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# Comparison of quality characteristics of tomato paste produced under ohmic-vacuum combination heating and conventional heating

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ABSTRACT

The proposed work compares a combination of ohmic and vacuum heating (OH-VC) with conventional heating. Tomato paste was freshly extracted from tomatoes and subjected to 0-220 V alternating current (AC) with 50 Hz frequency under a pressure of 0.3-0.7 bar until the temperature reached 87 °C and compared with tomato paste heated in a double jacket vat. Tomato paste was further analyzed using Fourier transform infrared spectroscopic analysis (FTIR), volatile analysis using gas chromatography-mass spectrometry (GC-MS), minerals analysis using scanning electron microscope – energy dispersive spectrometer (FEG-SEM), scanning electron microscopy, and colour measurements. Based on FTIR analysis, tomato paste processed with OH-VC heating was found to have higher deformations of sugars than conventionally heated paste. Similarly, OH-VC heated product contained caramel-like odours associated with furfural and 5-methyl furfural generation due to electric treatment of food. Electrodes used in ohmic heating did not cause any changes in the minerals content due to heavy metal ion migration. Structurally, OH-VC treated cells were found to have a more regular and preserved structure than conventional heating. No effect on the colour of the tomato paste was observed. These results demonstrate the advantageous effect of OH-VC heating compared to conventional heating, primarily attributed to the lower treatment time and higher heating homogeneity. Yet, the generation of caramel-like odours suggests the need to optimize OH-VC treatment for each particular product.

## Introduction

Tomato is an important edible berry crop belonging to the Solanaceae family (Iftikhar et al., 2021). It is one of the most consumed crops worldwide (FAO, 2020), as it is used daily in the human diet (EL-Mansy et al., 2021). Tomato is considered to be of high nutritional value because it contains a large number of components that are important for the human body (Dzakhmisheva et al., 2021), such as micronutrients (Gholami et al. 2021), sugars, vitamins (Zhu et al., 2021) and many organic acids (Yan et al., 2021). Tomato pulp is also an essential source of antioxidants such as phenols, flavonoids (Silva-Beltrán, 2015), chlorophyll (Briones-Labarca et al., 2019), carotenoids (Rattanavipanon et al., 2021), lycopene (Vitucci et al., 2021), and lutein (Dannehl et al., 2021). It also contains large amounts of histamine (Sánchez-Pérez et al., 2018), monounsaturated and polyunsaturated fatty acids (Fernandes et al. 2021), as well as organic acids, folic acid (Upadhyaya et al., 2016), and malic acid (Choe et al., 2021), which are key factors in tomato flavor (Agius et al., 2018).

Compared to conventional heating techniques, the ohmic heating technique can be considered a more efficient heat treatment (Jan et al., 2021). It is particularly suitable for thermal treatment of liquid foods (Shirsat et al., 2004). Conventional heating uses high temperatures, which led to a decrease in the quality of the final product, and a reduction in the nutritional value (Indiarto et al., 2019; Mandal et al., 2020). On the contrary, ohmic heating is rapid and volumetric, which minimizes the deleterious effects of conventional thermal processing (Alkanan et al., 2021). The aroma and bioactive compounds of tomato and its products are essential attributes that significantly influence consumer acceptability and preference. Thermally processed tomato products prepared by conventional pasteurization or canning techniques lose many bioactive compounds and accumulate volatile compounds due to excessive heat treatment (Colle et al., 2010). Ohmic heating, owing to

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its rapid processing capability, has been employed for tomato processing (Darvishi et al., 2012; Boldaji et al., 2015; Makroo and Rastogi, 2017).

Different researchers have investigated the aroma of tomatoes, and more than 400 aroma compounds have been identified (Marković et al., 2007). Gas chromatography-mass spectrometry (GC–MS) has been extensively used in different aroma studies, and allows direct evaluation of critical volatile compounds in foods. Several papers characterize the key volatiles such as (Z)-3-hexenal, hexanal, 1-octen3-one, methional, 1-penten-3-one and 3-methylbutanal and bioactive compounds of Tomato, and its processed products using the GC–MS technique (Ochida et al., 2019).

Vacuum assisted evaporation is another common method used in the food industry as a moisture removal process (Pratap-Singh et al., 2020). This technique can be carried out at temperatures that are less harmful to food compared to atmospheric evaporation but require a longer processing time and more energy consumption (Icier et al., 2017). As a consequence, vacuum evaporation must become more efficient in order to increase the effectiveness of its use in evaporation systems under vacuum, and to reduce the loss of nutritional value, and the possibility of using vacuum evaporation with ohmic heating in combination (Fadavi et al., 2019). Ohmic heating has been augmented with vacuum for concentration of juices like sour cherry juice (Sabanci and Icier, 2017), pomegranate juice (Icier et al., 2017), drying of strawberries (Moreno et al., 2012), and apples (Moreno et al., 2011).

The aim of this study is to shed light on the efficiency of producing tomato paste by ohmic heating under vacuum. Herein, we study the ohmic heating-vacuum combination's ability to preserve the bioactive compounds while not contaminating the food with the metals of the electrodes used. We also attempt to detect the damages that may result from the chemical reactions of the food components and their nature with the electrodes.

## Materials and methods

### *Sample preparation and processing*

About Five kg ripe tomatoes from the farms of southern Iraq were selected and then washed and subjected to a cleaning process to eliminate dust, dirt, and reduce the microbial load. A cold crushing process was used, wherein the tomatoes were placed in a mechanical compressor after cutting to isolate the juice from the peels and seeds. The filtration process used sterilized gauze to remove impurities, particles, seeds, and husks. After the filtration, the weigh of tomato juice was approximately 4.80 kg, while the weigh of seeds and peels were 0.20 kg. The tomato juice was then heated using a manufactured ohmic-vacuum (OH-VC) combination device or conventional thermal processing. The tomato paste was transferred into a clean sterilized glass container and kept at 4°C until used.

### *Conventional heating*

The conventional heating treatment was carried out using the jacketed vat through a heat transfer fluid (water) to prevent direct contact with the heat source. The temperature was controlled in the range from 87- 90°C. The equipment included two basins, one inside the other, the outer basin with a radius of 37 cm, and the inner basin with a radius of 32 cm, with a gap of 5 cm width between them, filled with water for heating.

### *Ohmic-Vacuum (OH-VC) Combination heating device*

The ohmic-vacuum (OH-VC) combination heating device (Fig. 1) consisted of an ohmic heating cylinder provided with a control valve, thermocouple, vacuum pressure gauge, and two rectangular electrodes. The other parts of the system were a vacuum pump connected with an ohmic heating cylinder via plastic pipe, two hunters used to separate

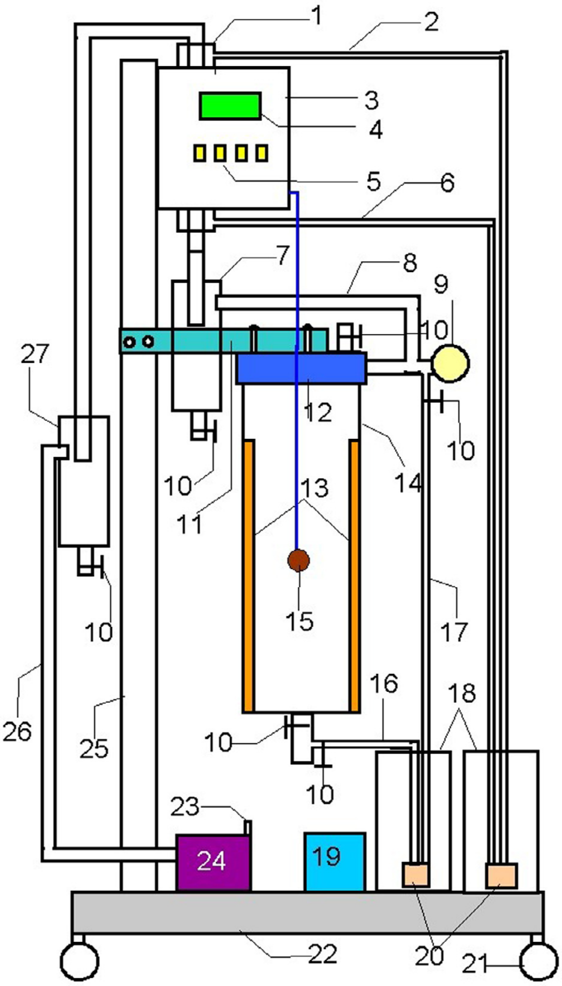


**Fig. 1.** Schematic diagram of (OH-VC) consisting of 1- Heat exchanger. 2- pipe of outlet hot water. 3- Control Panel. 4- digital temperature gauge. 5- lamps. 6- pipe of inlet cold water. 7- Hunter. 8- Pip of outlet steam. 9- Pressure gauge. 10- Handle valve. 11- base. 12-cover. 13- Electrodes. 14- Heating cylinder.15- Thermocouple. 16 and 17-Washing pipe. 18-. Containers of cold water. 19- Variable AC power supply. 20- Pumps. 21- Tires. 22- Base. 23- Air outlet port. 24- Vacuum pump. 25- Supporting bar. 26- Air suction pipe. 27- Steam hunter.

water from air, a glass condenser used to condense vapor to liquid (water), and a control panel is an in-system cleaning device. The cylindrical ohmic heating chamber (thickness of 1.5 cm, diameter of 27 cm, height of 85 cm, and capacity of 8 L) was made of heat-resistant plastic. Stainless steel type 316 (dimensions of 35×10 cm) rectangular electrodes were fixed into the inner wall of the cylindrical ohmic chamber. The heat generation system generated alternating current (AC) and voltage ranging from (0-220 V) and frequency (50 Hz), which were controlled by a voltage regulator. The operation pressure in the ohmic heating cylinder ranged between 0.3-0.7 bar (lower than the atmosphere pressure). The tomato juice was heated at optimum condition of 3.64 V/cm of electric field, 87.30°C of temperature, and 0.3 bar of pressure. The tomato paste was collected in a stainless steel 10L tank.

### *Fourier-transform infrared (FTIR) spectra*

KBr powder was mixed with produced tomato paste using OH-VC heating and produced tomato paste using conventional heating separately in order to prepare a slurry at 1 % (w/v) concentrations. A KBr disc was prepared for FTIR by pressuring to approximately 4.5 tons for 3.5 min. At a resolution of 5 $cm^{-1}$ spectra were obtained (FT-IR-84002 Shimadzu, Japan) and recorded over the mid infrared range of 400-4,000 $cm^{-1}$ (Ochida et al., 2019).

### *Determination of volatile compounds using gas chromatography-mass spectrometry (GC-MS)*

Characterization of the tomato paste samples produced by the methods of Ohmic heating and conventional heating was carried out using a gas chromatography-mass spectrometry (GC-MS) technique (Shimadzu-QP2010 Ultra, Japan) in the Consumer Protection laboratory at the College of Agriculture, University of Basrah. An Inert Cap WAX column (Gl Sciences, Tokyo, Japan) (30 M × 0.32 mm) was used. The sample was injected at an amount of 8 µL into a separation column, the injection temperature was set 220°C in the split-less injection mode for one minute/ The flow was controlled at a linear velocity at a pressure of 49.7 kPa, and the total flow rate of 34.1 mL/min. For a column flow rate of 1 mL/min, a linear velocity for column flow of 36.1 cm/sec, Purge flow 3 mL/min, the initial oven temperature in GC was set at 40°C for a period of 3 minutes. The oven temperature was raised to 250°C at the rate of 10°C per minute, and then the peaks that appeared were matched with the NIST08 library (Kamil et al.,2011)

### *Mineral analysis*

For Scanning electron microscope-energy dispersive spectrometer (SEM-EDS) analysis, the samples were first loaded on sample stub using double side carbon tape and powder was sprinkled the on it. Then all stubs on the specimen holder were tightened after blowing to remove non-adherent particles. Prepared samples were loaded on SEM-EDS (Zeiss Supra 55 VP, Oberkochen, Germany) via airlock door depend on low voltage to exceed the coating technique and avoid charging. A secondary electron detector (SE2) was used for a high resolution and sharp image with fixed magnification and a well-calibrated instrument (Wasik, 2007).

### *Scanning electron microscope analysis*

The microstructural morphology of tomato paste using different methods was investigated using SEM microscopic methods (Zeiss Supra 55 VP, Oberkochen, Germany) . Samples were sputter coated with a thin layer of gold-palladium (6–11 nm; 10 mA; 40 s) at room temperature before imaging (Asare et al., 2014).

### *Determination of Colour*

Image processing was employed to determine the colour of the tomato paste. Images were captured by a 6 megapixel digital camera (Android & PC Endoscope, type-C, China) in appropriate light. ImageJ software was used to analyze the images and the mean values of colour parameters were converted to standard values as follows according to Yam & Papadakis (2004):

$$L^* = \frac{L}{255} \times 100 \quad (1)$$

$$a^* = \frac{240a}{255} - 120 \quad (2)$$

$$b^* = \frac{240b}{255} - 120 \quad (3)$$

Where, L is the lightness, a is the redness/greenness, b is the yellowness/blueness, $L^*$, $a^*$ and $b^*$ are corrected values.

### *Statistical analysis*

All experiments were performed in triplicate, and data are presented as mean ± standard deviation (SD). Analyses were calculated using the Statistical Package of Social Sciences (SPSS) software package (version 16.0). Data were assessed for significant difference employing one-way ANOVA and were considered to be statistically significant at $p < 0.05$.

## Results and discussion

### *FTIR Spectral Profile of Tomatoes paste*

Figs. 2 and 3 show the FTIR spectra of the OH-VC heated, and conventionally heated tomato paste respectively. Differences in the spectra

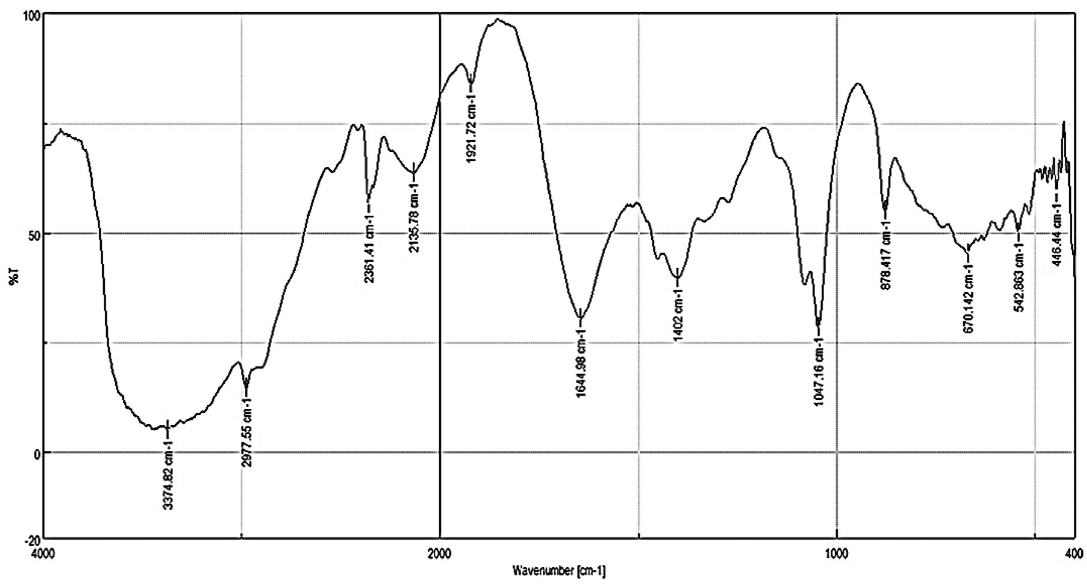


**Fig. 2.** FTIR Spectrum of produced tomato paste using OH-VC heating.

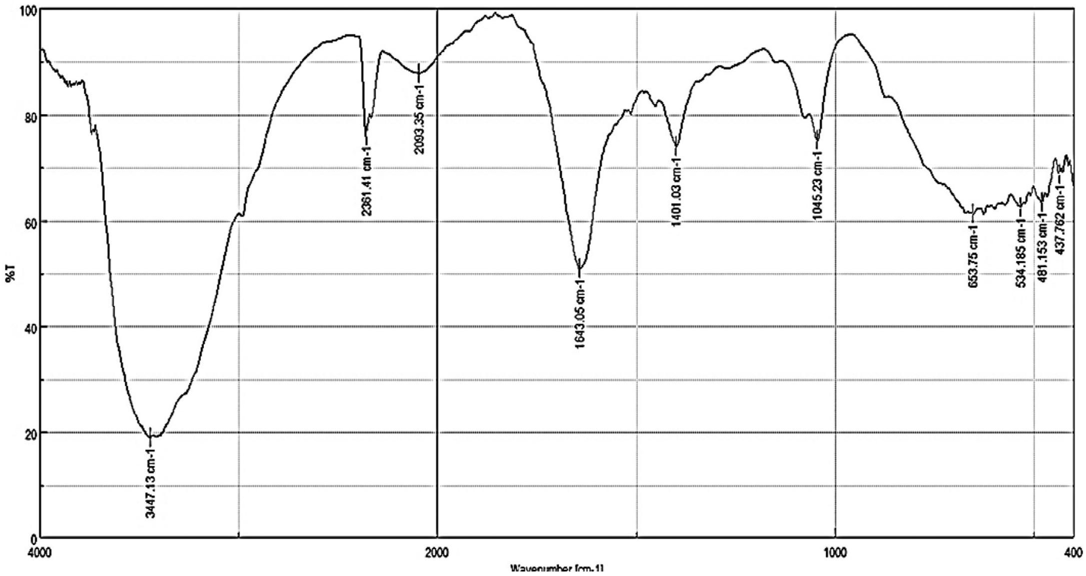


**Fig. 3.** FTIR Spectrum of produced tomato paste using conventional heating.

**Table 1**
FTIR Profile of Tomato paste for ohmic-vacuum heating treated samples (OH-VC) and conventional heating (CH).

| Wave number ($cm^{-1}$) | Functional Group | Assignment | Groupfrequency $cm^{-1}$ | Source | Wave number ($cm^{-1}$) | Functional Group | Assignment | Group frequency $cm^{-1}$ | Source |
|---|---|---|---|---|---|---|---|---|---|
| OH-VC | CH | | | | | | | | |
| 3374.82 | Alcohols and Phenols | Hydrogen Bonded O-H Stretch | 3100-3600 | Ochida et al. (2019) | 3447.13 | Alcohols and Phenols | Hydrogen Bonded O-H Stretch | 3100-3600 | Ochida et al. (2019) |
| 2977.55 | Alkanes | H-C-H Asymmetrical Stretch | 2850-3000 | Ochida et al. (2019) | 2361.41 | Alkyne | C≡C Stretch | 2361.41 | Nikalje et al. (2019) |
| 2361.41 | Alkyne | C≡C Stretch | 2361.41 | Nikalje et al. (2019) | 2093.35 | Isothiocyanate | NCS- | 1990-2150 | Coates, (2000) |
| 2135.78 | Isothiocyanate | NCS- | 1990-2150 | Coates (2000) | 1643.03 | Alkenes | C=C Stretch | 1640-1680 | Ochida et al. (2019) |
| 1921.72 | | | | | | | | | |
| 1644.98 | alkenes | C=C Stretch | 1640-1680 | Ochida et al. (2019) | 1401.03 | Alkanes | C-H Bend | 1350-1470 | Ochida et al. (2019) |
| 1402 | Alkanes | C-H Bend | 1350-1470 | Ochida et al. (2019) | 1045.23 | Aliphatic Amines | C-N Stretch | 1020-1250 | Ochida et al. (2019) |
| 1047.16 | Esters | C-O Stretch | 1000-1300 | Ochida et al. (2019) | 653.73 | Alkyne | C-H bend | 610-680 | Coates, (2000) |
| 878.417 | Aromatics | C-H out of plane deformation | 675-900 | Ochida et al. (2019) | 534.185 | disulphide | S –S | 520-588 | Ahmad et al., 2014 |
| 670.142 | Alkyne | C-H bend | 610-680 | Coates, (2000) | 481.153 | Polysulfides | s-s stretch | 470-500 | Coates, (2000) |
| 542.863 | disulphide | S –S | 520-588 | Ahmad et al., 2014 | 437.762 | Aryl disulfides | S-S stretch | 430-500 | Coates, (2000) |
| 446.44 | Aryl disulfides | S-S stretch | 430-500 | Coates, (2000) | | | | | |

bring out the characteristic changes taking place during thermal processing. The peaks corresponding to the wavenumber range between 3000-3600 $cm^{-1}$ and between 1500-1700 $cm^{-1}$ relate to the vibrational stretching of the OH group in water. The peak of 2977 $cm^{-1}$ for the OH-VC tomato paste was attributed to the stretching of CH2 groups, which was absent from the conventionally heated paste. In both cases, the peaks of 2361 $cm^{-1}$ is attributed to the C≡C stretching. Regions from 900-1500 $cm^{-1}$ denote the influence of C-C and C-O stretching and C-O-C and C-O-H deformation in sugars which were higher in case of the OH-VC heated product. Regions below 600 $cm^{-1}$ was attributed to the S-S stretching. This result was in agreement with Aykas et al. (2020).

*Volatile Organic Compounds of tomatoes paste*

Table 2, and Figs. 4 and 5 show the volatile organic compounds contents in the thermally processed. The results for the volatile organic compounds show some basic differences in the profile of the volatile compounds formed after different thermal processes. Levels of volatile compounds, namely, the 1-hydroxy-2 Propanone, acetic acid, formic acid, 2,4-Dihydroxy-2,5-dimethyl-3(2H)-furan-3-one, 1, 3-2-dihydroxy propanone, 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-Pyran-4-one, and 3,5- dihydroxy-2-methyl-4H-Pyran-4-one were almost similar as found by GC-MS. These results were in agreement with Yu et al. (2013) and Ban et al. (2007), who reported that 4H-Pyran-4-one, and 3,5-dihydroxy-2-methyl-4H-Pyran-4-one are considered most natural compounds that act as a powerful antioxidant and prevent the growth of cancer cells by acting as an antioxidant and a reducing agent. The main difference arising from the difference in thermal process is the generation of compounds like furfural and 5-methyl furfural in OH-VC heated product. These compounds signify the presence of caramel-like odour in the paste after OH-VC processing. Presence of 5-Methyl-2-furancarbaldehyde denoted the generation of almond-like odor in conventionally heated paste. The furfural and other furan derivatives are important volatile compounds that are formed in the thermally pro-

**Table 2**
Volatile organic compounds of tomato paste tested by GC-MS.

| Ohmic heating | | | | Conventional heating | | | |
|---|---|---|---|---|---|---|---|
| Peak | Retention time | Area % | Compound name | Peak | Retention time | Area % | Compound name |
| 1 | 9.541 | 3.04 | 1-hydroxy-2-Propanone | 1 | 9.662 | 2.02 | 1-hydroxy-2Propanone |
| 2 | 11.604 | 18.64 | Acetic acid | 2 | 11.562 | 14.34 | Acetic acid |
| 3 | 11.845 | 2.56 | Furfural | 3 | 12.427 | 3.27 | Formic acid |
| 4 | 12.485 | 3.17 | Formic acid | 4 | 12.598 | 1.04 | 2,4-Dihydroxy-2,5-dimethyl-3(2H)-furan-3-one |
| 5 | 12.589 | 2.57 | 2,4-Dihydroxy-2,5-dimethyl-3(2H)-furan-3-one | 5 | 12.734 | 1.17 | [R-(R*,R*)]-2,3-Butanediol |
| 6 | 13.182 | 1.59 | [R-(R*,R*)]-2,3-Butanediol | 6 | 13.264 | 1.34 | 5-Methylfurfural |
| 7 | 13.270 | 0.86 | 5-Methylfurfural | 7 | 18.391 | 0.34 | 2,5–Dimethyl-4-hydroxy-3(2H)-furanone |
| 8 | 18.388 | 0.77 | 2,5-Dimethyl-4-hydroxy-3(2H)-furanone | 8 | 19.054 | 0.72 | 1,3-dihydroxy-2-Propanone |
| 9 | 19.039 | 1.08 | 1,3-dihydroxy-2-Propanone | 9 | 20.792 | 22.23 | 2,3-dihydro-3,5-dihydroxy-6-methyl 4H-Pyran-4-one |
| 10 | 20.765 | 30.81 | 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-Pyran-4-one | 10 | 20.869 | 0.45 | 3,5-dihydroxy-2-methyl-4H-Pyran-4-one |
| 11 | 20.862 | 0.55 | 3,5-dihydroxy-2-methyl-4H-Pyran-4-one | | | | |

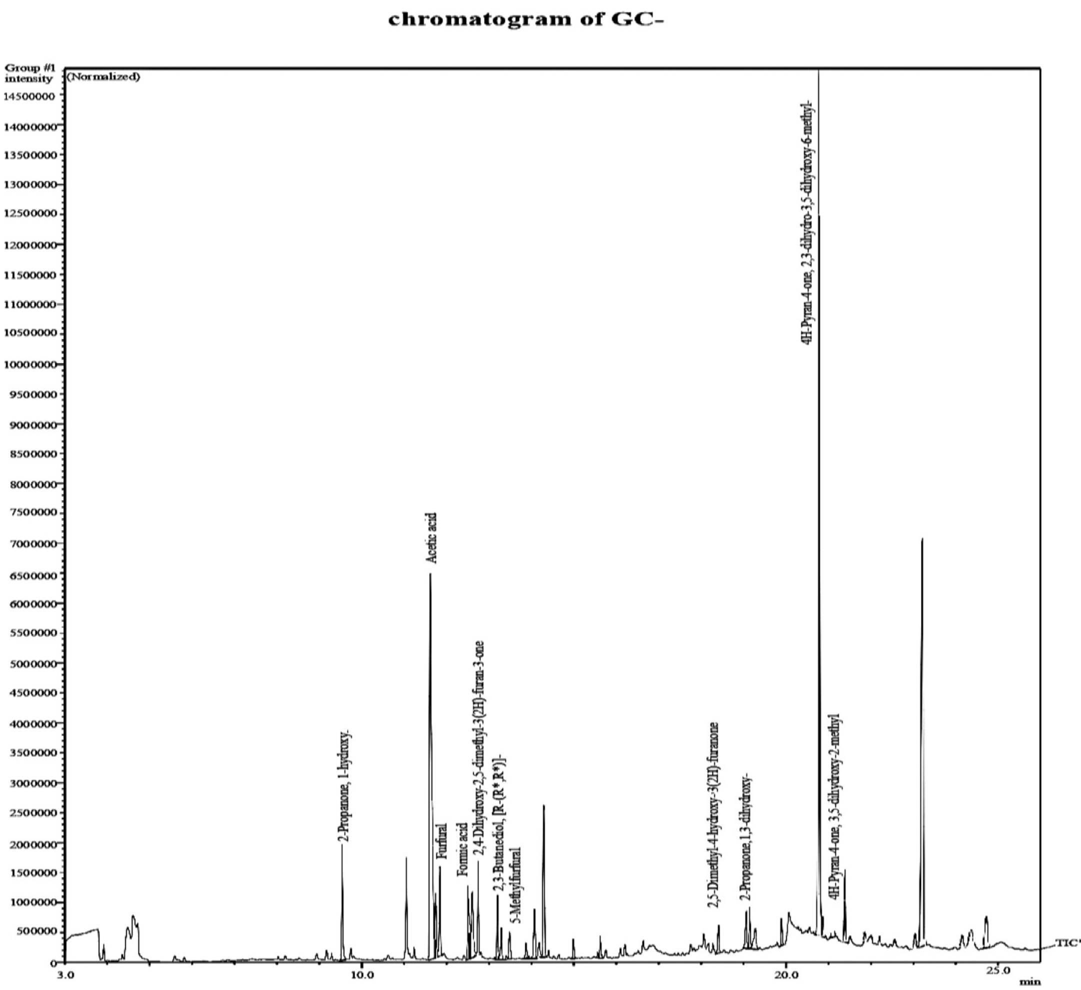


**Fig. 4.** GC Chromatogram of tomato paste produced by OH-VC heating.

cessed tomatoes while being absent in the fresh tomatoes (Marković et al., 2007).

*Mineral content of tomato paste*

Table 3 shows the values of minerals for tomato paste produced by Ohmic heating and conventional heating. The two treatments showed the same types of minerals, namely K, Cl, P, S, Na and Mg whose values were (4112, 5147, 359, 373, 3435, and 345 mg/kg) respectively in the samples treated with ohmic heating, while the values of minerals were (4109, 5140, 352, 368, 3427, and 325 mg/kg) for K, Cl, P, S, Na and Mg respectively in the samples treated with conventional heating.

The results show that the electrodes used in the manufacture of the ohmic heating device did not cause any migration of heavy metal ions. This means no harmful chemical reactions occurred between the components of the tomato paste and the electrodes that might cause metal leakage. In addition, it was confirmed that the value of the electric field (3.64 V/cm) used was suitable for generating sufficient heat by the colli-

**chromatogram of GC-**

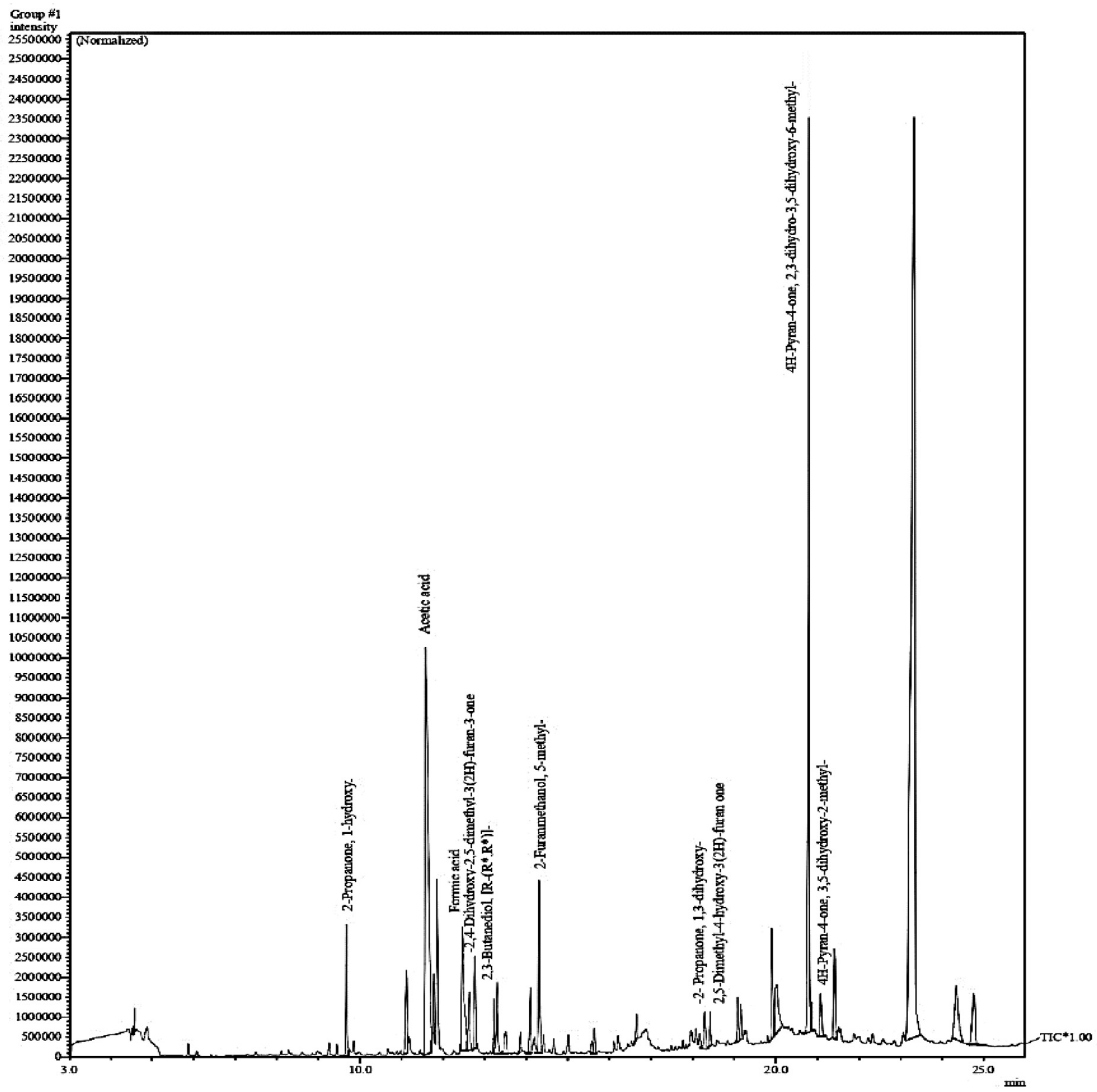


**Fig. 5.** GC Chromatogram of tomato paste produced by conventional heating.

**Table 3**
Mineral content of tomato paste.

| Treatments | Mineral (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | K | Cl | P | S | Na | Mg |
| Ohmic heating | 4126 ± 5.66[a] | 5147.50± 3.54[a] | 348 ± 1.41[a] | 375.50 ± 4.95[a] | 347.50 ± 3.54[a] | 343 ± 2.83[a] |
| Conventional heating | 4125 ± 2.83[a] | 5145.50±2.12[a] | 347 ± 1.41[a] | 371 ± 2.83[a] | 348 ± 7.07[a] | 341.5 ± 2.12[a] |

[a]Means with same letters along a column are not significantly different ($p > 0.05$).

sion of particles without corroding the electrodes. The statistical results showed no significant differences between ohmic heating and conventional heating regarding all studied minerals. The results were in agreement with Mohd-taufek et al. (2019) who mentioned that pasteurization had no significant effect on the minerals that were studied before and after pasteurization. The results also agreed with Jun et al. (2007), who found that the heating treatment ohmic does not cause the transfer of metal ions to food samples, thus indicated that this technique was good for the safety and quality of foods.

**Table 4**
The colour components of treated tomato paste using ohmic heating and conventional heating.

| Treatments | L* | a* | b* |
|---|---|---|---|
| Ohmic heating | 54.90±0.83[a] | 58.12±0.33[a] | 48.47±0.00[a] |
| Conventional heating | 57.06±0.39[a] | 55.76±0.12[a] | 47.76±0.12[a] |

[a] Means with same letters along a column are not significantly different ($p > 0.05$).

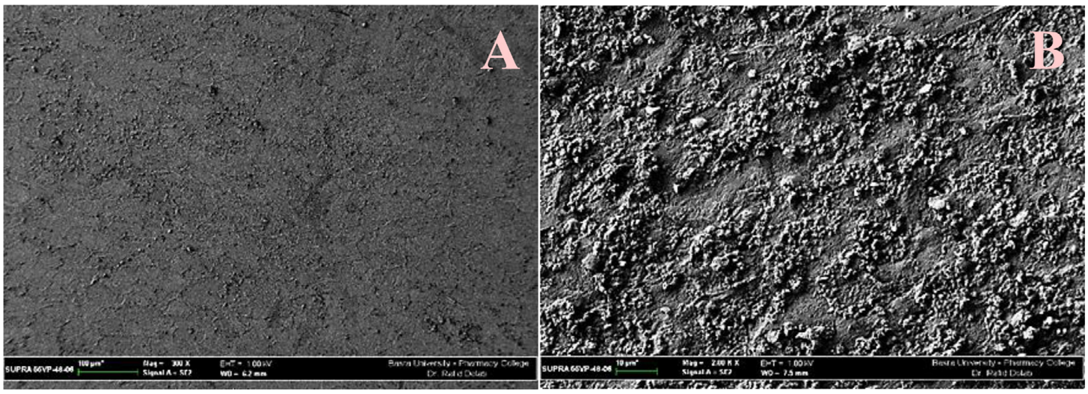


**Fig. 6.** SEM images of tomato paste samples. Panel A ohmic heating treated samples; Panel B conventional heating treated samples.

*Scanning electron micrograph of tomato paste*

SEM Examination of the microstructure of tomato samples showed a clear difference between the morphological structure of ohmic heating treated samples and conventional heating treated samples (Fig. 6). The SEM of ohmic heating treated samples cells look tender and firm with regular structure compared to conventional heating treated samples cells, which had rough surface with irregular structure. This result confirmed that ohmic heating can ensure uniform and rapid heating (Ochida et al.,2019) . In addition, using pressure at 0.3 bar was successfully able to maintain the morphological structure of cells and concentrate the tomato juice in a short time, thus protecting the cell membrane from collapse.

*Determination of Colour*

Table (4) shows the colour-related compounds of the tomato samples produced by the ohmic heating and the conventional heating. The results showed that there was no significant difference ($p > 0.05$) between the ohmic heating treatment sample and the conventional heating. The L * value of the treated tomato samples by ohmic heating was 54.90 ± 0.83 compared to the conventional (thermal) treatment samples which amounted to 57.06 ± 0.39. The L* value using Ohmic heating was 3.7% lower than that of conventional heating. The results showed that the value of a* (redness) was higher using ohmic heating than conventional heating. This shows that the dominant red colour in tomato paste increased more. This result was in agreement with Boldaji et al. (2015) who found that ohmic heating did not cause any damage to the colours (pigments) and was effective in preserving colour. The value of b* using ohmic and conventional heating were close with a very slight difference. The b * value of the treated tomato samples by ohmic heating was 48.47±0.00 compared to the conventional heating samples which amounted to 47.76±0.12.

## Conclusion

Tomato paste, freshly extracted from tomatoes, was subjected to an ohmic-vacuum combination heating, and compared with conventional heating in a double jacket vat. Fourier transform infrared spectroscopic analysis (FTIR) revealed higher deformations of sugars in the OH-VC heat product than conventionally heated paste. There was no heavy metal ion migration noted on account of the electricity used. OH-VC products had a more regular and preserved structure than conventional heating, with no effect of OH-VC on the colour of the product. Apart from these advantageous effects, OH-VC was found to generate a higher number of volatile organic compounds, with some like furfural and others associated with the caramel-like odours in appreciable quantities. This is attributed to the effect of electric heating, which underlines the need for further optimization of the technology. The advantage of using a vacuum results from lowering of the boiling point of water, which was clearly demonstrated in the better preservation of organic compounds in the OH-VC tomato products. These results will inspire the use of this new innovative technology in the tomato, other fruits. and vegetable processing industry.

## Declaration of Competing Interest

Authors declare no conflicts of interests.

## Acknowledgement

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