Heating Performances of Tomato-Based Dressing Sauces Undergoing Moderate Electric Fields

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Moderate electric fields (MEF) heating belongs to electro-assisted heating technologies. MEF involves the use of electrical alternate current, which is forced to pass through a food material, applying an electrical potential gradient up to 1000 V/cm with frequency going from 1 Hz to 1e4 Hz. In MEF assisted heating, the electrical current dissipates heat inside the food product, thus overcoming the heat transfer resistances due to convection or conduction. Tomato based dressing sauces represent a worldwide appreciated food product. Industrially heat transfer operations related to the production of such dressing sauces are based on the use of hot water or steam as heat carriers. Exploring new heating technologies able to shorten production times, can contribute the shift of food industry towards more efficient and less environmentally impacting processes. In order to assess the applicability of MEF heating to tomato-based dressing sauces, three different products were analysed. Namely, tomato sauce, tomato sauce with eggplant, tomato sauce with minced meat were considered. Tests were performed in a custom MEF system imposing an electrical potential difference from 50 V to 80 V. Given the fair even temperature distribution, a macroscopic transient energy balance was used to estimate the electrical conductivity of the considered products and, furthermore, the model of the electrical conductivity as a function of the temperature. Results showed that the investigated products are characterized by electrical conductivity in the range of 1 to 5 S/m, making these sauces keen to MEF heating treatment and opening new opportunity to exploit such heating technology in the preparation and processing of tomato-based dressing sauces.

1. Introduction

Moderate electric fields (MEF) heating, also described as ohmic heating, belongs to electro-assisted heating technologies. Their heating involves the use of electrical alternate current, which is forced to pass through a food material, applying an electrical potential gradient up to 1000 V/cm with frequency going from 1 Hz to 1e4 Hz. It provides an uniform and rapid heating, reducing the long processing times, unwanted temperature peaks, and overprocessing (Jaeger et al., 2016). Hence, the thermal damage is lower than that of traditional thermal treatment. These characteristics could allow producers to reduce the impairment of nutritional, sensory and structural characteristics of foods. Even if the topic is controversial and needs further insights, ohmic heating could also have the advantage of non-thermal effect on microorganism when used as alternative to pasteurization or sterilization (Kubo et al., 2020). A recent bibliometric analysis highlighted the increasing tendency to use ohmic heating as alternative to pasteurization (Silva et al., 2022). The use of alternative heating techniques may also be one of the ways to reduce the environmental impact of industrial food processing. In example, Ghnimi et al. (2021) compared energy requirements of the production in real industrial lines of chopped tomatoes with juice by means of appertization and ohmic heating with aseptic filling reporting 65% energy saving for ohmic heating compared to the traditional heating with retort canning system. The same authors evaluated the global warming potential, of the innovative and conventional method, showing a reduction of about 40% for ohmic heating. Anyway, it should not be neglected that the sustainability of electric-based technologies, is

strongly dependent on the primary sources used for electricity production, a real convenience in the use of this technology will be obtained when the electricity will be provided by alternative energy sources (Paini et al., 2023).

Industrially heat transfer operations are generally based on the use of hot water or steam as heat carriers for most of the food products, including tomato processing and pasta sauces production. Pasta sauce, traditionally more consumed in Europe, due to the popularity of pasta as an alternative to staple meals also in other cultures is characterized by a fast-growing market worldwide (Grand View Research, 2020). The use of alternative processing techniques could contribute to the reduction of environmental impact of this industry as well as to reduce the operating costs for the producers. Indeed, most of the energy is dissipated within the heated material, eliminating the necessity to heat the heat exchange walls in between. As a result, the process achieves an energy transfer efficiency close to 100% (Shim et al., 2010). The application of engineered techniques in the design of ohmic heaters, such as higher frequencies, pulsed square waveforms, and the utilization of chemically inert materials for electrodes, has significantly enhanced the reliability and commercial viability of this technique (Shim et al., 2010).

To date, different ohmic equipment producers state the suitability of ohmic heating for the treatment of tomato-based dressing sauces. Nevertheless, there is a lack of information in scientific literature on the suitability of MEF heating for the treatment of tomato-based dressing sauces as well as the behavior of this product. Indeed, the success of the application of MEF heating depends on the characteristic of the product, from the composition to its structure. To our best knowledge, the suitability of tomato-based dressing sauces to be treated with MEF has never been explored. This work aims to provide a characterization of electrical conductivity of three pasta dressing sauces: tomato-based, tomato-based with minced meat (Bolognese) and tomato-based with eggplant.

2. Materials and methods

2.1 Samples

Three commercial tomato-based dressing sauces were employed in this study. Samples and their ingredients list are indicated in Table 1, sauces composition is reported in Table 2. Bolognese sauces contained minced meat (4%), whereas eggplant sauce contained cubed eggplant (8%)

Table 1: Tomato-based dressing sauces

Sample	Ingredients list
Tomato	Tomato pulp, tomato paste, olive oil, onion, basil, salt, sugar, white pepper
Bolognese	Tomato pulp, tomato paste, cattle meat, pork meat, carrots, onion, olive oil, celery, salt, sugar, yeast extract, black pepper, lactic acid
Eggplant	Tomato pulp, tomato paste, aubergines, onion olive oil, salt, garlic, sugar, parsley, oregano, aroma

Table 2: Tomato-based dressing sauces composition

Sample	Fats	Carbohydrates	Sugars	Fibre	Protein	Salt
Tomato	1.1	6.8	6.1	1	1.6	0.8
Bolognese	2.4	6.3	5.6	1.6	2.9	0.7
Eggplant	1.1	6.4	5.7	1.2	1.5	0.8

Data were collected from the sample label.

2.2 MEF heating system and sample treatment

An experimental MEF system was used in this work. The MEF system (Figure 1) was composed of a custom programmable AC power source able to provide up to 2.5 kW; a MEF cell made of glass with internal dimensions of 10 cm × 6 cm × 5.1 cm (length × height × width, respectively) able to contain 200 g of product, hosting plate stainless steel (AISI316) electrodes, 96 mm one from each other; a fiber optic measurement system (FOTEMP-OEM-PLUS; Weidmann-Optocon, Dresden, Germany) connected to 4 optic fibres put inside the sample at each run in four different positions.

2.3 Electrical conductivity measurement

The electrical conductivity (σ) was evaluated using a macroscopic energy balance, as reported in eq.1. Power (in W) released by the MEF circuit to the food was acquired at fixed temperature values (from 20°C to 100°C, with steps of 10°C) and fixed imposed voltage differences (namely 50V, 60 V, 70 V, and 80 V). Electrical conductivity was calculated according to the following equation:

$$\sigma = \frac{L^2}{\Delta V^2} P_{MEF}\, \varrho \tag{1}$$

Where σ is the electrical conductivity (in S/m), L is the distance between electrodes (in m), P_{MEF} is the power (in W) released by the MEF circuit to the food, ϱ is the food density (in kg/m^3) and ΔV is the potential difference (in V) applied to the electrodes.
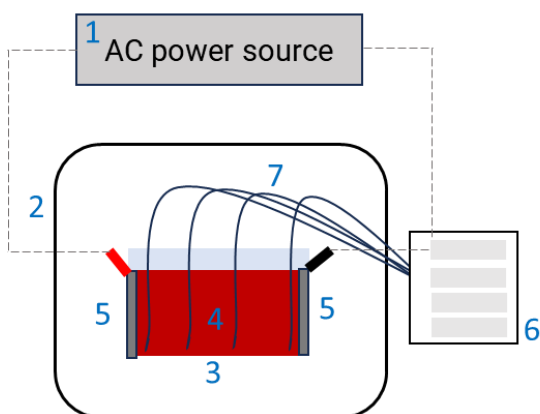The reported value of electrical conductivity for each sample is the average of five replicates.

Figure 1 Schematic diagram of MEF system. 1) AC power source; 2) insulated chamber; 3) glass cell; 4) sample; 5) plate stainless steel electrodes; 6) fiber optic measurement system; 7) optic fibers.

2.4 Data analysis

Data were collected and treated with Excel (Office 365, Microsoft Corporation, Redmond, Washington, USA). One way ANOVA followed by Tuckey post hoc test at 95% confidence interval was performed with XLSTAT Premium version (2020.4.1).

3. Results and discussion

3.1 Electrical conductivity

The samples showed different electrical conductivity values (Figure 2). The values were comprised between 1.29 and 4.02 S/m. As expected, in line with other reports, electrical conductivity values increased with temperature. The increase in the electrical conductivity values with temperature is related to the reduced drag of ions (Darvishi et al., 2015; Icier & Ilicali, 2004; Fadavi et al., 2018)
Electrical conductivity values at all considered temperatures were higher ($p<0.05$) for tomato sauce compared to eggplant and Bolognese sauces (Table 3). In general, different factors can affect electrical conductivity. It has been reported that temperature, applied voltage gradient, frequency, particle size; and concentration of electrolyte affect the rate of ohmic heating and hence, the electrical conductivity (Banti et al., 2020). In this work, the presence of vegetable and meat particles within the tomato sauce could have impaired thermoelectrical properties of the sauces (Sastry, 2014). Indeed, electro assisted heating of heterogenous systems is a challenge (Casaburi et al., 2021b) and it would be desirable to have similar electrical conductivities for all the phases of a heterogeneous food product in order to assure an uniform heating. In addition, food composition and the presence of specific ingredients can influence the electrical conductivity. The investigated samples had slightly different compositions. It can be noted (Table 2) almost twice fat content in Bolognese dressing sauce compared to tomato and eggplant (2.4 % vs 1.1 %) and higher protein content (2.9 % vs 1.5 and 1.6 %), whereas only

0.1% more salt was in Bolognese sauce compared to the others. Generally, salt concentration and the presence of fat have a large effect on the electrical conductivity.
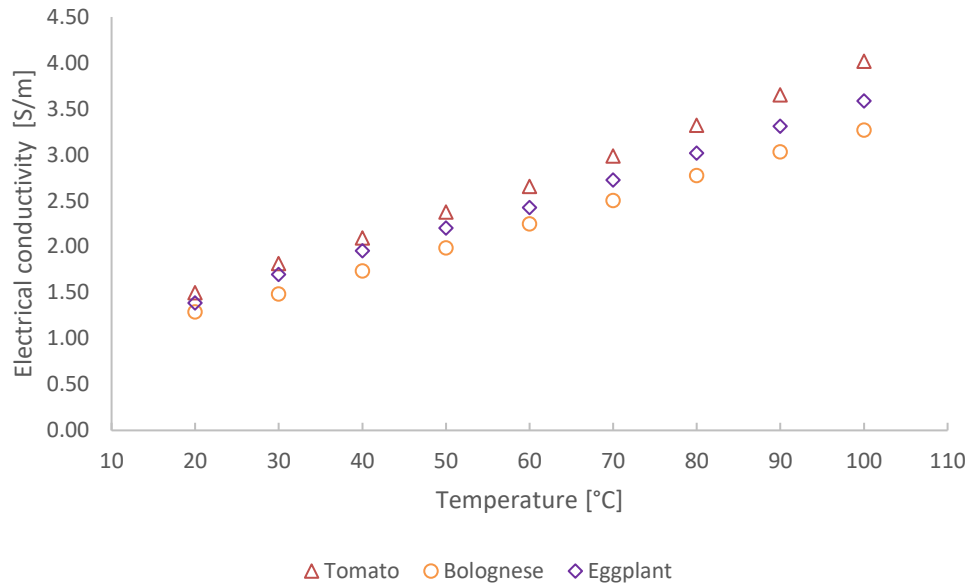

Figure 2 Electrical conductivities of three tomato-based dressing sauces. Data are reported as mean values of 5 replicates.

The difference in composition could affect electrical conductivity. In example, it has been reported that the presence of non-conductive fat tissue in meat samples caused the decrease in the conductivity and higher treatment times in the cooking of meat with ohmic heating (Bozkurt & Icier 2010). In this work, no significant correlation were found between electrical conductivity values at the different temperatures and fat, protein and salt concentration. This could be both due to the composition only slight diffent but also the very small sample size.

In the context of pasta sauces, Casaburi et al. (2021a) previously reported a scarce response to MEF heating due to high fat concentrations for basil-based dressing sauce, confirming that higher fat concentration led to a higher degree of resistance to the electrical current. In addition, they also investigated the effect of the salinity on electrical conductivity, reporting a decreasing passage of the current with lower salt concentration.

Despite the slight differences in electrical conductivity values for the three samples, all of them showed values suitable for the treatment with MEF heating.

Future activities could involve mixing of the dressing sauces to have homogeneous particles in the three samples; this could help to investigate if the differences has to be attributed to the presence of meat and egglplant particles or to the differences, even if small, in dressing sauces composition.

Bolognese sample data, mainly for temperatures higher than 50 °C, showed higher standard deviations values compared to tomato and eggplant samples, thus indicating a higher variability in the measurement probably, which could be attributed to the presence of meat particles.

Table 3 Electrical conductivity values acquired at different temperatures

	20 °C	30 °C	40 °C	50 °C	60 °C	70 °C	80 °C	90 °C	100 °C
Tomato	1.5±0.02[a]	1.82±0.05[a]	2.1±0.03[a]	2.38±0.06[a]	2.66±0.07[a]	2.99±0.09[a]	3.32±0.05[a]	3.66±0.08[a]	4.02±0.07[a]
Bolognese	1.29±0.05[b]	1.48±0.04[b]	1.74±0.08[b]	1.99±0.1[b]	2.25±0.17[b]	2.51±0.21[b]	2.78±0.26[b]	3.03±0.32[b]	3.27±0.27[b]
Eggplant	1.39±0.01[c]	1.7±0.03[c]	1.96±0.07[c]	2.2±0.09[c]	2.43±0.03[b]	2.73±0.03[b]	3.02±0.02[b]	3.31±0.03[b]	3.59±0.01[b]

Data are reported as mean values of 5 replicates ± standard deviation. Different superscript letters within the column indicate different mean values (p<0.05)

Experimental data were linearly fitted by the following equation:

$$\sigma = \sigma_0 + mT \tag{2}$$

Where σ_0 and m respectively represent the intercept and the slope of the linear model.

Results of the fitting procedure are reported in Table 4. R^2 values indicate a good agreement between the measured values and the linear fitting procedure. Slope value for Bolognese and eggplant sample were slightly different compared to tomato dressing sauce. Fat content and protein content showed significant negative correlations (-0.999 and -0.998 p=0.005 and p=0.03) with σ_0 values, anyway these correlation data should be considered cautiously due to the very small sample size.

Table 4: Electrical conductivity of tomato-based dressing sauces

Sample	σ_0 [S/m]	m [S/(m °C]	R^2
Tomato	0.851	0.0310	0.998
Bolognese	0.745	0.0271	0.999
Eggplant	0.852	0.0253	0.999

4. Conclusions

This work explored the application of MEF heating on heterogeneous system like tomato-based sauces with meat or vegetable added ingredients. For the purpose a plain tomato dressing sauces with basil, Bolognese dressing sauce (with minced meat) and eggplant dressing sauce (with cubed eggplant) were employed. All the samples had electrical conductivity values comprised between 1 and 5 S/m indicating that it is possible to apply ohmic heating to these types of samples. The tomato-based basil sauce showed higher conductivity values compared to sauce with eggplant and meat at all temperatures. In example, at 100 °C it tomato based dressing sauce electrical conductivity was 4.02 S/m, that of Bolognese was 3.57 S/m and 3.28 S/m for eggplant sauce. The presence of pieces could impair electrical conductivity of the products, or the composition of the food itself. Further insights are needed to understand if the differences found could be due to the slightly different composition of the food matrix or to the different structure. Anyway, the data shows the applicability of this electro assisted heating technique on tomato-based dressing sauce. The information is promising since they represent a worldwide spread foodstuff whose market will continue to grow in a context where the processing of sauces is energy consuming and more costly compared to the past, also due to the recent increase in the price of commodities.

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