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MULTIDIMENSIONAL COMPARATIVE ANALYSIS OF THREE BAKING METHODS OF THE CUPCAKE – THERMOPHYSICAL APPROACH

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ABSTRACT

Background. A microwave susceptor is a device that alters heating patterns, making it more similar to conventional heating. Therefore, the novelty of this research is the use of a new susceptor, which was used to investigate its effects on the thermophysical properties of cupcakes baked in a microwave.
Materials and methods. Cupcakes were baked in a microwave with a susceptor at different power levels (150, 300, 450, and 600 W). The effect of a susceptor on baking rate, moisture loss, and quality was investigated during the baking process. It was then compared to baking in a microwave without a susceptor at the same operational power as susceptor baking and conventional baking, but at different operational temperatures (140, 160, 180, and 200°C).
Results. The time taken to reach the final processing decreased with power. Among the three methods (2.5, 2.6, and 39.2 minutes for microwave susceptor, microwave, and conventional baking, respectively), the cupcake processed at higher operational power and with a microwave susceptor took the shortest time. Increasing the power of the microwave susceptor also reduced density and processing time, and increased weight loss and porosity. In addition, the color change and browning index (BI) increased at a higher operational power, and microwave susceptor heating was utilized.
Conclusions. By employing this new approach, it is possible to combine the benefits of both microwave technology (reduced time and energy consumption) and conventional baking methods (enhanced browning and reduction of certain quality issues).

Keyword: cupcake, density, microwave susceptor, porosity, color

INTRODUCTION

Heat transfer in conventional baking is slow because of the convection, and conduction is the most important way for heat transfer. Therefore, a high temperature and long processing time in the conventional baking process damaged the quality, for example, the nutritional value, color, flavour, and texture of the baked product. In addition, energy efficiency was low. Therefore, researchers were looking for an alternative method to produce high-quality products. One solution for an effective and rapid thermal process is the use of a microwave (Izadi Najafabadi et al., 2014).

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Microwave baking has increased over the past few decades, due to faster heating and delivery of foods of a higher quality. The microwave energy is absorbed directly by food, thereby producing volumetric heating through conversion of electromagnetic energy into heat by polar molecules and ions (Tang and Resurreccion, 2009).

An electromagnetic field does not distribute heat evenly. It causes non-uniform heating and the creation of hot and cold spots in food. Therefore, there is no microbial safety of food (Vadivambal and Jayas, 2010). Moreover, when food is heated in a microwave oven, it creates significant interior vapour pressure and concentration gradients. It then increases the flow of the fluid through the food to the boundary. The air temperature inside the oven is slightly above the ambient temperature. As a result of water vapour condensing on the surface of food materials, the temperature never exceeds the boiling point of water. Therefore, both color and flavour do not develop (Ibrahim et al., 2012; Zuckerman and Miltz, 1997).

The main challenge for food scientists was to improve the quality of microwaved food. To fix the problem, a susceptor was suggested. A susceptor can absorb and convert electromagnetic energy into heat faster than the food material (Albert et al., 2009; Zuckerman and Miltz, 1997).

There are some examples of traditional microwave susceptor (Al_2O_3+SiC application in food processing, especially for protein-based food (Albert et al., 2009; Basak, 2007; Basak and Meenakshi, 2006; Bhattacharya and Basak, 2016) in the literature. Moreover, the microwave susceptor has been used for bread and pastry baking (Içöz et al., 2004; Nor Mazlana Main, 2008; Yolacaner et al., 2017). This proved that this method could help improve its quality parameters; however, this approach was not used to investigate the effect of a susceptor on the quality parameters of the cake, such as color, density, and porosity. Thus, the primary goal of this research was to make a novel microwave susceptor. Investigating the effect of the novel susceptor on thermophysical properties is considered as another scientific contribution, and the last goal of this study was to comprise the baking methods such as conventional, microwave, and microwave susceptor heating at varying power levels (or temperatures), on baking rate, temperature, and thermophysical characteristics of cupcakes during baking.

MATERIALS AND METHODS

Making of microwave susceptor

In this study, a new kind of susceptor was made by mixing seven nano-metal oxides (WO_2, TiO_2, Al_2O_3, SiO_2, Y_2O_3, ZrO_2, and MgO) in a hydraulic press. This was followed by the preparation of discrete ceramic by a Vifer-machine. The prepared susceptor was covered with quartz pages (non-contact of nano-metal oxides with food materials for safety, and healthy aspects) and placed on the surface of the cupcake.

Preparation of cake batter

Vanilla batter (flour; 21.1 g, sugar; 21.1 g, milk powder; 1.6 g, emulsifier; 0.25 g, salt; 0.45 g, vanilla; 0.45 g, baking powder; 1.35 g, liquid egg; 24.7 g vegetable oil, 14.5 g, and 14.5 g water) was prepared by stirring the liquid egg using a mixer (Bosch-CNCM57, 1100 W, Slovenia) at high speed for 10 min and mixing with water and vegetable oil. Finally, other ingredients of batter were added and mixed until uniformity in the cake batter was obtained.

Baking procedure

Microwave baking: cupcake batter of 100 g was placed in a baking pan and baked in a microwave oven (Butane MR-1, Iran), with or without susceptor until the moisture content reached 19% (dry basis). The microwave was operated at the following powers: 150, 300, 450, and 600 W. The time of the microwave baking was 16, 7.4, 4.8, 3.5, and 2.6 min, respectively, and this parameter for microwave susceptor baking was 14.7, 7.1, 4.7, 3.1, and 2.5 min, respectively.

Conventional baking: the vanilla batter was baked in a forced electric oven (Butane MR-1, Iran) at 140, 160, 180, and 200°C until the moisture content reached 19% (dry basis), and the process time was 98, 77.3, 60, 40.8, and 39.2 min, respectively.

The operating temperature of the oven was set before placing the sample in.

Weight loss and moisture profile measurement

Weight loss of samples was recorded continuously using an online digital balance (AND, Japan) during baking, and the moisture content of the samples was plotted versus time.

Color measurement

The bottom and top surfaces and center color of the cooled samples were immediately read using a spectrophoto-colorimeter Mini Scan XE (Germany) as L^* (lightness), a^* (greenness to redness), and b^* (blueness to yellowness). An average of three replications was reported. Total color difference (ΔE), intensity (C), and purity of brown color (BI) are as follows (Askari et al., 2008; Soleimanifard et al., 2018):

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

$$C = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

$$BI = \frac{\left[100\left(\frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} - 0.31\right)\right]}{0.17} \quad (3)$$

Height determination

To evaluate the height of the cupcake, the samples were cut vertically along the center and the height was measured at five points (the centre and four other symmetric points on a cross-sectional surface) using a standard gauge. Then, it was calculated as the average of these values (AACC, 1999; Zareifard et al., 2009).

Density, and porosity determination

The mass of the sample and its bulk volume – that is, the product mass as measured using an analytical balance – determine bulk density. The rapeseed displacement method was utilized to ascertain the volume of every cupcake (AACC, 2000). True density is determined by the mass of the sample and its true volume without any pores. Porosity (ε) is a fraction of the empty volume and is estimated in accordance with the following equation (Krokida and Maroulis, 2000):

$$\varepsilon = 1 - \frac{\rho_b}{\rho_t} \quad (4)$$

Where, ρ_b and ρ_t are bulk and true density.

Statistical analysis

The experimental design was a split plot arranged in a completely randomized block design with three replications. The first factor was the baking method (microwave, microwave susceptor, and conventional), and the second was power levels (150, 300, 450, and 600 W). The data collected was subjected to analysis of variance (ANOVA) using SAS statistical programme and MSTAT-C procedures. Means of treatment were separated using the least significant difference (LSD) test (*p*\0.05).

RESULTS AND DISCUSSION

Effect of operational method on baking rate

As Figure 1a shows, the moisture content of the samples decreased with baking time and operational power. A smaller process time and the greater effect of power in the case of microwave susceptor heating, compared to other baking methods, could be related to the use of the susceptor in baking (Fig. 1b) that changes microwave heating pattern. Furthermore,

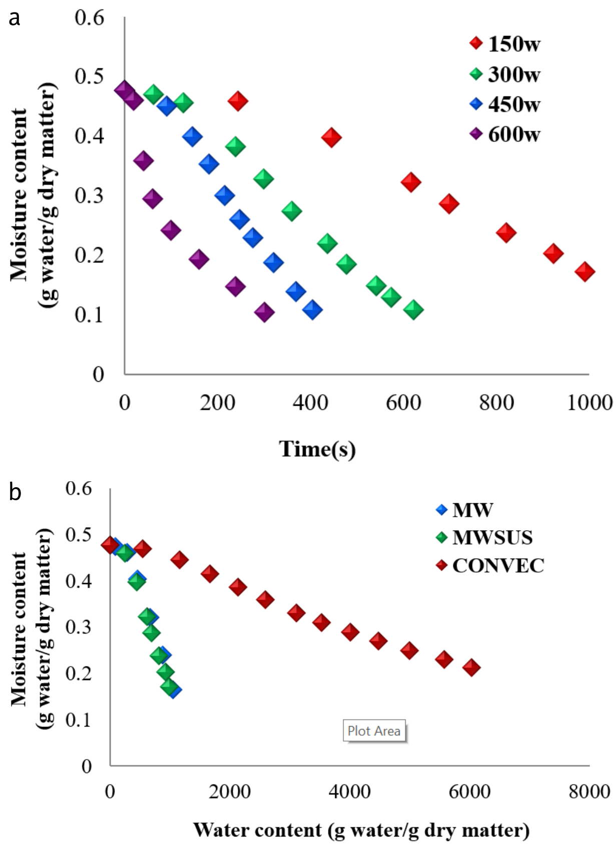

Fig. 1. Rate of moisture loss in the samples during microwave susceptor baking (a), the moisture loss in comparison of three baking methods (b)

by absorbing a lot of heat on the surface, it leads to an increase in the speed of heat transfer compared to other methods. Desired process times were 14.7, 16, 98 min for microwave susceptor, microwave, and conventional baking, respectively. Results showed that the average percentage reduction in baking time achieved by microwave baking with and without susceptor, compared to conventional baking, were 91% and 90%, respectively. Moreover, this parameter for the microwave baking with the susceptor compared to without the susceptor was 4.5%.

Color

The cupcake baked using a microwave susceptor shows a decrease in the L^* value while an opposite trend is observed for a^* and b^*, with an increase in power and time. According to Mandala et al. (2005), Ranger et al. (2017) and Vhangani and Van Wyk (2023), the decrease of L^* values and the increase of 'a^*' values correspond to the increase of sample browning, as shown in Figure 2c. The samples made with various baking techniques clearly differ from one another. Similar results for biscuit (Çinar et al., 2023), and bread were found in the literature (Içöz et al., 2004).

To obtain a better understanding of the effect of treatment on cupcake color, BI and total color difference (ΔE) were determined. The color changes (ΔE), BI, and color intensity (C) increased significantly with time and power (with or without susceptor) during baking (Fig. 2). The baking process alters the surface properties of food and subsequently changes light reflection and product color. Moreover, heat and oxidation – which occur during the baking procedure – cause chemical changes (Soleimanifard et al., 2018).

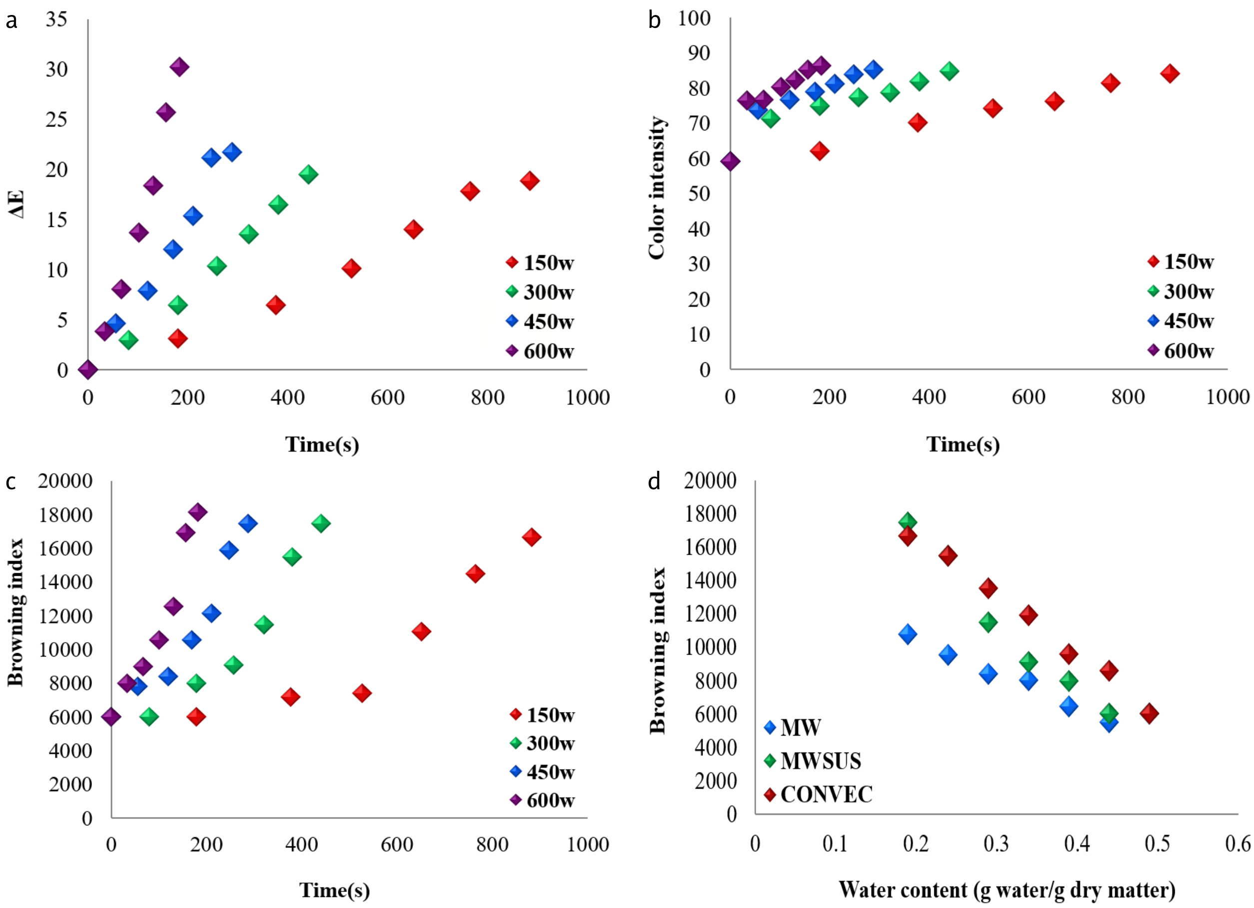

Fig. 2. Kinetic of color changes (a), color intensity (b), and browning index (c)by using microwave susceptor at different power and comparison of browning index in three methods (d)

A slight increase in the BI was noted at the start of the process, as Figure 2c illustrates. As time went on, the moisture content decreased, the BI then quickly grew to reach its ultimate value. This implies that a browning reaction, like caramelization or maillard, can be intensified with higher power and lower moisture content (Bchir et al., 2012; Şen and Gökmen, 2022). This effect is more noticeable in the microwave susceptor method compared to the others. On the other hand, final BI values obtained using a susceptor were higher than those using other methods (Fig. 2d).

A significant difference between all color parameters using a susceptor was noticed, when compared with other methods. This could be the result of high absorption of microwaves by the susceptor and a high difference of sensible temperature between the sample and susceptor. This, in turn, could lead to faster heat transfer and changes in color parameters.

Height

Height is very important in quality of bakery products. Lower height leads to less aeration in the crumb structure of the bakery products. This results in higher firmness values for products, which ultimately leads to a decrease in consumer acceptance.

Figure 3a showed height changes during cupcake baking. Initially, the cupcake expands when heated because of the vaporization of water inside it (Soleimanifard et al., 2018). This was incorporated while mixing the batter, producing CO_2 (Baik and Marcotte, 2003; Seranthian and Datta, 2023). When the cupcake temperature went over 85°C, the expansion ceased; however, the evaporation persisted. The end of cupcake expansion has proof, like an open structure, due to the development of bubbles and the large release of gas when the temperature goes beyond the coagulation temperature of proteins (Grenier et al., 2021; Lucas, 2014). The structure also became stiff after expansion stopped when the cupcake temperature reached starch gelatinization temperature (90°C). Finally, there was the end of expansion and water (Fig. 3b). Evaporation led to the cupcake shrinking (Lostie et al., 2002). As the results show, there is a noticeable variation in the height of cupcakes when using different power levels. Similar findings were documented by (Megahey et al., 2005). On the other hand, the height of the cupcake increased with power (Fig. 3a).

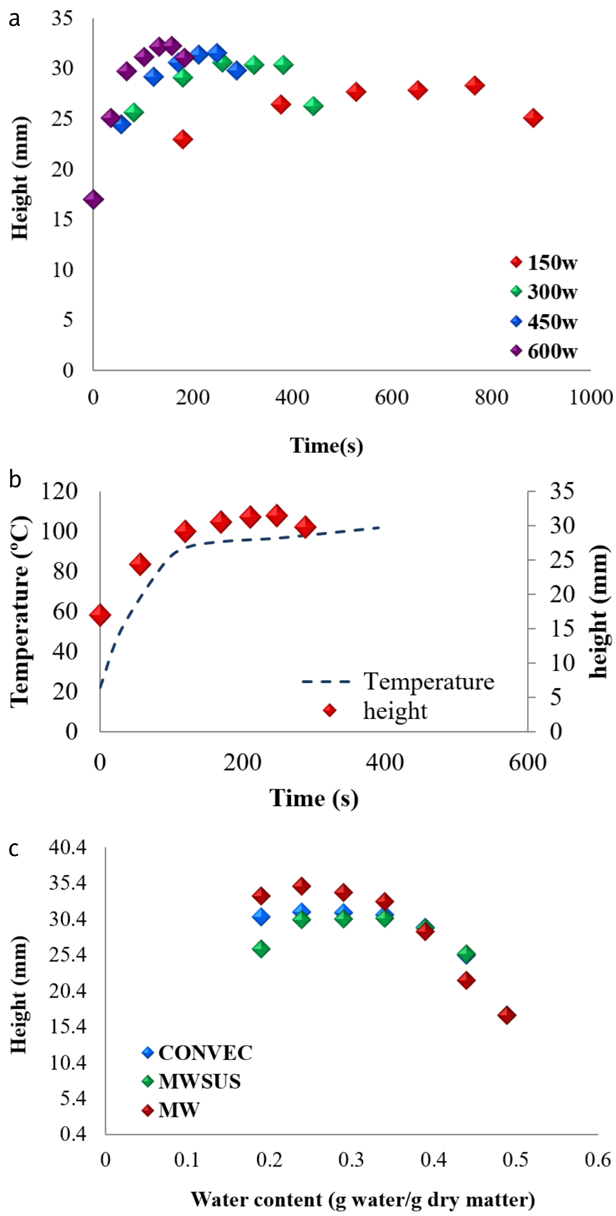

Fig. 3. Kinetic of height changes (a), relationship between temperature and height (b), and comparison of height in three different baking methods (c)

Density, and porosity

The results showed that a cupcake baked with increased power had greater porosity and decreased density, resulting in more sponge (Fig. 4a and 4b). The height of cupcakes with increased power increased (Fig. 3a), which leads to an increase in air aeration in

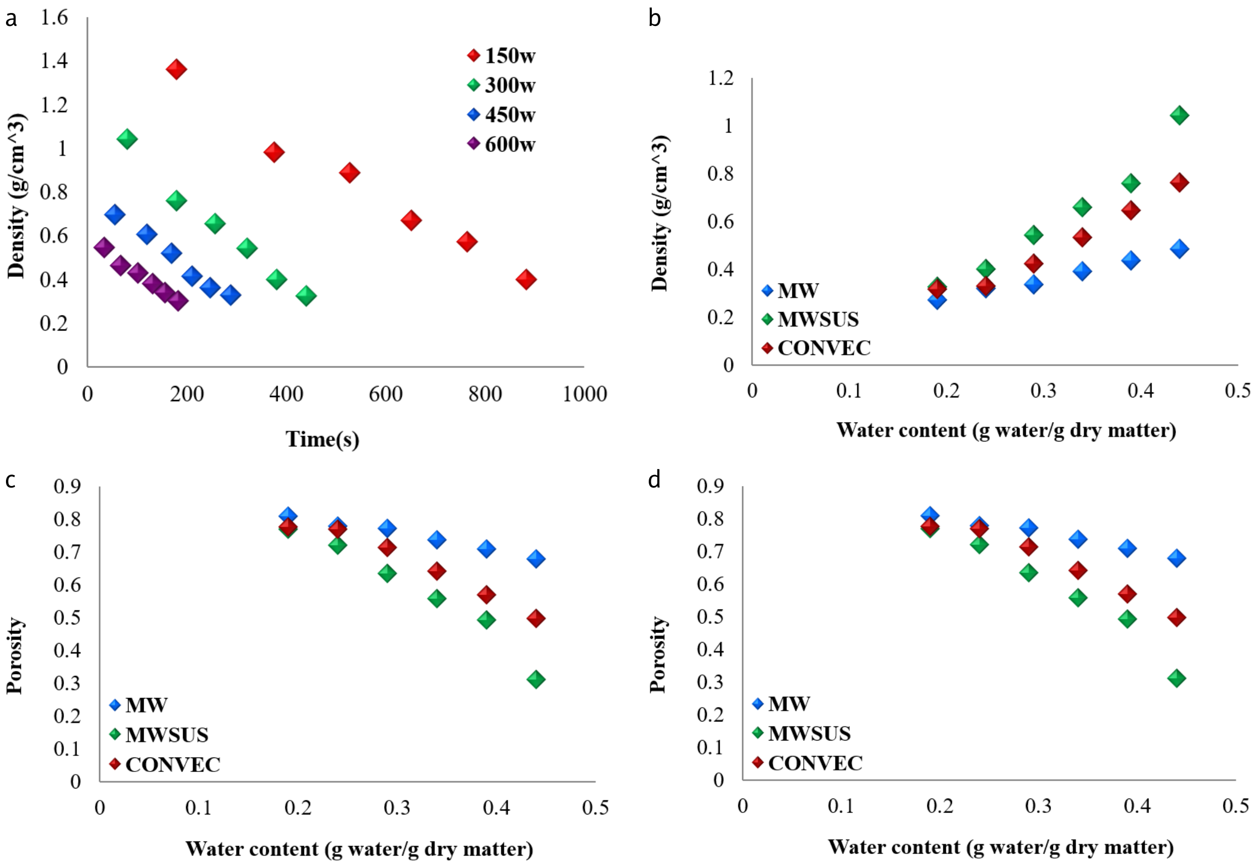

Fig. 4. Kinetic of density (a), porosity changes (c), comparison of density (b), and porosity (d) in three different baking methods

the crumb structure, an increase in porosity and volume, and a decrease in density.

As Figures 4(c and d) show, the lowest density and the highest porosity were produced by the microwave baking method. The microwave generates heat inside the samples. The internal vapour pressure then increases, and this leads to a more puffed-up structure compared to other methods (Fig. 3c). Similar findings have been documented by Rodríguez et al. (2022) on gluten-free muffins and Packkia-Doss et al., (2019) on bread. As previously mentioned, the susceptor absorbs microwaves and converts them into heat more rapidly than the sample itself. Therefore, the main part of the heat conductively transfers from susceptor to samples. This results in higher density and lower porosity compared to other methods. Unlike a microwave susceptor that had high absorption of microwave and great difference in sensible temperature between the sample and susceptor that led to faster heat transfer, the low rate of increasing temperature of the batter during the early stages of conventional baking (Megahey et al., 2005; Yong et al., 2002) resulted in greater height and porosity and lower density (Chakraborty and Dash, 2023).

However, the value of these parameters using a susceptor was close to conventional baking. As a result, it can be said that the use of a microwave susceptor approaches conventional cupcake baking.

CONCLUSIONS

The effects of a microwave, microwave susceptor, and conventional baking on baking rate, optical, physical, and textural properties were investigated. Findings indicated that the time required to achieve the desired baking outcome was influenced by the operating power and heating method. The shortest time was achieved when using a microwave susceptor baking at the highest power setting. The obtained results showed that the color change and browning index increased when higher operational power and microwave susceptor heating were used. Results also indicated that the baking rate of cupcakes depended on the process time. Examination of the physical characteristics of the samples revealed that the density decreased in all cases with increasing power. Microwave susceptor baking resulted in a product with density and porosity similar to conventionally baked cupcakes. However, it exhibited higher weight loss and color parameters compared to other samples. Therefore, it is a suitable alternative to conventional methods.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

OPEN ACCESS

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