jayalekshmy and John, 2004). The fruit juice was allowed to stand overnight at refrigerated condition and filtered using a sterile muslin cloth to obtain clarified cashew apple juice.

Ohmic heating set up

A laboratory scale ohmic heating device designed and developed at KCAET Tavanur, KAU was used for this study. The experimental set up consists of a feed tank, ohmic heating chamber, volt ampere meter, variable transformer and temperature measuring devices. The system can process 300 ml of cashew apple juice per batch. The ohmic heating chamber was developed using a Teflon cylinder with inner and outer diameter of 70 mm and 80 mm respectively and having a length 150 mm. Both sides of the cylinder were fixed with stainless steel (SS 304) electrodes with same inner diameter of chamber and covered with Teflon end caps. A temperature detection probe was installed in the middle of the chamber to measure the system temperature during operation.

Ohmic heating experiment

The cashew apple juice was filled in the feed tank and was then transferred to the ohmic heating chamber through opening valve V_1. The ohmic heating chamber was fully filled with cashew apple juice ensuring good contact with electrodes, by closing valve V_2. The predetermined voltage was set with the help of variable transformer and inside temperature of the juice was allowed to increase up to the required temperature. The juice was then held at that temperature for the prescribed holding time. The treated samples were collected in sterile amber colour PET bottles and stored in refrigerated condition.

Experimental design of ohmic heating process

Experiments were framed using Box-Behnken design of response surface methodology using Design expert software version 7.0 to optimize the voltage gradient, temperature and holding time combination required for the effective mild thermal treatment and thus to study the effect of treatment on the microbial and biochemical properties of the fruit juices. A three level factorial design was used with independent variables as voltage gradient (10, 12.50, and 15 V/cm), temperature (50, 55 and 60°C) and holding time (1, 3 and 5 min) based on the preliminary studies and thorough reviews. The three factors were coded with three levels (-1, 0, +1). The analysis of variance was obtained for each response to find out the significant differences. The response surface analysis used a generalized second-order polynomial model as per equation below:

$$Y=a_0+ a_1A + a_2B + a_3C + a_{12}AB + a_{13}AC + a_{23}BC + a_{11}A^2 +a_{22}B^2 + a_{33}C^2$$

Where Y= Response variable and the independent variables were denoted as A (voltage gradient), B (processing temperature) and C (holding time). The adequacies of the models were determined using model analysis, lack-of-fit test and R^2 (coefficient of determination) analysis as outlined by Lee et al.

(2000). From the analyzed data response surface contour plots were generated for each response (Myers and Montgomery, 1995). Optimization of the process variables was carried out with the help of desirability function. The responses were either minimized or maximized while independent factors were kept within the experimental range. The goals were combined into an overall composite function; d(x) called the desirability function (Myers and Montgomery, 2002).

Biochemical properties

Total soluble solids (TSS) were determined by using digital hand refractometer (Erma, Italy) and expressed in terms of degree Brix. The pH value of juice was measured using a digital pH meter (M/s Systronics). Ascorbic acid was determined by a Visual titration method with the dye solution 2, 6-dichlorophenol indophenol (DCPIP) (Sadasivam and Manickam, 1992).

Colour

The colour was measured using Colour flex meter (Model: 45°/0°, M/s Hunter Lab, Reston, Virginia, USA). The colour values in terms of L*, a* and b* were recorded and the total colour difference (*ÄE*) from the fresh samples was calculated using the following equation.

$$TCD = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where: L_0, a_0, b_0 were initial colour values.

Enumeration of bacteria, yeast and mould

The treated samples were observed for the growth of total plate count (TPC) and yeast and mould count (YMC) by the standard plate count method. The commonly used media, Plate count agar and Chloramphenicol yeast glucose agar were used for enumeration of bacteria and yeast and mould respectively.

Results and Discussion

pH

The pH values of the ohmic heated cashew apple juice ranged from 4.21 to 4.34. The highest pH value of 4.34 was obtained in the treatment with voltage gradient of 15 V/cm, temperature of 55°C and holding time of 1 min. The maximum percentage reduction in pH value was found when the juices were treated with voltage gradient of 10 V/cm, process temperature of 55°C and holding time of 5 min.

The 3D response surface plots of pH values of cashew apple juices for different levels of ohmic heating process parameters are shown in Figs. 1 a & b. It was observed that the process parameters *viz.,* voltage gradient and temperature had a significant ($p<0.05$) effect on the pH values of ohmic heated juice. With the increase in holding time, the pH values were found to decrease, whereas increase in voltage gradient resulted in a minimum reduction in pH from the initial value. These

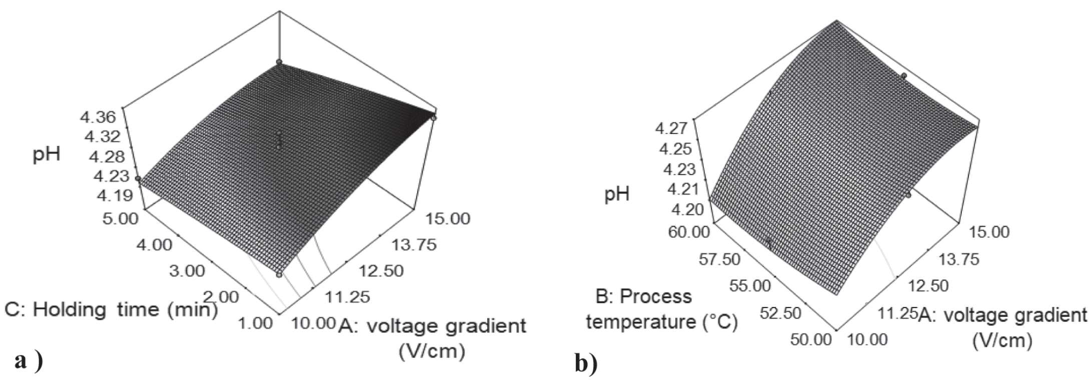

Figure 1. Effect of ohmic heating parameters on pH of cashew apple juice

findings were inconsistent with the study of Makroo et al. (2016) and Boldaji et al. (2014) in watermelon juice and tomato paste processing respectively. A similar trend was also observed in pomegranate juice and sapota juice (Darvishi et al., 2013;Thangalakshmi et al., 2018). These trends during ohmic heating might be attributed to the chemical reactions like hydrolysis of fruit juices and corrosion of electrodes (Assiry et al., 2010, 2003). The long time exposure to the electric fields and contact with the electrodes might have intensified reactions leading to the pH change of fruit juices (Darvishi et al., 2011).

TSS

The TSS value of cashew apple juice ranged between 7.22 and 7.91° Brix. The maximum percentage increase of TSS value was 8.7% (Figs.2.a&b). The minimum variation in TSS value was observed in juice samples treated with voltage gradient of 10 V/cm, holding time of 3 min and process temperature of 50°C.

TSS value increased with increase in voltage gradient and holding time. All ohmic heating process parameters showed a significant effect on the TSS value of cashew apple juice. Similar results were also reported by Abhilasha and Pal (2018) and Poojitha and Athmaselvi (2018) in ohmic heated sugar cane juice and banana purees respectively. This could be attributed to the loss of water content with increase in heating and evaporation which in turn increased the solute concentration (Purvis, 1983). The conversion of organic acids to sugars could also be a reason for the modification of TSS content (Echeverria et al., 1988).

Ascorbic acid content

Ascorbic acid can be considered as one of the most unstable compounds in fruits and vegetables. A significant ($p < 0.001$) reduction of ascorbic acid content was observed during ohmic heating of cashew apple juice. During ohmic heating the ascorbic acid values ranged between 154.32 and 167.23 mg/100 ml. The maximum reduction of ascorbic acid was obtained in treatment with voltage gradient of 12.5 V/cm, process temperature of 60°C and holding time of 5min whereas cashew apple juice treated with voltage gradient of 12.5 V/cm, process temperature of 50°C and holding time of 1min showed minimum reduction in the ascorbic acid content.

Increase in temperature and holding time resulted in a significant reduction of ascorbic acid content of juice (Figs.3. a & b). A similar line of ascorbic acid degradation was observed in pomegranate and orange juice (Paul and Ghosh, 2012). This could be due to the heat sensitive nature of ascorbic acid compounds. Several studies have shown that ascorbic acid follows a first order kinetic of degradation during exposure to elevated temperatures (Paul and Ghosh, 2012). An increase in the reduction of ascorbic acid was noted with increase in voltage gradient. The degradation of ascorbic acids might be attributed to chemical

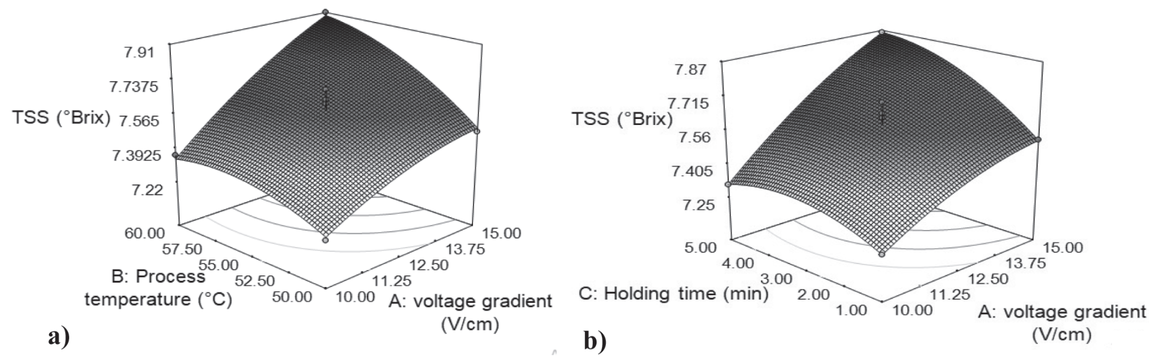

Figure 2. Effect of ohmic heating parameters on TSS of cashew apple juice

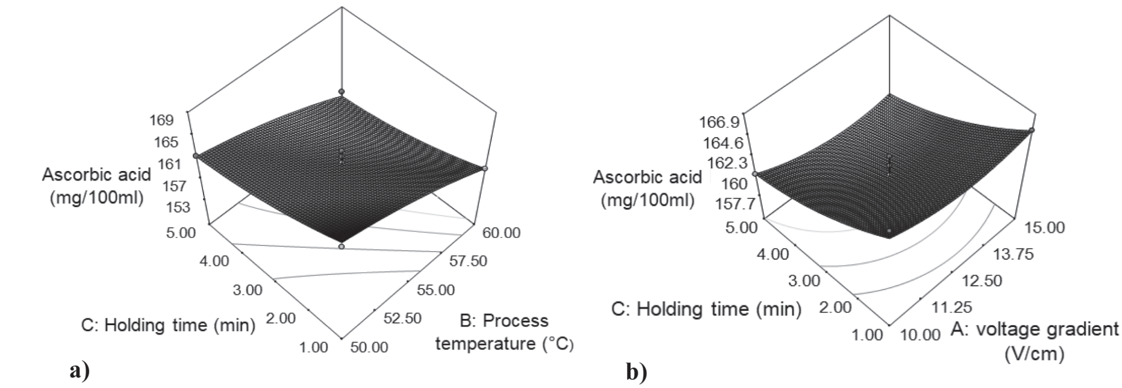

Figure 3. Effect of ohmic heating parameters on ascorbic acid content of cashew apple juice

reactions of electrolysis during ohmic heating (Assiry et al., 2003).

Total colour difference

The total colour difference was found to increase with the increase in voltage gradient and holding time. According to Tiwari et al. (2008), a notable visual colour change could be observed only when the total colour difference was above 2. For all ohmic heated samples, no notable colour change could be observed as the obtained total colour difference was below 2.

The total colour difference of cashew apple juice ranged from 0.3 to 0.88. The highest ΔE value was observed in cashew apple juice treated with voltage gradient of 15V/cm, holding time of 3 min and process temperature of 60°C. The effects of voltage gradient, holding time and process temperature on the total colour difference of ohmic heated juice are presented in Figure 4 (a) and (b). The total colour difference increased significantly with the increase in voltage gradient and process temperature. Thangalakshmi et al. (2018) and Chakraborty and Athmaselvi, (2014) also reported an increase in total colour difference with increase in voltage gradient or electric field. It was reported that colour changes during ohmic heating could be due to browning in presence of oxygen and metal ions (Icier et al., 2008). The active carbonyl groups released during the degradation of ascorbic acid could also help in enzymatic browning (Leizerson and Shimoni, 2005). But the enzymatic browning would be negligible during ohmic heating since the oxidative enzymes get inactivated at higher temperatures.

Total bacterial, yeast and mould population

The total bacterial and yeast reduction in cashew

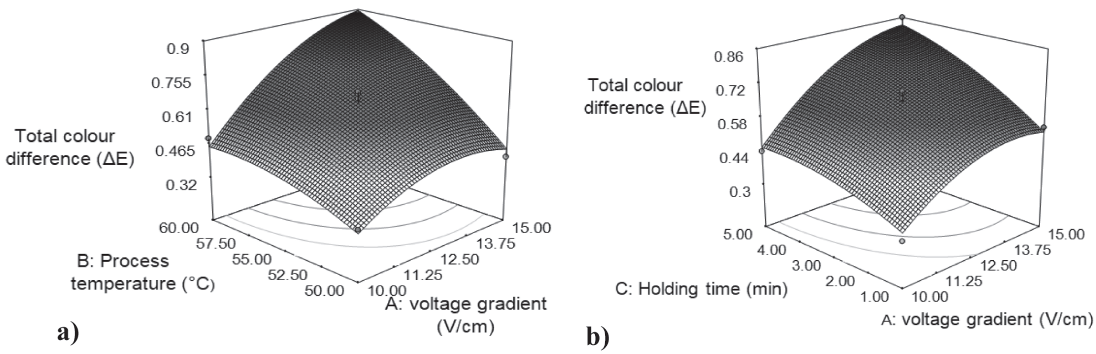

Figure 4. Effect of ohmic heating parameters on total colour difference of cashew apple juice

apple juice was obtained in the ranges from 1.71 to 4.26 and 1.5 to 3.17 log cfu/ml respectively. Highest bacterial log reduction of 4.26 log cfu/ml and yeast and mould reduction of 3.17 log cfu/ml was observed during the ohmic heating treatment where the voltage gradient was 12.5 V/cm, holding time 5 min and process temperature 60°C, while the lowest reduction in bacterial and yeast was observed when the voltage gradient was10 V/cm, holding time 1 min and process temperature 55°C.

The effects of voltage gradient, holding time and process temperature on the log reduction of bacterial and yeast count of ohmic heated juice samples are presented as in Figures. 5 (a & b) and 6 (a & b). All process parameters had a significant effect on bacterial and yeast reduction. According to the time-temperature combination the microbiological reduction was also found to vary. The microbiological inactivation during ohmic heating was primarily due to the thermal effects. The higher temperatures and longer heating time during ohmic heating could have successfully created a hostile environment for the microorganisms through membrane destruction and inactivation of microbial enzymes (Sun et al., 2008). This result was in conformation with findings of Uemura and Isobe (2003) on *B. subtilis* spores and Ryang et al. (2015, and 2016) on *Bacillus cereus* spores.

Previous investigators reported that microbial reduction during ohmic heating had an additional non thermal mechanism of inactivation (Cho et al., 1999; Sun et al., 2009). During ohmic heating, the exposure of low frequency electric field might have resulted in electroporation of cell membrane through the formation of pores in the lipid bylayer and proteins of cell membrane due to changes in internal

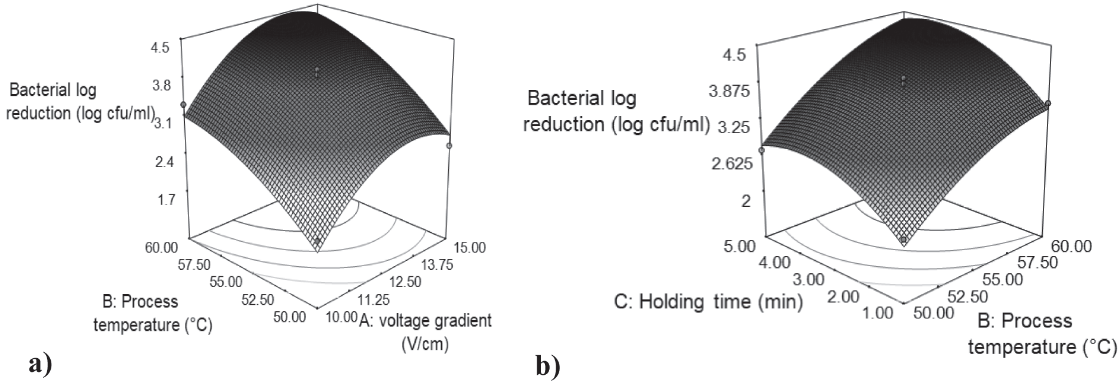

Figure 5. Effect of ohmic heating parameters on bacterial log reduction of cashew apple juice

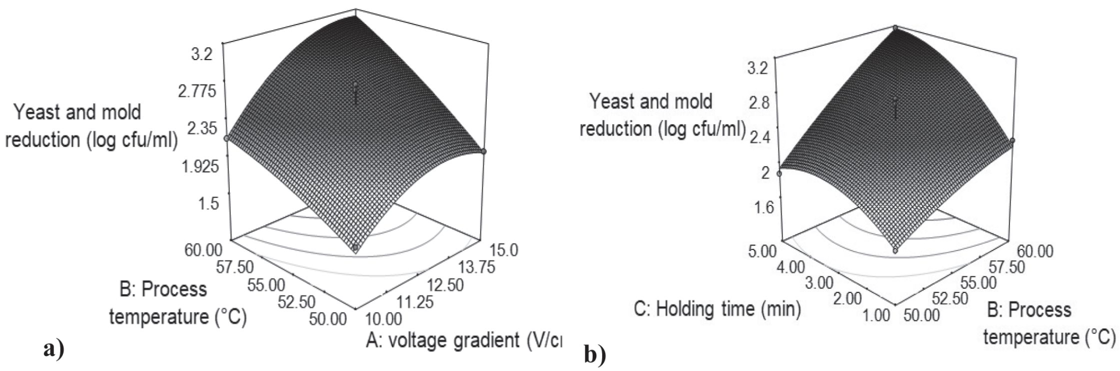

Figure 6. Effect of ohmic heating parameters on yeast and mould log reduction of cashew apple juice

Table 1. Effect of different ohmic heating process parameters on the responses of cashew apple juice

Run	Voltage gradient (V/cm)	Process temperature (°C)	Holding time (min)	pH	TSS °Brix	Ascorbic acid (mg/100ml)	Total colour difference	Bacterial reduction (log cfu/ml)	Yeast and mold reduction (log cfu/ml)
1	10	60	3	4.22	7.36	156.65	0.49	3.32	2.14
2	12.5	55	3	4.26	7.53	159.58	0.69	3.96	2.75
3	15	60	3	4.32	7.91	155.72	0.88	4.13	3.05
4	10	55	1	4.24	7.25	166.85	0.3	1.71	1.5
5	12.5	60	5	4.24	7.72	154.32	0.84	4.26	3.17
6	12.5	50	1	4.33	7.3	167.23	0.37	2.21	1.66
7	12.5	60	1	4.32	7.42	159.06	0.58	3.53	2.27
8	10	55	5	4.21	7.31	160.29	0.44	2.45	1.79
9	12.5	50	5	4.25	7.41	161.42	0.51	2.72	1.88
10	15	55	1	4.34	7.52	165.21	0.54	2.94	1.86
11	15	55	5	4.26	7.86	157.79	0.86	4.24	2.95
12	12.5	55	3	4.27	7.64	158.35	0.68	3.94	2.39
13	12.5	55	3	4.31	7.69	162.34	0.61	3.6	2.5
14	10	50	3	4.23	7.22	165.35	0.34	1.94	1.6
15	15	50	3	4.31	7.48	165.24	0.41	2.56	1.99
16	12.5	55	3	4.28	7.55	160.15	0.64	3.86	2.69
17	12.5	55	3	4.29	7.62	161.29	0.66	3.88	2.42

and external cell potentials (Castro et al., 2004; Sitzmann, 1995).

Optimization

Optimum process conditions within a specific domain were predicted by the optimization of ohmic heating parameters to provide the desired response goal. For optimization of the operative parameters during ohmic heating the responses were minimized or maximized to get the desired outcome. The microbial log reduction, ascorbic acid, and pH value were maximized, the total colour difference was minimized and all independent values were kept in range. The higher desirability values were found for optimum process conditions of ohmic heating treatment. The optimum conditions for ohmic heating process were found to be a voltage gradient of 14.21 V/cm, treatment temperature of 55.47°C and holding time of 2.43 min with predicted responses such as bacterial log reduction of 3.46, yeast and mould reduction of 2.36, and ascorbic acid content of 163.45 mg/100 ml.

The study portraits the effect of ohmic heating of cashew apple juice with the objective of optimizing the process conditions. The process parameters such as voltage gradient, process temperature, and holding time were studied for their influence on bacterial, yeast and mould inactivation. A bacterial log reduction of 4.26 log cfu/ml and yeast and mould reduction of 3.17 log cfu/ml were observed during the treatment with voltage gradient of 12.5 V/cm, process temperature of 60°C and holding time of 5 min. The ascorbic acid showed a gradual degradation during the process. The maximum total colour difference of 0.88 was observed in treated cashew apple juice without any visual colour change. The ohmic heating reduced the bacterial, yeast and mould population in the juice, and reduction in ascorbic acid content was minimum compared to other reported studies. It could be concluded that ohmic heating process at the optimized process conditions as stated could be an alternative mild heat treatment process that retained the quality parameters of the processed cashew apple juice.

Acknowledgment

Cashew Research Station, Madakkathara, KAU is acknowledged for providing raw material for the research.

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