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Vacuum Ohmic Heating: A Promising Technology for the Improvement of Tomato Paste Processing, Safety, Quality and Storage Stability

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Abstract: Ohmic heating (OH) is an electrothermal technology used to inactivate enzyme and microbial activities. This work aimed to study the impact of Ohmic Heating Under Vacuum (OHUV) which compared to conventional heating (CH) as well as storage stability at 5°C and 25 °C on microbial safety, and nutritional quality. The evaluation parameters were pH, titratable acidity, TSS, lycopene, ascorbic acid, PME, HMF, and microbiological activity. The obtained results showed that tomato paste samples that were treated by OHUV are significantly superior to CH in terms of all physicochemical and microbiological characteristics, as well as being the least harmful during storage in both transparent and dark packages. The results showed the changes in ascorbic acid, lycopene, and HMF values that were treated by OHUV at 25 °C and filled in transparent package are most affected compared to other treated samples. On the other hand, tomato paste samples stored in dark packages at 5 °C performed significantly better than those subjected to CH under the same conditions and activated PME the most had higher ascorbic acid and lycopene and fewer changes in HMF during storage time for 90 days. OHUV found to be a good alternative treatment in the production of tomato paste.

Keywords: HMF, Ohmic heating, Paste, PME, Tomato.

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most planted crops in the world and the fourth most economically valuable food crop with an estimated worldwide production of 88 billion US$ (FAOSTAT, 2019; Buajaila *et al*., 2021). It is considered one of the most valuable crops because of its high content of essential nutrients and antioxidant-rich phytochemicals (Ali *et al*., 2021; Xalmuminova & Sulaimonova, 2021). Also, tomato fruit is rich in flavonoid and anthocyanin content (Hmiz *et al*., 2019). Therefore, it reduces the activity of free radicals besides containing a variety of vitamins such as vitamin A and ascorbic acid, phenolic compounds including phenolic acids and flavonoids, lycopene, minerals, fiber, and carbohydrates, which have a positive impact on health due to bioactive compounds that are

important for cardiovascular health, anti-cancer properties and skin health (Bazani *et al.*, 2021; Khan *et al*., 2021; Zhao *et al*., 2021a; Collins *et al*., 2022; Dewantara *et al*., 2022; Eweys *et al*., 2022).

Several studies have revealed that different tomato treatment techniques have different effects on its compounds such as producing ketchup, puree, sauce, juice, soup, and canned tomatoes to reduce their rapid spoilage (Jafari *et al.,* 2021; Kiralan & Ketenoglu., 2022; Wu *et al.,* 2022). Therefore, it is usually subjected to heat traditional methods such as pasteurization, sterilization, peeling, cooking, and drying, which leads to degradate of the nutritional value and thus negatively affects the quality (Zhang *et al*., 2019; Alkanan *et al*., 2021a).

Ohmic heating is one of the recent technologies that uses alternating electric current to heat food and food acts as a resistance to heat rapidly in which alternating current passes by two electrodes in direct contact with food through the OH device. In conventional heating, heat transfer from a heated surface to the product interior occurs by conduction and convection, but in OH it occurs volumetrically (inside-outside heat transfer pattern) and can reduce over-processing. Additionally, OH is similar to high-temperature short-time (HTST) treatments and heats juices rapidly and uniformly. Besides, OH is a rapid and consistent heating technology that inactivates enzymes and microbial load in a lower time with less odor and ascorbic acid loss than traditional heating (Abedelmaksoud *et al*., 2018).

Tomato paste is one of the main products of tomato and its quality depends mainly on raw material quality and treatment conditions including treatment design, required time, temperature, pressure, storage period, and method of storage (Shatta *et al*., 2017). Of course, citric acid is the primary acid in tomatoes that affects the pH and acidity of tomato paste (Wilkerson *et al*., 2013). In addition, heat and light are the key factors that have a main effect on lycopene decomposition reactions during processing (Martínez-Hernández *et al*., 2016). Also, the formation of HMF compound during the treatment of tomato sauces is limited compared to the possibility of increasing its content when stored at 37°C (Apaiah & Barringer, 2001). It is also important to inactivate pectin methylesterase by heat at 90-95 °C because of its effect on the pectin quality that will give a product with high viscosity (Hsu, 2008). Therefore, the objective of this study was to determine the impact of vacuum ohmic heating on the quality, safety and storage stability of tomato paste.

Materials & Methods

Sample preparation and processing

Ripe tomatoes were chosen, washed, and cleaned. After tomato cutting, a cold crushing of the tomato was done and then placed in the mechanical press to separate the juice from peels and seeds (Alkanan *et al*., 2021b). Then, the particles, impurities, seeds, and husks were removed by filtration using sterilized gauze. The seeds and peels weighed between 0.200 and 0.340 kilograms, while the juice of tomatoes weighed between 4.660 and 4.800 kilograms. An OH-VC combination device was utilized to treat the tomato juice. For each of the 20 treatments, the control panel was utilized to set the temperature, pressure, and electrical field for 70, 80, and 90 ºC, as well as 0.7, 0.5, 0.3 bar, and 1.82, 2.73, and 3.64 Vcm^{-1}, respectively. Until further analysis, the tomato paste was transferred into a clean, sterilized glass container and kept at 4ºC.

Conventional Heating

In order to maintain a temperature of 87-90 °C and avoid direct contact with the heat source, the conventional heating treatment was carried out by means of a heat transfer fluid (water) in the double jacket vat.

Ohmic-Vacuum (OH-VC) combination heating device

The Food Engineering Laboratory, situated within the Department of Food Science of the College of Agriculture at the University of Basrah in Iraq, the OH-VC combination heating device manufactured by Alkanan *et al.* (2021b) was used (Fig. 1). The apparatus consisted of two rectangular electrodes, an OH cylinder, a control valve, a thermocouple, and a vacuum pressure gauge. To remove water from the air, two hunters were employed, and a glass condenser was used to turn the water vapor into a liquid form, a control panel was used, and an in-system cleaning device was the system's other components. A vacuum pump was connected via a plastic pipe to an ohmic heating cylinder. The heat-resistant plastic of the cylindrical OH chamber had a capacity of 8 L, a thickness of 1.5 cm, a diameter of 27 cm, and a height of 85 cm. The inner wall of the cylindrical OH chamber was fixed with rectangular electrodes made of stainless steel of type 316 with dimensions of 35 × 10 cm. A voltage regulator controlled the 50 Hz frequency and the alternating current (AC) produced by the heat generation system, which ranged from 0 to 220 V.

The operating pressure of the OH cylinder was between 0.3 and 0.7 bar, which was lower than the atmosphere pressure. The tomato paste was collected in a tank of 10 L made of stainless steel.

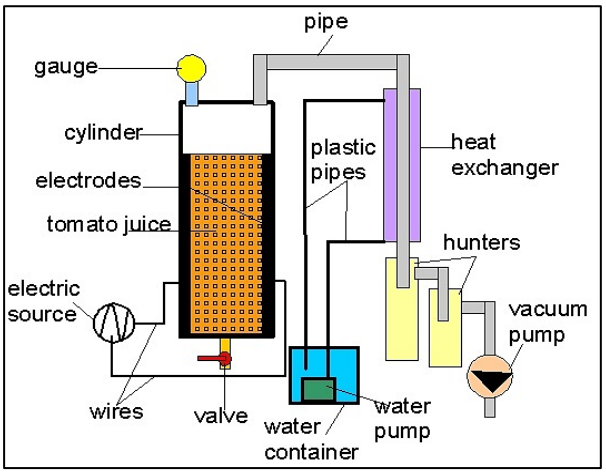

Fig. (1) Schematic diagram of the ohmic-vacuum(OH-VC) combination heating device

Physicochemical analysis

pH determination

About 10 ml of deionized water was combined with approximately 5g of tomato paste. The mixture was heated to 100ºC in an ultra-homogenizer.The pH was determined after the mixture cooled to 20ºC (AOAC, 2016)..

Titratable acidity

Ten ml of distilled water was added to 10 g of tomato paste and heated to 100°C to eliminate CO_2 (AOAC, 2016). The solution was then adjusted to a pH of 8.03 using 0.1 N NaOH (AOAC, 2016).), and the following equation was used to calculate the acidity in terms of a percentage of citric acid:

$$Titrable\ acidity\ (\%\ citric\ acid) = \frac{V_{NaOH} \times C_{NaOH} \times 0.070 \times 100}{V_{sample}} \quad (1)$$

Where V_{NaOH}= titratable volume of solution; Vsample= titratable volume of sample; C_{NaOH}= concentration of NaOH solution.

Total Soluble Solids (TSS)

A refractometer (Bellingham + Stanly, Bellingham, UK) was used to measure total soluble solids (TSS). The tomato paste sample was poured onto the SCO, Dingetstädt,

Germany, refractometer prism (Dingetstädt, Germany).

Ascorbic Acid (AA) content

Ascorbic Acid (AA) Content inside tomato paste was determined using an iodine titration method (AOAC, 2016; Tudor-Radu *et al*., 2016). After weighing five grams of tomato paste in a beaker, 100 ml of 2% hydrochloric acid were added. The mixture was then left for 15 min before being filtered (Whatman no. 1 paper). After that, 5 ml of this solution was filtered, and 3ml of 1% potassium iodide and 5ml of distilled water were added. 2ml of a fresh starch solution containing 1% (w/v) was used as an indicator. To achieve a clear, dark brown color, the tomato juice solution was titrated with potassium iodate KIO3 (0.0017 M). The following equation was used to calculate the amount of AA present:

$$AA=0.88\times IS \quad (2)$$

Where, AA is the ascorbic acid content ($mg100^{-1}$ ml^{-1} sample), and IS is the iodine solution (ml).

Lycopene content

Ranganna (1986) and Abdullah *et al*. (2019) method for crude lycopene extraction was used with a few minor adjustments. Thirty grams of the dried tomato waste powder were put into 150 ml of acetone. The mixture was stirred for 30 min using a magnetic stirrer. After that, the filtrate was taken out and extracted once more for another 30 minutes using 150 ml of acetone. After that, the filtrate was taken out, and the extraction process was repeated until the color disappeared. A separatory funnel was filled with 60 ml of petroleum ether, then a small amount of acetone extract was added. The aqueous acetone was thrown away from the two phases that were achieved; after being collected, the petroleum ether phase was dried with anhydrous sodium sulfate, and then it was evaporated using a rotary evaporator at 35°C until the final volume was 5 ml. For the purpose of quantifying lycopene, Rodriguez-Amaya & Kimura's (2004) method was utilized. Before being diluted with petroleum ether, a 50-ml aliquot of lycopene-containing petroleum ether phase was poured into a 10 ml volumetric flask. After that, petroleum ether was used as a blank for the absorption measurement at 470 nm. The following equation was used to determine the amount of lycopene.

$$TLC = A \times V \times 104 / A_{1cm}^{1\%} cm \times W \quad (3)$$

Where, TLC is the Total Lycopene Content (µg g-1), A is the absorbance; V is the total volume of extract (ml), A 1cm^(1%)cm: absorption coefficient of lycopene in petroleum ether = 3450, and W is the sample weight (g).

Hydroxymethyl furfural (HMF)

Hydroxymethyl furfural content was done according to Cohen *et al.* (1998). Five mL of 95% ethyl alcohol and tomato juice sample was mixed. The mixture was separated into two parts by centrifugation at 1000 g for 15 minutes. A 16ml screw cap tube was filled with 2ml of each ingredient. A 2ml of Trichloroacetic acid (12% w/w) (TCA, Sigma, Germany) and 2ml of thiobarbituric acid (0.025 M) (TBA; BDH Limited, England) were added later. For 50 minutes, the tubes were kept at 40˚C ±0.5˚C in the water bath (Grant-England) followed by cooling using tap water. The absorbance was measured at 443 nm and a calibration curve of HMF (Aldrich, Germany) was utilized to quantify the HMF concentration.

Pectinmethylesterase (PME)

PME content was estimated according to Kimball (1999) with a slight adjustment. A standard solution of 1 percent pectin salt was

made by dissolving 15.3 g of NaCl and 10 g of pectin in distilled water. A 2N and 0.05N NaOH solutions were prepared as stock. Ten ml tomato juice and 40 ml pectin-salt solution were mixed in a 100-ml beaker. The 100-ml beaker was placed inside another 250-ml beaker filled with water. Both the beakers were stirred magnetically at 30°C; afterward, a few drops of NaOH (2N) solution was added to reach neutrality. A 0.1ml of NaOH (0.05N) was added to the solution to determine its activity, and the time it took to reach the same pH level was recorded. The equation utilized for the PME was as follows :

$$\text{PME (unit/ml)} = \frac{NaOH\ (0.05N) * 0.1\ ml\ NaOH\ (0.05N)}{10\ ml\ of\ sample * time\ (minute)} \quad (4)$$

Microbiological analysis

A serial dilution method was used to evaluate the microbiological analysis: 9 ml of peptone water and 1 g of tomato paste were added to a sterilized glass tube. The agar plates received 1 ml of each test tube. TPC was performed on the plates after an incubation period of 24-28 hours at 35°C. MacConkey agar was utilized to estimate coliform bacteria. Potato dextrose agar was used for yeast and mold. At 25-28°C, the incubation time was three days. The obtained results were expressed using the tomato log CFU. ml^{-1} (Keyser *et al*., 2008; Zhao *et al*., 2021b).

Statistical analysis

Analysis of variance (ANOVA) XLSTAT software (Addinsoft, New York, NY, USA) was used to analyze the experimental data, three replicates were used and the results were presented as the mean ± the standard error of the mean. The significant level of $P < 0.05$ was used to determine the significance of variance from the mean of the samples.

Results & Discussion

Effects of storage condition on the physico-chemical properties of tomato paste

The pH of the tomato paste samples during the storage period

In general, the pH values for all treated tomato paste samples was increased with passing the storage time either at 25°C or at 5°C using transparent and dark packages (Table 1). All samples stored in transparent packages were most affected compared to dark packages either treated by ohmic heating under vacuum (OHUV) or conventional heating (CH). The pH value of tomato paste treated by OHUV at 25°C in transparent package ranged from 4.20-4.49 and started to increase after 30 days of storage time. While in case of dark packages ranged from 4.20-4.48 and started to increase after 45 days of storage. Also, the pH value of tomato paste treated by OHUV at 5°C in transparent and dark packages ranged from 4.20-4.42 and 4.20-4.38, respectively and the change was observed after 60 days of storage time .

On the other hand, the pH value of tomato paste samples treated by CH and stored in transparent packages increased compared to samples stored in dark packages at 25°C. The increase in pH values was observed in both transparent and dark packages after 15 days of storage, reaching from 4.38 to 4.67 and from 4.32 to 4.65, respectively. The same changes in pH value of tomato paste samples treated by CH and stored in transparent and dark packages at 5°C. The increase in the pH values was observed after 30 days for the samples stored in transparent and dark packages, as they ranged from 4.34-4.56, respectively. As for the sample of dark packages under the same conditions, it ranged from 4.32-4.56. This is consistent with what was mentioned by Mgaya-Kilima *et al.* (2015) that the pH could

change according to the storage period and temperature. Additionally, these results are close to what was found by Jafari *et al*. (2021) in their study of the effect of storage on the pH value of tomato paste stored at 25°C for six months. Additionally, Tamuno & Onyedikachi (2015) mentioned that storage at room temperature for 3 to 4 months significantly increased the pH of the juice .

Fig. (2) showed a significant variance ($p < 0.05$) between samples subjected to ohmic and conventional heating and stored in transparent or dark packages at 5 and 25 °C. The pH average values for samples stored at 5 °C in transparent packages were 4.26 and 4.40, respectively. For dark packages at 5°C, the pH values were 4.24 and 4.39, respectively. On the other hand, for the samples stored at 25°C, there was a significant ($p < 0.05$) variance between the samples of transparent packages or dark packages subjected to OHUV and CH. For transparent packages, pH values ranged between 4.31 and 4.56. For dark packages, the pH values ranged between 4.30 and 4.46. It was in agreement with what was mentioned by Poojitha & Athmaselvi (2016) in their study, which demonstrated that the increase in pH values during the storage period was less in the sample subjected to ohmic heating compared to the sample treated conventionally. The result showed that the type of treatment, temperature, type of used packages, and type of storage had significant variance; while the interaction between them had no significant effect ($p < 0.05$). Ohmic heating can cause changes in the chemical structure of food components, such as proteins and carbohydrates, leading to the formation of new compounds.For example, the Maillard reaction, which is a chemical reaction between mino acids and reducing sugars, can occur at a faster rate during ohmic heating compared to conventional heating.

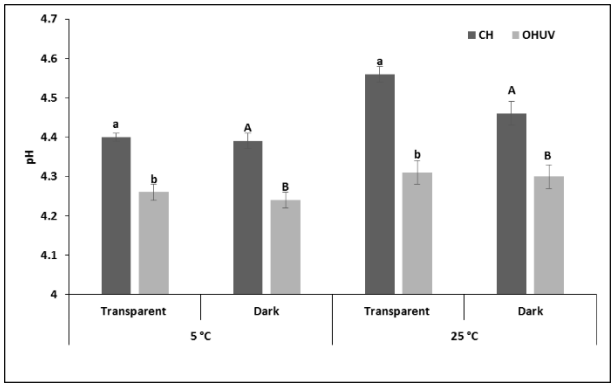

Fig. (2): The average pH value in paste samples produced by ohmic (OHUV) and conventional heating (CH) treatments and stored at temperatures of 25°C and 5 °C for 90 days (the deferent capital and small letters in each bar indicate a significant difference for transparent and darkness, respectively)

This reaction can lead to the formation of brown pigments and the release of protons, which can increase the acidity of the food product. Additionally, ohmic heating can cause changes in the ionization of acidic and basic groups in food components, which can affect the pH of the food product. For example, the dissociation of carboxylic acid groups in tomato paste can result in the release of protons and the formation of carboxylate ions, leading to a decrease in pH. However, the exact mechanism underlying the pH increase during storage in ohmic heated tomato paste samples compared to conventionally treated samples may depend on a range of factors, such as processing conditions, storage temperature, and the composition of the tomato paste itself.

Table (1): Effect of different heating treatments, packaging materials and temperatures on (pH) during 90 days of storage.

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	4.2 ±0.007	4.2 ±0.007	4.21 ±0.014	4.25 ±0.056	4.39 ±0.007	4.45 ±0.035	4.49 ±0.014
		Dark	4.2 ±0.007	4.2 ±0.004	4.2 ±0.015	4.24 ±0.045	4.38 ±0.010	4.44 ±0.049	4.48 ±0.009
	5	Transparent	4.2 ±0.007	4.2 ±0.018	4.2 ±0.012	4.2 ±0.003	4.26 ±0.021	4.36 ±0.008	4.42 ±0.043
		Dark	4.2 ±0.007	4.2 ±0.0.026	4.2 ±0.024	4.2 ±0.011	4.22 ±0.021	4.34 ±0.020	4.38 ±0.019
Conventional heating	25	Transparent	4.3 ±0.007	4.38 ±0.006	4.52 ±0.028	4.58 ±0.012	4.62 ±0.014	4.65 ±0.020	4.67 ±0.004
		Dark	4.3 ±0.007	4.32 ±0.012	4.39 ±0.014	4.44 ±0.029	4.57 ±0.028	4.6 ±0.033	4.65 ±0.021
	5	Transparent	4.3 ±0.007	4.31 ±0.007	4.34 ±0.007	4.41 ±0.021	4.43 ±0.565	4.5 ±0.035	4.56 ±0.0141
		Dark	4.3 ±0.007	4.31 ±0.007	4.32 ±0.007	4.39 ±0.014	4.4 ±0.0141	4.49 ±0.021	4.56 ±0.035
LSD0.05 for interaction of treatments×Temperature×package×storage period			0.0123						

Titration acidity of tomato paste samples during the storage period

There is an indirect relationship between titratable acidity % and pH values. Therefore, a decrease in titratable acidity % in all treated tomato paste samples was observed with passing the storage time either at 25°C or at 5°C using transparent and dark packages (Table 2). All the samples stored in transparent packages were most affected compared to dark packages either treated by ohmic heating under vacuum (OHUV) or conventional heating (CH). The acidity development was started in the samples subjected to OHUV and stored in transparent packages at a temperature of 25 °C after a month storage period (Table 2), where it decreased from 0.42 to 0.29% during storage time. The samples stored in dark packages were similar to transparent packages, but less in the development of acidity values. The change in the acidity values started after 45 days and decreased from 0.42% to 0.31during the storage period. This is similar to what Singh *et al.* (2020) found in their study on tomato paste during storage for 60 days at 25°C, that there is a slight increase in titratable acidity values.

Tomato paste samples treated by CH and stored in transparent packages at 25°C were the highest in the decrese of acidity values and more developed than the samples treated by OHUV. The acidity change was slight for all samples throughout the storage period from 0-90 days which decresed from 0.35-0.18 %. However, the change of paste samples in dark packages for the same temperature were slightly lower and decreased from 0.35 - 0.20%. It is evident from table (2) that the

acidity of the OHUV treated samples stored at 5 °C gave the lowest change in acidity. The decrease in acidity values started from day 45 to the end of storage time in transparent packages from 0. 41 to 0.35%, while in dark packages the acidity decreased after day 60 and decreased from 0.41to 0.36%. The samples subjected to the CH and stored at the same temperature were the fastest in the development of acidity compared to the samples subjected to OHUV. Its reduction started on the 15th day for transparent and dark packages, as it decreased from 0.35 to 0.20% and 0.35 to 0.23%, respectively. There is a significant variance between the transparent package sample for both the OHUV and CH treatments at 5°C (Fig. 3). A significant variance was also obtained between the dark package samples for both treatments. The average values of acidity values were 0.28 and 0.39 % for the sample of transparent packages subjected to HUV and CH.while for the dark packages, these samples were 0.29 and 0.4 % for both treatments, respectively. There were significant ($p < 0.05$) variance between the transparent packaging samples subjected to OHUV and CH treatment with averaged acidity values of 0.25 and 0.37%, respectively. In addition, significant variance ($p < 0.05$) between the surface acidity of dark packages for both OHUV and CH treatments were 0.27 and 0.38 %, respectively. Gould (1992) attributed the reason for the change in acidity values when treating tomato products and its interaction with storage temperature to the oxidation of alcohols and aldehydes.

The results showed that the type of used treatment in the process of heating and temperature had a significant effect ($p < 0.05$) on the buoyant acidity. There was no significant variance ($p > 0.05$) between transparent and dark packages. In contrast, the type of storage had a significant effect ($p < 0.05$) on surface acidity. Also, there was no significant variance ($p > 0.05$) in the interaction between type of treatment, temperature, type of packaging, and type of storage. Choi *et al*. (2012) mentioned that heat-treatment and 60-day of stored sterilized garlic pulp paste reduced the acidity values, which helping prevent or reduce the growth of microorganisms.

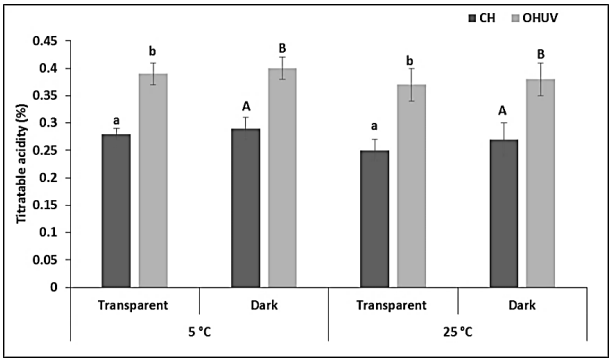

Fig. (3): The average values of titratable acidity in paste samples produced by ohmic (OHUV) and conventional heating (CH) treatments and stored at temperatures of 25°C and 5°C for 90 days (the defrent capital and small letters in each bar indicate a significant difference for transparent and darkness, respectively

Table (2): Effect of different heating treatments, packaging materials and temperatures on titratable acidity content (%) during 90 days of storage

Treatments	Temperatu-re (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	0.42 ±0.042	0.42 ±0.017	0.41 ±0.011	0.39 ±0.002	0.36 ±0.008	0.33 ±0.002	0.29 ±0.001
		Dark	0.42 ±0.042	0.42 ±0.005	0.42 ±0.031	0.4 ±0.021	0.37 ±0.019	0.35 ±0.004	0.31 ±0.009
	5	Transparent	0.42 ±0.042	0.42 ±0.005	0.42 ±0.015	0.41 ±0.021	0.39 ±00.019	0.37 ±0.016	0.35 ±0.014
		Dark	0.42 ±0.042	0.42 ±0.012	0.42 ±0.008	0.42 ±0.017	0.41 ±0.010	0.38 ±0.003	0.36 ±0.003
Conventional heating	25	Transparent	0.35 ±0.014	0.32 ±0.028	0.29 ±0.025	0.25 ±0.022	0.22 ±0.024	0.2 ±0.030	0.18 ±0.021
		Dark	0.35 ±0.014	0.34 ±0.026	0.3 ±0.025	0.27 ±0.014	0.24 ±0.016	0.22 ±0.027	0.2 ±0.023
	5	Transparent	0.35 ±0.014	0.34 ±0.007	0.3 ±0.022	0.28 ±0.012	0.26 ±0.017	0.23 ±0.006	0.2 ±0.033
		Dark	0.35 ±0.014	0.34 ±0.014	0.31 ±0.003	0.29 ±0.008	0.28 ±0.012	0.26 ±0.017	0.23 ±0.035
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			0.0115						

Total soluble solids of tomato paste during storage period

The changes in the TSS were followed every 15 days for three months (Table 3). The results showed a slight decrease in the TSS values during storage at 25ºC in both transparent and dark packages. TSS of OHUV treated samples at 25ºC was decreased from 27.5 to 26.63 °Brix for transparent package and from 27.5 to 26.66°Brix for dark package. Regarding, CH samples stored at 25˚C, it decreased from 28 to 27.01 °Brix for transparent packages and 28 to 27.04°Brix for dark packages during storage for 90 days. The TSS of samples treated by OHUV stored at 5ºC and filled in transparent and dark packages decreased from 27.5 -27.10 and 27.5 - 27.13 °Brix, respectively. While TSS in samples treated by CH and stored at 5ºC decreased from 28-27.42% and 28 -27.45 Brix, respectively. These results matched with the findings of Nwanekezi & Onyeali (2005) that the decrease in the concentration of total soluble solids was greater in tomato pulp stored at 25°C compared to a low temperature of -10°C.

Fig. (S1) shows a significant variance ($p < 0.05$) between samples subjected to OHUV and CH and stored in transparent packages at a temperature of 5°C, with TSS were 27.24 and 27.73 °Brix, respectively. Moreover, there

were significant ($p < 0.05$) variance between the samples of dark packages for the OHUV and CH treatments at the same temperature, TSS were 27.25 and 27.75 °Brix, respectively.

For the samples stored at 25 °C, there was significant ($p < 0.05$) variance between the samples of transparent packages subjected to OHUV and CH and TSS was 27.01 and 27.51 °Brix, respectively. In addition, there is significant variance ($p < 0.05$) between the dark packages for both treatments at the same temperature and TSS was 27.03 and 27.54 ° Brix for the sample subjected to OHUV and CH , respectively. The results agreed with the findings of Poojitha & Athmaselvi (2016) in their study of the concentration of total dissolved solids on the pulp of bananas subjected to ohmic and conventional heating, which found that the change in the percentage of total dissolved solids (TSS) in the sample subjected to ohmic heating is less when compared to the sample subjected to convectional heating and indicated that this may depend on the processing time and storage method. There was significant variance ($p < 0.05$) for each temperature, type of treatment, method of storage and type of packaging. Significant variance ($p < 0.05$) has been obtained after the interaction between temperature, type of treatment, storage method and type of packaging. Asgar (2020) explained that the reason for the decrease in total solid concentration during storage may be attributed to enzyme activity, as well as the growth of microorganisms that work to break down and damage nutrients, thus reducing the values of total dissolved solids.

Ascorbic acid content in tomato paste during storage

The results showed that the decrease in ascorbic acid content was most affected by the temperature of 25°C for the transparent packages for OHUV and CH treatments, which started on the 15th day until 90 days (Table 4). The content of ascorbic acid during this period ranged from 49.20 - 64.77 $mg.100^{-1}$ ml^{-1} for tomato paste samples subjected to OHUV, while the content of ascorbic acid in ascorbic acid in the tomato paste samples subjected to CH ranged from 30.73- 46.55 $mg.100^{-1}$ ml^{-1} at the same conditions and storage period.

The paste samples stored in dark packages at a temperature of 25°C gave slightly lower values compared to the values of ascorbic acid content in transparent packages during the storage period for each sample subjected to ohmic heating and conventional heating was 52.36-67.76 $mg.100^{-1}.ml^{-1}$ and 32.91 -50.16 $mg.100^{-1}$ ml^{-1}, respectively.

During storage time (90 days), the concentration of ascorbic acid in the samples subjected to OHUV and stored in transparent and dark packages at 25°C ranged from 57.98 - 67.76 $mg.100^{-1}$ ml^{-1} and 58.63 - 67.76 mg 100^{-1} ml^{-1}, respectively. But, the samples treated by CH under the same conditions ranged from 40.89 - 50.16 mg100-1 ml-1 and 41.93 -50.16 mg 100^{-1} ml^{-1}, respectively. Additionally, Famurewa *et al.* (2013) found a slight reduction in ascorbic acid content when tomato paste was stored for six weeks. Besides, Famurewa *et al*. (2013) explained that increasing temperatures usually lead to losing a high percentage of ascorbic acid. Also, Francis (2015) found a significant decline in the content of ascorbic acid to less than 65% in the samples packed in transparent packages, while the closed or dark packages maintained the ascorbic acid content to more than 90%. Fig. (S2) indicated a notable variance ($p < 0.05$) between samples treated with OHUV and CH, and packaged in either transparent or dark materials at a temperature of 5°C.

Table (3): Effect of different heating treatments, packaging materials and temperatures on TSS content (brix) during 90 days of storage.

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	27.5 0.707±	27.43 0.282±	27.2 0.346±	26.92 0.749±	26.76 0.622±	26.66 0.940±	26.63 0.622±
		Dark	27.5 0.707±	27.47 0.191±	27.17 0.078±	26.94 0.014±	26.8 0.155±	26.69 0.961±	26.66 0.629±
	5	Transparent	27.5 0.707±	27.42 0.24±	27.34 0.636±	27.21 0.29±	27.19 0.127±	27.15 0.240±	27.1 0.028±
		Dark	27.5 0.707±	27.45 0.643±	27.36 0.198±	27.22 0.113±	27.21 0.502±	27.17 0.127±	27.13 0.071±
Conventional heating	25	Transparent	28 1.414±	27.92 0.106±	27.79 0.197±	27.56 0.339±	27.22 0.106±	27.11 1.103±	27.01 0.827±
		Dark	28 1.414±	27.95 0.113±	27.83 0.035±	27.58 0.275±	27.25 0.169±	27.15 0.063±	27.04 0.021±
	5	Transparent	28 1.414±	27.90 ±0.141	27.81 0.064±	27.74 0.375±	27.74 0.120±	27.55 0.282±	27.42 0.255±
		Dark	28 1.414±	27.93 0.106±	27.82 0.375±	27.78 0.049±	27.7 0.212±	27.61 0.318±	27.45 0.417±
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			0.121						

Samples packaged in transparent materials had an average ascorbic acid content of 63.62 $mg.100gm^{-1}$, while those in dark packages had an average of 46.56 mg.100-1gm-1. Similarly, at 25°C, there was a significant ($p < 0.05$) variance between samples packaged in transparent materials and treated with OHUV and CH, with average ascorbic acid contents of 58.53 and 39.82 $mg.100^{-1}.ml^{-1}$, respectively. There was significant variance ($p < 0.05$) between the dark packages for both treatments at the same temperature, and which averaged values of ascorbic acid content were 60.35 and 41.12 $mg100^{-1}.ml^{-1}$ for the sample subjected to OHUV and CH, respectively. These results were similar to the results which were discovered by Poojitha & Athmaselvi (2016) in that the rate of decomposition of ascorbic acid during storage was lower in the sample .

These results were near to the results of Poojitha & Athmaselvi (2016) in that the rate of decomposition of ascorbic acid during storage is lower in the sample subjected to ohmic heating compared to the sample subjected to conventional heating during 35 days of storage. Additionally, as found by Shalaby *et al*. (2013) in the ascorbic acid content is significantly affected by the thermal concentration of tomato juice. There was significant variance ($p < 0.05$) for each temperature, types of treatment, storage method, and type of package. It was noted from the results that there was no significant variance ($p > 0.05$) for an interaction between the mentioned four factors. Therefore, the decrease in ascorbic acid content may be due to its oxidation to dehydroascorbic acid resulting in hydrolysis to convert to 2, 3-

diketogluconic acid, which is subjected to polymerization to turn into other inactive products (Dewanto *et al*., 2002).

Lycopene content of tomato paste during the storage period

Lycopene content was stable in the two samples subjected to OHUV and CH and at the two used temperatures (Table 5). The lycopene content in tomato paste samples stored in transparent packages at a temperature of 25°C was more affected than the sample stored in dark packages. The values ranged from 33.93 - 29.01 mg. kg^{-1} for the sample subjected to OHUV compared with the lycopene content in CH treated sample stored in transparent packages at the same storage conditions, which amounted to 28.51-23.21 $mg.kg^{-1}$. While the dark packages gave less decrease in lycopene content for both OHUV and CH treatments, it was 33.93-30.11 $mg.kg^{-1}$ and 28.51-24.73 $mg.kg^{-1}$, respectively. Lin & Chen (2005) and Markovic *et al*. (2007) also estimated the concentration of lycopene in tomato products and noticed a significant decrease in the lycopene content when stored at 25°C.

The results showed a slight change in lycopene content when tomato paste samples were stored at 5°C for both transparent and dark packages. The values of lycopene content in the sample treated by OHUV ranged from 33.93 - 31.67 mg. kg^{-1}, while for the dark package sample, the values of lycopene content ranged from 33.93 - 31.86 mg kg^{-1} during the storage period.

Table (4): Effect of different heating treatments, packaging materials and temperatures on Ascorbic acid content (mg 100^{-1}. ml^{-1}) during 90 days of storage.

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	67.76 ±1.244	64.77 ±0.014	61.43 ±0.318	58.53 ±0.297	55.39 ±0.417	52.67 ±0.431	49.2 ±0.113
		Dark	67.76 ±1.244	65.62 ±0.381	63.56 ±0.523	60.55 ±0.368	58.15 ±0.919	54.48 ±0.212	52.36 ±0.325
	5	Transparent	67.76 ±1.244	66.115 ±0.473	65.03 ±0.452	64.82 ±1.160	62.59 ±0.332	61.05 ±0.544	57.98 ±0.481
		Dark	67.76 ±1.2440	66.55 ±0.289	65.415 ±0.289	65.45 ±0.339	62.87 ±0.643	61.48 ±0.516	58.63 ±0.226
Conventional heating	25	Transparent	50.16 ±1.2440	46.55 ±0.494	42.41 ±0.155	39.57 ±0.296	36.37 ±0.516	33.01 ±0.148	30.73 ±0.721
		Dark	50.16 ±1.2440	47.68 ±0.9404	43.90 ±0.190	40.19 ±0.233	37.68 ±0.947	35.37 ±0.770	32.91 ±0.650
	5	Transparent	50.16 ±1.244	49.60 ±0.537	48.65 ±0.452	47.52 ±0.502	45.98 ±0.905	43.34 ±0.282	40.89 ±0.127
		Dark	50.16 ±1.244	49.44 ±0.459	48.32 ±0.4808	47.20 ±0.389	45.23 ±0.233	44.66±0.346	41.93 ±1.237
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			1.226						

Table (5): Effect of different heating treatments, packaging materials and temperatures on Lycopene content (mg. kg^{-1}) during 90 days of storage.

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	33.93 ±1.435	33.6 ±0.247	33.20 ±0.318	32.6 2±0.6576	31.74 ±0.5868	30.56 ±0.3394	29.01 ±0.7636
		Dark	33.93 ±1.435	33.62 ±0.244	33.34 ±0.3464	33.27 ±0.1131	32.92 ±1.039	31.90 ±0.4879	30.20 ±0.1202
	5	Transparent	33.93 ±1.435	33.70 ±0.141	33.55 ±0.3535	33 ±0.1909	32.25 ±0.9192	32.21 ±0.0212	31.67 ±0.2474
		Darkness	33.93 ±1.435	33.81. ±0.106	33.34 ±0.3394	33.40 ±0.2828	32.85 ±0.1414	32.50 ±0.1767	31.86 ±0.7566
Conventional heating	25	Transparent	28.51 ±1.173	28.11 ±0.127	27.90 ±0.1909	26.99 ±0.8980	25.58 ±0.3256	24.82 ±0.4171	23.01 ±0.6222
		Dark	28.51 ±1.173	28.26 ±0.289	28.20 ±0.2899	27.89 ±0.7283	26.87 ±0.7424	25.41 ±0.4171	24.73 ±0.6929
	5	Transparent	28.51 ±1.173	28.24 ±0.219	28.46 ±0.1484	28.17 ±0.2687	27.18±0 .17677	27.97 ±0.6293	26.12 ±0.9545
		Dark	28.51 ±1.173	28.32 ±0.388	28.76 ±0.197	28.27 ±0.700	27.75 ±0.452	27.30 ±0.233	26.54 ±0.367
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			0.110						

Referring to CH samples, the lycopene content in the two transparent and dark package samples was close to each other. It decreased from 28.51 to 26.12 mgkg^{-1} and 28.51 to 26.54 mg. kg^{-1}, respectively. Although the lycopene content in the sample filled in dark packages was slightly higher than the transparent packages for both treatments. Besides, Anese *et al.* (1999) found that the rate of decomposition of lycopene to isomers is slower at lower temperatures.

There was a significant variance ($p < 0.05$) between samples subjected to OHUV and CH and stored in transparent packages at 5°C (Fig. S3). The average values for lycopene content were 63.62 and 46.59 mg.kg^{-1}, respectively. The statistical analysis also showed that there was significant variance ($p < 0.05$) between samples of dark packages that treated by OHUV and CH at the same temperature, which averaged lycopene values of 58.53 and 39.82 mg.kg^{-1}, respectively. At 25°C, the results showed that there were significant ($p < 0.05$) variances between the samples of transparent packages subjected to OHUV and CH , the lycopene content was 58.53 and 39.82 mg.kg^{-1}, respectively. Additionally, there was a significant variance ($p < 0.05$) between the dark packages for both treatments, which averaged values for lycopene content were 60.35 and 41.12 mg.kg^{-1} for OHUV and CH samples, respectively. Trifiro *et al.* (1998) mentioned that oxidative stress can be the cause of the decrease in lycopene content, which results in the decomposition of lycopene that depends on temperature and humidity. As mentioned by D'Evoli *et al.* (2013), there is a molecular decomposition and isomerization of lycopene in tomatoes treated at high temperatures.There was a significant variance ($p < 0.05$) in the lycopene concentration in tomato paste samples and this was attributed to treatment type, temperature, and storage

method, while packaging type gave a non-significant effect ($p > 0.05$) in the lycopene content. In contrast, the interaction between type of treatment, temperature, type of packaging, and type of storage gave a non-significant variance ($p > 0.05$) in the lycopene concentration in tomato paste. Similar to our results, Distefano *et al.* (2020) reported that storage temperature significantly affected the lycopene concentration. However, Sandei *et al.* (2000) indicated that there was no significant variance ($p > 0.05$) in the content of lycopene when tomato puree was stored for one year. While the results came close to what was found by Famurewa *et al*. (2013) which indicated a decrease in lycopene content inside tomato paste in the sixth week of storage.

Hydroxymethyl furfural content in tomato paste during storage period

Table (6) shows that the tomato paste samples in transparent packages stored at 25°C for samples subjected to OHUV and CH have the highest increase in hydroxymethyl furfural content (HMF) compared to the samples stored in other conditions. It ranged from 1.05 - 3.72 ppm and 3.49 - 8.11 ppm for OHUV and CH, respectively. It was followed by the increase in the HMF content of the paste samples stored in dark packages at the same temperature, which reached 1.05 - 3.17 ppm for the sample subjected to OHUV and 3.49 - 7.91 ppm for the sample subjected to CH.

The paste samples subjected to OHUV and stored at 5°C have a slight increase in HMF content in both transparent and dark packages, which ranged from 1.05–1.79 $mg.kg^{-1}$ and 1.05–1.77 $mg.kg^{-1}$, respectively. HMF contents in CH treatment were 3.49-4.94 $mg.kg^{-1}$ and 3.49-4.28 for transparent and dark packages, respectively. The statistical analysis showed significant variance ($p < 0.05$) between the samples subjected to OHUV and CH and filled in transparent packages at 5°C (Fig. S4). The average values for HMF content were 1.46 and 4.03 ppm, respectively. There was a significant variance ($p < 0.05$) observed between samples packaged in opaque materials and subjected to OHUV and CH treatments at the same temperature. The average HMF content was 1.43 ppm for OHUV treatment and 3.86 ppm for CH treatment. For tomato paste samples stored at 25°C, there was also a significant ($p < 0.05$) difference observed between samples packaged in transparent materials and treated with OHUV or CH. The HMF values were 2.68 and 5.7 ppm, respectively. The statistical analysis showed significant variance ($p < 0.05$) between the dark packages for both treatments at the same temperature, which averaged values for HMF content being 2.17 and 5.08 ppm for the sample subjected to OHUV and CH, respectively. Apaiah & Barringer (2001) indicated that the quality loss in tomato sauces during heat treatment is more than during storage, especially when stored at temperatures higher than 37°C.

There was significant variance ($p < 0.05$) in the values of HMF content in the paste samples for each type of treatment, temperature, storage method, and type of packaging. On the other hand, the statistical analysis showed that the interaction between the type of treatment, temperature, type of packaging, and type of storage had a non-significant variance ($p > 0.05$) in the HMF concentration in tomato paste.

The study came close to the findings of Ordóñez-Santos *et al*. (2009) when following up on the effect of storage on HMF content in packed tomato pulp, which found the increase in HMF content ranged from 3.95-9.94 $mg.kg^{-1}$ for 0-180 days. Additionally, Toker *et al.* (2013) found a linear increase in both time and

temperature leads to a significant change ($p < 0.05$) in HMF content.

Pectinmethylesterase content of tomato paste during storage period:

A slight change in Pectinmethylesterase (PME) activity of tomato paste samples treated by OHUV over the storage period (Table 7). Its values ranged 0.1135 × 10-4 to 0.2316 × 10-4 U.ml^{-1} for transparent packages at the laboratory temperature. The PME values for samples packaged in opaque materials were comparable to those of samples packaged in transparent materials, falling within the range of 0.1135 × 10-4 to 0.2279 × 10-4 U ml^{-1}. Likewise, tomato paste samples treated by CH had no significant increase in PME activity at the same temperature. The PME value in the transparent packages reached 0.1500 × 10-3– 0.3007 × 10-3 U ml^{-1}, while in dark packages samples ranged from 0.1500 × 10-3– 0.2978 × 10-3U ml^{-1}. Makroo *et al*. (2020) indicated that the inhibition of the enzyme's activity by OHUV is mainly because of the thermal effect resulting from it. In addition to what was indicated by Yıldız & Baysal (2006) that the use of the electric field on the tomato paste leads to an acceleration of inhibition for PME activity.Regarding tomato paste samples stored at 5 °C, the experiments showed that the change in PME activity was the least increase during the storage period in comparison with storage at a high temperature. The samples of the paste subjected to ohmic heating gave a similar increase for both transparent and dark packages with values 0.1135 × 10^{-4} and 0.1526 × 10-4 U ml^{-1} and 0.1135 × 10^{-4}- 0.1507 × 10-4U ml^{-1}, respectively. In CH treated sample, the PME activity ranged from 0.15 × 10^{-4}- 0.2224 × 10-4and 0.15 × 10^{-4}- 0.2186 × 10^{-4} U ml^{-1} for both transparent and dark package samples, respectively. During storage, the activity of PME in tomato paste can be reduced through several mechanisms. One mechanism is the thermal inactivation of the enzyme at high temperatures. The rate of inactivation is dependent on the temperature and the duration of storage. Another mechanism is the decrease in pH that occurs during storage due to the production of organic acids, which can inhibit the activity of PME. Additionally, the presence of inhibitors in tomato paste can also reduce the activity of PME during storage. For example, calcium ions can bind to the enzyme and reduce its activity. Other compounds, such as citric acid and some phenolic compounds, can also act as inhibitors.

There was a significant variance ($p < 0.05$) between samples treated by OHUV and CH and stored in transparent packages at 5 °C (Fig. S5). The average PME activity were 0.1305 × 10^{-4} and 0.1827 × 10-4 U ml^{-1}, respectively. The results showed that there was a significant ($p < 0.05$) variance between samples filled in dark packages and treated by OHUV and CH treatments at the same temperature, which averaged values of PME 0.1303 × 10^{-4} and 0.1776 × 10-4 U ml^{-1}, respectively.

For tomato paste samples stored at 25°C, there was a significant variance ($p < 0.05$) between samples of transparent packages subjected to OHUV and CH, which averaged values of PME were 0.1756 × 10^{-4} and 0.1801 × 10-4 U ml^{-1}, respectively. The experiments showed a significant variance ($p< 0.05$) between the samples filled in dark packages for both treatments at the same temperature, which averaged values of PME were 0.1728 × 10^{-4} and 0.2210 × 10^{-4} U ml^{-1} for the sample treated by OHUV and CH, respectively. Aghajanzadeh *et al*. (2017) indicated that the PME has a protein structure and so it is sensitive to heat treatment.

Table 6. Effect of different heating treatments, packaging materials and temperatures on HMF content (mg kg^{-1}) during 90 days of storage

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	1.05 ±0.052	1.93 ±0.070	2.55 ±0.360	2.87 ±0.148	3.15 ±0.091	3.55 ±0.190	3.72 ±0.247
		Dark	1.05 ±0.052	1.33 ±0.163	1.99 ±0.863	2.42 ±0.594	2.48 ±0.255	2.75 ±0.29	3.17 ±0.53
	5	Transparent	1.05 ±0.052	1.29 ±0.226	1.37 ±0.035	1.40 ±0.495	1.64 ±0.827	1.71 ±0.219	1.79 ±0.071
		Dark	1.05 ±0.052	1.27 ±0.113	1.34 ±0.148	1.42 ±0.424	1.54 ±0.099	1.62 ±0.424	1.77 ±0.021
Conventional heating	25	Transparent	3.49 ±0.077	4.19 ±0.989	4.99 ±0.367	5.27 ±0.247	6.48 ±0.657	7.41 ±0.523	8.11 ±1.117
		Dark	3.49 ±0.077	4.02 ±0.813	4.77 ±0.445	4.98 ±0.919	5.20 ±0.226	6.71 ±0.219	7.91 ±0.162
	5	Transparent	3.49 ±0.077	3.55 ±0.325	3.87 ±0.601	3.93 ±0.085	4.11 ±0.156	4.38 ±0.092	4.94 ±0.198
		Dark	3.49 ±0.077	3.65 ±0.219	3.69 ±0.064	3.86 ±0.113	3.96 ±0.226	4.13 ±0.021	4.28 ±0.12
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			0.154						

Statistical analysis showed a significant effect ($p<0.05$) on PME activity in the paste samples for each type of treatment, temperature, and storage method. However, the type of packaging had a non-significant effect ($p > 0.05$) on the enzyme content. On the other hand, the result of the statistical analysis of the interaction between the type of treatment, temperature, type of packaging, and type of storage showed a non-significant variance ($p > 0.05$) in PME activity in tomato paste. These results came close to that found by Moreno *et al*. (2013) in their study on apples subjected to OHUV and followed up on the activity of polyphenol oxidase during storage and compared with the conventionally treated sample. As a result, the ultra-heat treatment may enhance the quality of the food in comparison with the conventional heat treatment (Makroo *et al.,* 2017).

Microorganisms in tomato paste during storage period

The results indicated that there was no growth of coliform bacteria, yeasts, and molds in tomato paste samples treated by OHUV and CH and filled in transparent and dark packages for three months at 5 and 25°C. These results agreed with Maity & Raju (2015) who studied the microbial content in tomato paste. They noticed no growth of yeasts, molds, and colon bacteria when stored for four months at a temperature of 37°C. Also, the results were similar to those that were found by Olaniran *et al.* (2015) who studied the total bacterial count of tomato paste without additives when stored for eight weeks.Table (8) shows that there was

no bacterial growth on day zero of the paste production by OHUV and CH. In addition, bacterial growth was less in the samples treated by OHUV during the storage period in all the used storage conditions. The samples stored at 25 °C gave the highest bacterial growth of the sample filled in transparent packages for OHUV and CH between 15th – 90th days, which total bacteria count values ranged from 1.62-9.18 log cfu. g^{-1} and 2.71 - 13.18 log cfu. g^{-1} respectively. Whereas, the dark packages at the same temperature only gave less bacterial growth with a slight difference than the transparent packages for both the sample teated by OHUV and CH, which ranged from 1.55 -9.11log cfu.g^{-1} and 2.53-12.61 log cfu.g^{-1}, respectively, during storage.

The dark packages may have had less bacterial growth than the transparent packages at the same temperature for several reasons. The dark packages could have blocked out more light, inhibiting the growth of light-sensitive bacteria. They may have also had less oxygen exposure, inhibiting the growth of oxygen-dependent bacteria. Differences in temperature variation and package material could have also played a role. If the dark packages were better insulated or made of a material that absorbed moisture better, this could have created a less hospitable environment for bacteria, leading to less growth.

Tomato paste samples treatedby OHUV and stored at 5 °C had the lowest bacterial growth compared to the paste sample subjected to CH for the two types of packages.

Regarding, transparent and dark packages samples treated by OHUV from day 15 until the end of storage were 1.51 - 5.40 and 1.33 - 5.27 log cfu.g^{-1}, respectively. CH treated samples gave bacterial content at the same temperature and storage period of 1.76 -10.84 and 1.84 - 10.81 log cfu.g^{-1} for transparent and dark packages, respectively. The study came close to Moreno *et al*. (2013) who mentioned that the treatment of juice with OHUV led to a decrease in the number of microorganisms and prolongation of its storage life.Additionally, heat treatment at 50 °C was effective in inhibiting the growth of molds and yeasts, especially when stored at a temperature of 5°C. Fig. (S6) shows that the average values of bacterial growth content of tomato paste samples produced by OHUV and CH and stored for 90 days in transparent and dark packages.

There was significant variance ($p < 0.05$) between the paste samples subjected to OHUV and CH for both transparent and dark packages samples at 5 °C, which average values of bacterial growth content were 2.74 and 4.84 log cfu g^{-1}, respectively, while the dark packages were 2.71 and 4.83 log cfu. g^{-1}, respectively. Statistical analysis of tomato paste samples stored at 25°C showed significant variance ($p <0.05$) between samples of transparent packages subjected to OHUV and CH, with average values for bacterial growth content of 4.97 and 6.5 logs cfu g^{-1}, respectively. There were significant variance ($p < 0.05$) between the dark packages for both treatments at the same temperature, which averaged values for the content of bacterial growth of 4.9 and 6.19 log cfu. g^{-1} for the sample treated by OHUV and CH, respectively. Ohmic heating resulted in a more effective reduction of microorganisms in food compared to conventional heating methods for several reasons.

Table (7): Effect of different heating treatments, packaging materials and temperatures on PME content (unit. ml^{-1}) during 90 days of storage

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	0.1135×10^{-3} ± 0.2121×10^{-6}	0.1363×10^{-3} ± 0.2199×10^{-6}	0.159×10^{-3} ± 0.8053×10^{-6}	0.1761×10^{-3} ± 0.1951×10^{-6}	0.1974×10^{-3} ± 0.3698×10^{-6}	0.2156×10^{-3} ± 0.2192×10^{-6}	0.2316×10^{-3} ± 0.6434×10^{-6}
		Dark	0.1135×10^{-3} ± 0.2121×10^{-6}	0.1366×10^{-3} ± 0.263×10^{-6}	0.1533×10^{-3} ± 0.1456×10^{-6}	0.1762×10^{-3} ± 0.2121×10^{-6}	0.1948×10^{-3} ± 0.3401×10^{-6}	0.2073×10^{-3} ± 0.362×10^{-6}	0.2279×10^{-3} ± 0.6788×10^{-6}
	5	Transparent	0.1135×10^{-3} ± 0.2121×10^{-6}	0.1199×10^{-3} ± 0.2128×10^{-6}	0.1202×10^{-3} ± 0.2043×10^{-6}	0.1229×10^{-3} ± 0.3535×10^{-6}	0.1352×10^{-3} ± 0.2192×10^{-6}	0.1497×10^{-3} ± 0.106×10^{-6}	0.1526×10^{-3} ± 0.2665×10^{-6}
		Dark	0.1135×10^{-3} ± 0.2121×10^{-6}	0.1174×10^{-3} ± 0.1428×10^{-6}	0.1202×10^{-3} ± 0.1772×10^{-6}	0.1279×10^{-3} ± 0.5487×10^{-6}	0.1362×10^{-3} ± 0.2213×10^{-6}	0.1464×10^{-3} ± 0.1371×10^{-6}	0.1507×10^{-3} ± 0.2835×10^{-6}
Conventional	25	Transparent	0.15×10^{-3} ± 0.8485×10^{-6}	0.1817×10^{-3} ± 0.1463×10^{-6}	0.2017×10^{-3} ± 0.1463×10^{-6}	0.2218×10^{-3} ± 0.1327×10^{-6}	0.2431×10^{-3} ± 0.1178×10^{-6}	0.2664×10^{-3} ± 0.7071×10^{-6}	0.3007×10^{-3} ± 0.1344×10^{-6}
		Dark	0.15×10^{-3} ± 0.8485×10^{-6}	0.1727×10^{-3} ± 0.1625×10^{-6}	0.1996×10^{-3} ± 0.1158×10^{-6}	0.2179×10^{-3} ± 0.3252×10^{-6}	0.2473×10^{-3} ± 0.5529×10^{-6}	0.2622×10^{-3} ± 0.1709×10^{-6}	0.2978×10^{-3} ± 0.1908×10^{-6}
	5	Transparent	0.15×10^{-3} ± 0.8485×10^{-6}	0.1618×10^{-3} ± 0.133×10^{-6}	0.1685×10^{-3} ± 0.5359×10^{-6}	0.1729×10^{-3} ± 0.1166×10^{-6}	0.1824×10^{-3} ± 0.1435×10^{-6}	0.2209×10^{-3} ± 0.5296×10^{-6}	0.2224×10^{-3} ± 0.1343×10^{-6}
		Dark	0.15×10^{-3} ± 0.8485×10^{-6}	0.1514×10^{-3} ± 0.3535×10^{-6}	0.1613×10^{-3} ± 0.1426×10^{-6}	0.1777×10^{-3} ± 0.5084×10^{-6}	0.1824×10^{-3} ± 0.1273×10^{-6}	0.2023×10^{-3} ± 0.1414×10^{-6}	0.2186×10^{-3} ± 0.8697×10^{-6}
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			1.8×10^{-4}						

Firstly, ohmic heating provides more uniform heating throughout the food, reducing the likelihood of hot spots where microorganisms can survive. Secondly, ohmic heating can heat food rapidly, reducing the time that microorganisms are exposed to the heat. Thirdly, ohmic heating can achieve the same level of microbial reduction at lower temperatures compared to traditional heating methods, which can help to preserve the quality of the food. Finally, the electrical field generated during ohmic heating can cause changes in the cell membrane of microorganisms, making them more permeable to heat and other antimicrobial agents, leading to more effective microbial reduction. Also, Leizerson & Shimoni (2005) found that juice sample subjected to OHUV that has a shelf life of more than 105 days with continuous sensory evaluation during the storage time.

Table (8): Effect of different heating treatments, packaging materials and temperatures on Total plate count (log cfu. ml^{-1}) during 90 days of storage

Treatments	Temperature (°C)	Package	Storage periods (days)						
			0	15	30	45	60	75	90
Ohmic heating	25	Transparent	0	1.62 ±0.247	3.30 ±0.205	5.35 ±0.268	6.82 ±0.558	8.55 ±0.481	9.18 ±0.622
		Dark	0	1.55 ±0.311	3.28 ±0.580	5.02 ±0.339	6.91 ±0.495	8.43 ±0.163	9.11 ±0.346
	5	Transparent	0	1.51 ±0.381	1.63 ±0.339	2.42 ±0.502	3.73 ±0.226	4.50 ±0.474	5.40 ±0.537
		Dark	0	1.33 ±0.162	2.08 ±0.552	2.27 ±0.169	3.60 ±0.375	4.44 ±0.297	5.27 ±0.212
Conventional heating	25	Transparent	0	2.71 ±0.374	4.67 ±0.141	6.49 ±0.311	8.37 ±0.247	10.12 ±0.254	13.18 ±0.056
		Dark	0	2.53 ±0.120	4.27 ±0.162	6.38 ±0.353	8.16 ±0.091	9.4 3±0.445	12.61 ±0.551
	5	Transparent	0	1.76 ±0.106	2.33 ±0.269	4.43 ±0.693	6.25 ±0.509	8.36 ±0.552	10.84 ±0.523
		Dark	0	1.73 ±0.530	2.60 ±0.346	4.35 ±0.488	6.15 ±0.771	8.23 ±0.120	10.81 ±0.396
$LSD_{0.05}$ for interaction of treatments×Temperature×package×storage period			0.221						

Moreover, it showed that its safety from microorganisms compared to the juice sample treated by CH, as its shelf life for microbial safety was up to 50 days. Statistical analysis showed a significant effect ($p < 0.05$) on bacterial growth in the paste samples for each type of treatment, temperature, and storage method, while the type of package had a non-significant effect ($p > 0.05$) on the total number of bacteria. Whereas the statistical analysis showed that the interaction between the type of treatment, temperature, type of packaging, and type of storage gave non-significant variance ($p > 0.05$) in the total number of bacteria in tomato paste.

Conclusion

This work aimed to study the impact of Ohmic Heating Under Vacuum (OHUV) that compared to conventional heating (CH) as well as storage stability at 5 and 25 °C on microbial safety, and nutritional quality. The obtained results showed that tomato paste samples treated by OHUV were significantly superior to CH in terms of all physicochemical and microbiological characteristics, as well as

being the least harmful during storage in both transparent and dark packages. Tomato paste samples stored in dark packages at 5 °C performed much better than those subjected to CH under the same conditions, which were the best sample in activation in PME, lower total plate count, higher ascorbic acid, lycopene, and fewer changes in HMF during storage time for 90 days. Finally, OHUV was better than CH treatment and succeed as an alternative treatment in the production of tomato paste. The limitations are that this technology requires a high current when using a high electric field intensity and large surface area of the electrical electrodes. In terms of future direction, this technology can be developed into a continuous method with the presence of vacuum and used in food processing plants as an industrial scale.

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A.R.A.: Methodology, data curation, writing—original draft.

A.B.A: Supervision, writing—review and editing.

Z.T.A.: Validation, writing—review and editing, methodology.

I.H.: Software, validation, formal analysis. **A.B.A**. and **F.C**.: Supervision, writing—review and editing; conceptualization, software, writing—original draft writing—review and editing.

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Conflicts of interest

The authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.5281/zenodo.8098646

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التسخين الأومي تحت التفريغ: تقنية واعدة لتحسين تصنيع معجون الطماطة وسلامته وجودته وثباتية تخزينه

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المستخلص: التسخين الأومي (OH) هو تقنية كهروحرارية يتم استخدامها لإيقاف نشاط الإنزيمات والكائنات الحية الدقيقة. هدف الدراسة هو دراسة تأثير التسخين الأومي تحت التفريغ (OHUV) مقارنة بالتسخين التقليدي (CH) وكذلك ثبات التخزين عند درجة حرارة 5 مئوية و 25 مئوي على السلامة الحيوية والجودة الغذائية. كانت معايير التقييم هي الرقم الهيدروجيني (pH) والحموضة القابلة للتحلل، ومحتوى المواد الصلبة الذائبة الكلي (TSS)، والليكوبين، وحامض الأسكوربيك، وبولي جلاكتورونيك ميثيل استيريز (PME)، والهيدروكسي ميثيل فورفورال (HMF)، والنشاط الميكروبيولوجي. أظهرت النتائج المستحصلة أن عينات معجون الطماطمة المعاملة بتقنية OHUV كانت متفوقة بشكل كبير على CH من حيث الخصائص الفيزيوكيميائية والميكروبيولوجية، بالإضافة إلى كونها الأقل ضررًا خلال التخزين في كلا العبوتين الشفافة والمعتمة. أظهرت النتائج ان التغيرات في محتوى حامض الأسكوربيك والليكوبين وقيمة الهيدروكسي ميثيل فورفورال (HMF) في العينات المعاملة بتقنية OHUV عند 25 درجة مئوية والمعبأة في عبوات شفافة اقل تأثرًا مقارنة مع العينات الاخرى. من ناحية أخرى، أداء عينات معجون الطماطمة المخزنة في عبوات معتمة عند 5 درجات مئوية كان أفضل بكثير من تلك التي تعرضت لتقنية CH تحت نفس الظروف. من بين العينات المختلفة، كانت الأفضل في تثبيط بولي جلاكتورونيك ميثيل استيريز (PME) وعدد الحمل المايكروبي الكلي، والحفاظ على حمض الأسكوربيك والليكوبين، وتقليل التغيرات في الهيدروكسي ميثيل فورفورال (HMF) خلال فترة التخزين لمدة 90 يومًا. وأخيراً، تبيّن أن تقنية OHUV كانت أفضل من تقنية CH ونجحت كمعاملة بديلة في إنتاج معجون الطماطمة.

الكلمات المفتاحية: هايدروكسي مثيل فرفرال، التسخين الاومي، معجون، بولي مثيل استريز، طماطة.