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ORIGINAL PAPER

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THE EFFECT OF A MICROWAVE SUSCEPTOR ON THE TEXTURAL PROPERTIES OF CUPCAKES DURING BAKING – A COMPARISON WITH MICROWAVE AND CONVENTIONAL BAKING METHODS

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ABSTRACT

Background. A susceptor is a material that can absorb electromagnetic energy and convert it to heat more rapidly than food materials, effectively transforming a microwave oven into a conventional oven. This study used a new nano-composite ceramic as a microwave susceptor to bake cupcakes and investigated its effects on texture characteristics, as well as comparing this method with baking in a conventional oven and the use of a microwave without a susceptor.

Materials and methods. The nano-composite susceptor was utilized to bake cupcakes at various operational power levels (150, 300, 450, and 600 W). The study examined the impact of using a susceptor on the rate of baking, temperature, and texture attributes. A comparison was made between the use of a microwave with a susceptor, the use of a microwave without a susceptor at the same power level, and conventional baking at various temperatures (140, 160, 180, and 200°C).

Results. The susceptor has a higher rate of microwave absorption and heat conversion than cupcakes. Heat is primarily transmitted from the susceptor to the cupcake through conduction. A significant difference in detectable temperature between the sample and the susceptor resulted in accelerated heat transfer. This also yielded the highest rate of baking among the three methods. Moreover, the surface temperature of the cupcake increased with power during baking, and the final surface temperature of the cupcake baked using the microwave susceptor was similar to that of conventionally baked cupcakes. Baking using the susceptor led to a reduction in hardness and chewiness, and an increase in springiness, cohesiveness, and resilience. Furthermore, the cupcakes baked using the susceptor had hardness and chewiness values similar to conventionally baked ones. The use of a microwave susceptor led to an increase in crispiness compared to cupcakes baked without a susceptor, and the crispiness value was close to that obtained with conventional baking.

Conclusions. The use of a microwave susceptor led to an improvement in cupcake texture, resulting in a texture that was close to that obtained with conventional baking. Overall, microwave baking with a susceptor is the most suitable baking method for cakes due to the high surface temperature, cohesiveness, and springiness obtained using this method, and also the minimal processing time, hardness, and chewiness.

Keywords: hardness, cupcake, microwave susceptor, crispiness, baking

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INTRODUCTION

Texture analysis focuses on measuring the mechanical qualities of a food item, i.e. their sensory properties as detected by humans. In bakery products, some textural properties, such as hardness, springiness, cohesiveness, chewiness, crispiness, and resilience, are very important (Bourne, 2002; Nogueira and Guiné, 2022).

Hardness—a negative characteristic in cakes—is the result of two primary factors: the crumb losing moisture or the starch underneath undergoing retrogradation. Hardness can also be seen as a disadvantage for the crust of most bakery products (Pateras, 2007; Young, 2012). Cohesiveness is often regarded as a favorable quality in all kinds of baked products. This feature is influenced by both the amount of moisture and the strength of the network that surrounds the holes in the crumb (Cauvain, 2004). The degree to which a sample recovers from deformation, in terms of speed and derived forces, is defined as the resilience. Finally, chewiness is the energy required to disintegrate a semisolid food until it is ready to be swallowed (Bolhuis and Forde, 2020; Zareifard et al., 2009).

Since texture is one of the major quality parameters of foods, achieving the desired textural quality of microwave-baked products is an ongoing challenge for food researchers. Some textural problems of cakes include crumb hardness, reduced crispiness, and lower moisture content (Baik et al., 2000; Soleimanifard et al., 2018). To solve these problems, a proposed solution is the combination of microwaves with other heating methods. In this regard, Şumnu et al. (2000) have investigated the quality of cakes baked in microwave, infrared (IR), and IR-microwave combination ovens. The use of an IR-microwave combination for cake baking was found to reduce hardness compared to microwave baking, while the hardness of cakes baked using a halogen lamp-microwave combination was found to be similar to that obtained using conventional baking. They observed that the loss in cake weight increased with power for all methods, the baking time was reduced in the halogen lamp method, and power was the most influential parameter in cake-baking. Datta et al. showed that infrared and hot air baking combined with microwave cooking reduced the surface temperature and moisture content (Datta and Ni, 2002).

A susceptor is a material that can absorb electromagnetic energy and convert it to heat faster than food materials. It leads to brown coloring, crispiness, and uniform heating in food processing. Furthermore, susceptors can change the thermal pattern of microwave baking to simulate conventional heating (Perry and Lentz, 2009; Savage and Baldwin, 2004; Zuckerman and Miltz, 1997).

However, the effect of using a susceptor on the textural parameters (hardness, springiness, cohesiveness, resilience, chewiness, and springiness) of cake has not been investigated. In this study, a new nano-composite ceramic was used as a susceptor for the first time, and the texture analysis approach is considered another scientific contribution. The study also compares the use of various baking methods, namely traditional, microwave, and microwave-susceptor heating, for vanilla cupcake baking.

MATERIALS AND METHODS

Three steps of materials and methods are summarized in Figure 1. More details are mentioned in part 1 of this article.

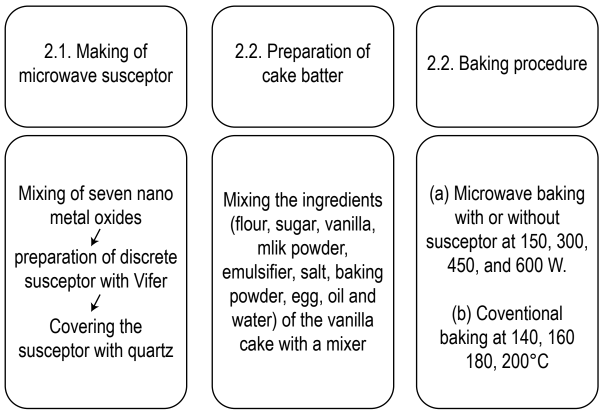


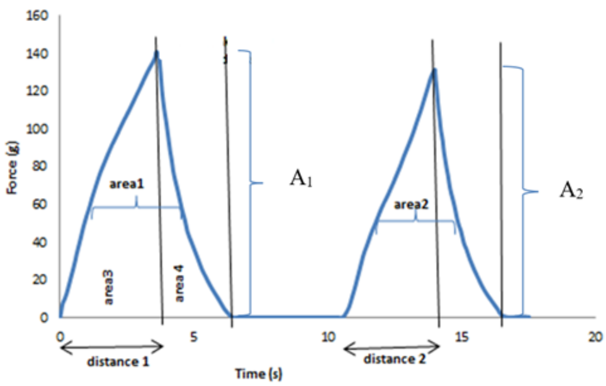
Fig. 1. Schematic of three steps of materials and method

Temperature measurements

The temperatures of the center and surface of the samples were recorded by thermometer at specified time intervals and all the temperature data were used to plot the temperature profiles.

TPA analysis

Double-compression texture profile analysis (TPA) tests were carried out on cake crumbs using a Texture Analyser (TA Plus, Lloyd Instruments, UK) equipped with a 50 N load cell. Cylindrical samples of 24.5 mm diameter and 20 mm height were compressed to 50% with a cylindrical probe (40 mm in diameter) at a speed of 60 mm/s. The hardness, springiness, cohesiveness, resilience, and chewiness were extracted from the resulting force-time curve and are shown in Figure 2 (Bourne, 2002; Zareifard et al., 2009).



Hardness=A_1

$$\text{Springiness} = \frac{Distance_2}{Distance_1}$$

$$\text{Cohesiveness} = \frac{Area_2}{Area_1}$$

$$\text{Chewiness} = \text{Hardness} \times \text{Cohesiveness} \quad \text{Resilience} = \frac{Area_4}{Area_3}$$

Fig. 2. The textural parameters of the TPA curve

Crispiness measurement

A puncture test using a texture analyzer (TA Plus, Lloyd Instruments, UK) was used to determine the crispness of each sample's 2.5 cm-thick top surface. The force required for the probe to puncture the sample thickness was expressed in N (Kang et al., 2015).

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, or conventional), and the second was the power level (150, 300, 450, or 600 W). The data collected was subjected to analysis of variance (ANOVA) using the 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 and temperature

Figure 3a illustrates the surface temperature of the cake when using the susceptor under different operational

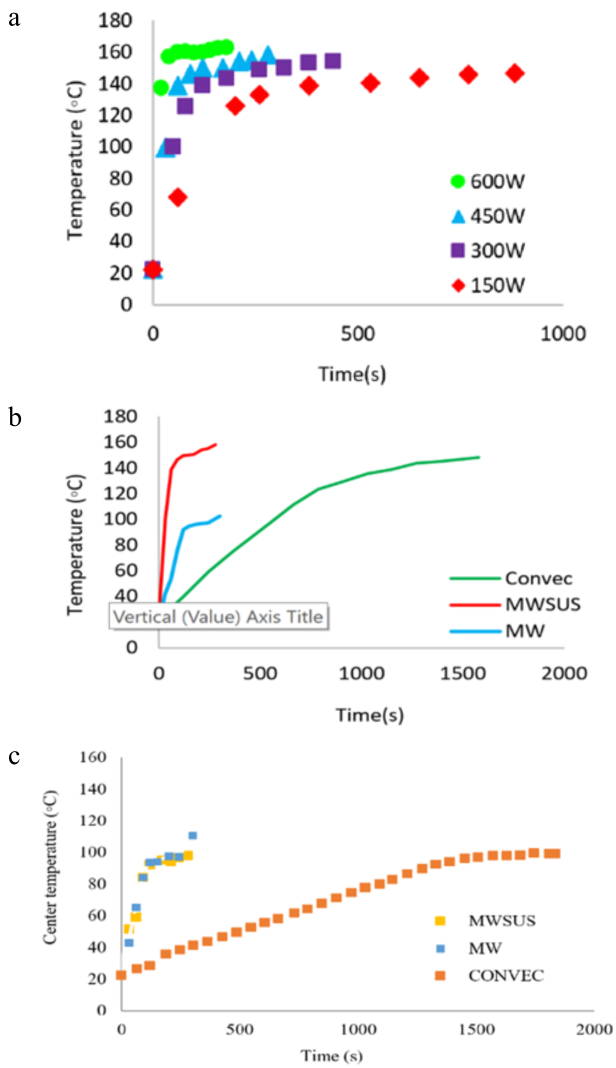


Fig. 3. Effect of time and power on cupcake surface temperature profiles during microwave baking with a susceptor (a). Comparison of surface (b) and center temperature (c) for the three baking methods

powers during baking. As can be seen, the temperature of the samples increased with baking time and power. The final surface temperature of the cupcake was higher for microwave susceptor baking than for other methods because the susceptor absorbs most of the microwaves and converts them to heat, which then conductively transfers to the samples. Also, comparison of the center temperature for the three baking methods showed that the temperature of microwave-baked cupcakes was higher than the temperature of cupcakes heated using the other methods, because the microwaves penetrated the samples and produced heat at the center of the cupcakes (Fig. 3c). Nevertheless, there was conductive heat transfer from the surface to the center of the cupcakes using the other methods. Similar fundings were reported by Sahin et al. (2002) for bread baking.

Moreover, the surface and center temperatures of the cupcake baked in a microwave susceptor were similar to those of the cupcakes baked by the conventional baking method but were obtained with less process time and energy consumption (Fig. 3b and 3c).

Hardness

Figure 4a shows the kinetics of cupcake hardness. Hardness was found to increase with time. The decrease in moisture content may be connected to the increase in hardness, since water acts as a plasticizer (He and Hoseney, 1990). The starch (gelatinized and retrograded), protein interactions, and starch-starch interactions speed up as the moisture content decreases, creating a harder texture. Therefore, crumb moisture content and hardness are closely related. Similar results were reported by Ozkoc et al. (2009) and Rogers et al. (1988) for bread baking, and Omidiran et al. (2023) for sweet potato chips.

An increase in the hardness of bread corresponding to an increase in power has also been reported in the literature (Keskin et al., 2004). However, the final

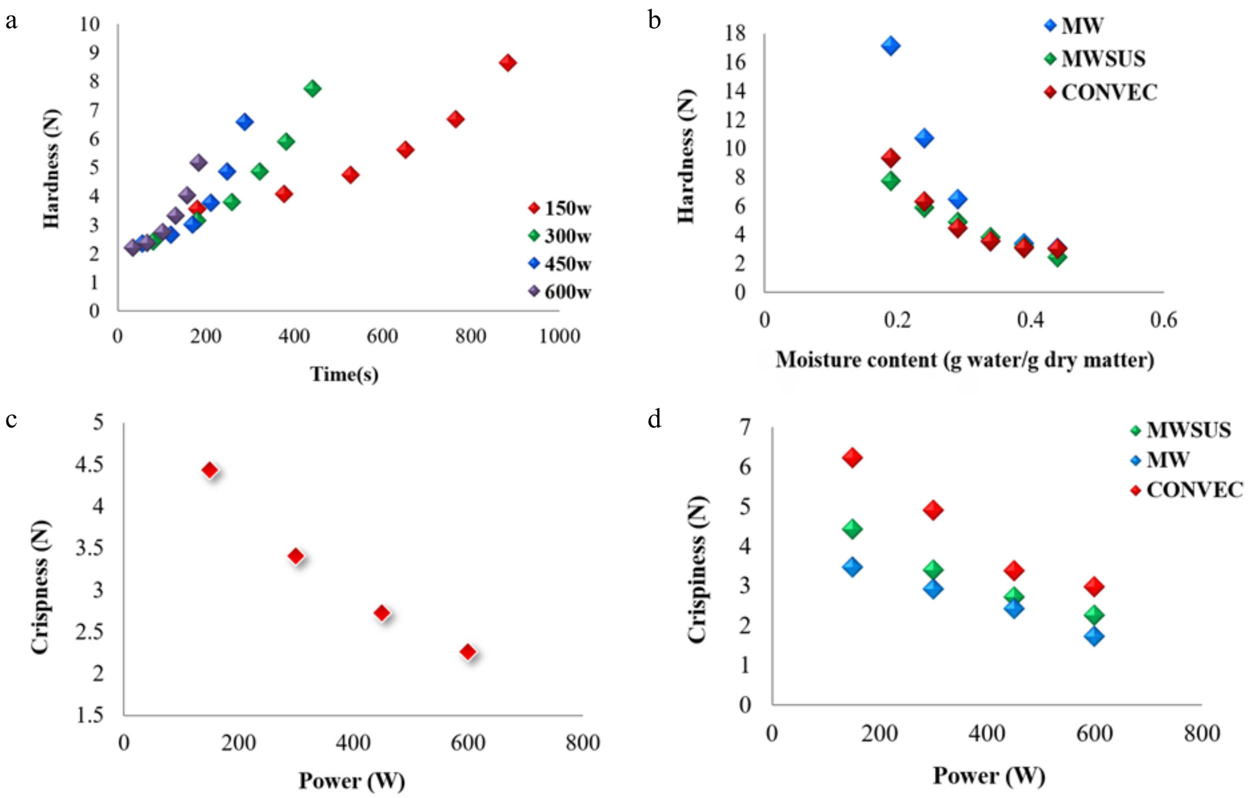


Fig. 4. Kinetics of cupcake hardness (a) and crispiness (c) with a microwave susceptor at different powers. Comparison of the hardness (b), and crispiness (d) obtained with the three methods

hardness of samples decreased with an increase in power. When the cake was baked at a higher power, baking required less time in the microwave, and therefore the hardness was reduced.

The comparison of baking using a microwave susceptor with other methods shows that the hardness values of cakes baked by microwave was the highest among the three heating modes. Içöz et al. (2004) and Sahin et al. (2002) reported less hardness with the conventional than the microwave method. Using a susceptor in the baking process leads to a decrease in this hardness, and in the current experiment, this parameter value was close to the value obtained with conventional baking. Therefore, the hardness of a cake baked using a susceptor is comparable to the hardness of a cake baked using the conventional method (Fig. 4b).

Crispiness

The crispiness of cupcakes baked using a susceptor decreased as the power increased. As shown in Figure 4c, at first the reduction in crispiness was rapid, but the slope decreased with increasing power, and at the highest experimental power (600 W) it was close to zero. When a cupcake was baked at a higher power, it needed less time in the microwave and so the crispiness declined.

The use of a susceptor underneath microwave cupcakes significantly increased the crispiness of the cupcakes compared to microwave baking without the susceptor. Its value was close to the values obtained using conventional baking. So, crispiness at the highest power is almost equal to its value following conventional baking (Fig. 4d). Similar findings have been documented by Albert et al. (2009b), Varela et al. (2008), Perry and Lentz (2009), Chen et al. (2017), and Bundit Jumras et al. (2020) for crusted food.

The reason for the low crispiness obtained with microwave baking compared to other methods is that the heat generated by the microwave only partially affects the surface (Hadiyanto, 2013).

Cohesiveness

Figure 5 shows the kinetics of cohesiveness changes during vanilla cupcake baking with a microwave susceptor at different powers. Irrespective of the baking method, the cohesiveness of the cake increased as the baking time increased, as shown in Figure 5b. Similar results were observed by Clarke and Farrell (2000). Moreover, this parameter increased with power for a given time. For example, final mean cohesiveness values ranged from 0.589 to 0.618 for a microwave susceptor power of 150 W to 600 W. As the power increased, the moisture content was reduced. As a result, the structure was more robust and more cohesive. Additionally, when the power increased, the sample acquired more energy over time; as a result, the process time needed to create the final structure decreased.

A comparison of microwave susceptor baking with other methods (Fig. 5b) shows that using a susceptor in the baking process led to a significant increase in cohesiveness; this parameter value decreased more slowly with a susceptor than with other methods. Therefore, the cake baked using a susceptor had the most integrated and the least fractured structure.

Springiness

Springiness significantly increased with time and power when baking using a microwave susceptor (Fig. 5c). The hardness of the cake increased with increasing process time, and more time was required for the cake to return to its original shape/size. Therefore, springiness increased with process time. Similar reports have been documented in the literature for pizza (Clarke and Farrell, 2000), and for high protein gel (Pure et al., 2021). As previously stated, the hardness of the final cake decreased as the power increased from 150 W to 600 W. As a result, increasing power reduced the time required for the cake to recover its initial shape, i.e. it increased the springiness of the final cake.

As shown in Figure 5, the lowest values for cohesiveness and springiness were produced by the conventional baking method. The samples were exposed to hot air, and more crispiness was found in the samples baked using the conventional method than in those baked using the other methods; mass transfer decreased in the interior of the samples, and the hardness of samples was reduced. Finally, less springiness was generated by conventional baking than by the other methods.

Resilience

Figure 6a shows the resilience changes during baking in a microwave susceptor. Resilience first increased and then decreased.

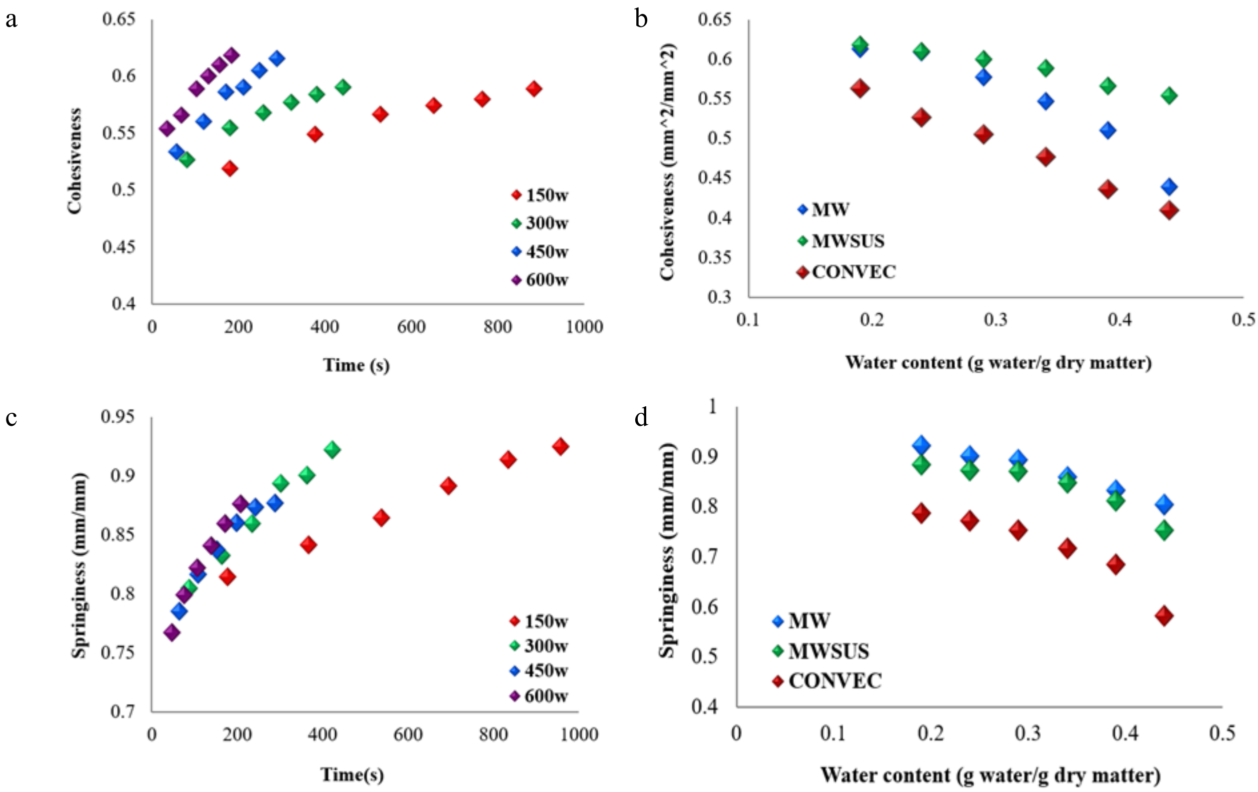


Fig. 5. Cohesiveness (a) and springiness (c) changes of cake baked in a microwave susceptor at different times and for different powers. Comparison of cohesiveness (b) and springiness (d) for the three methods

The cohesiveness and hardness of the cake increased (Fig. 4 and Fig. 5). Also, the height and volume of the cake changed during baking (Fig. 6b). These changes were desirable effects that led to the formation and strength of structure in the cake. The resilience was increased, i.e. the cake could return to its original state more quickly. When the cupcake temperature went over 85°C, the expansion ceased but the evaporation persisted. At the end of cupcake expansion, the cupcake had 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 (Tiphaine, 2014). After the starch gelatinization temperature (90°C) was reached, the structure of the cupcake stiffened. Finally, expansion ended and water began to evaporate. This evaporation led to the cupcake shrinking (Lostie et al., 2002). The texture was hard and resilience was reduced (Fig. 6b, c).

As Figure 6d shows, the highest resilience was created by the microwave susceptor baking method. Unlike baking with the microwave susceptor, which had high absorption of microwaves and a high difference between the detectable temperatures of the sample and the susceptor, which in turn led to faster heat transfer, the low rate of increase of the temperature of the batter in the early stages of conventional baking (Megahey et al., 2005; Yong et al., 2002) resulted in lower resilience. In fact, the use of the microwave susceptor resulted in a change in microwave heating and improved many quality parameters in the cakes baked using a microwave oven.

Chewiness

This parameter increased with time and power (Fig. 7a), similar to the results reported by Ozkahraman et al. (2016) and Yolacaner et al. (2017). Cakes baked in a microwave susceptor showed an overall increase

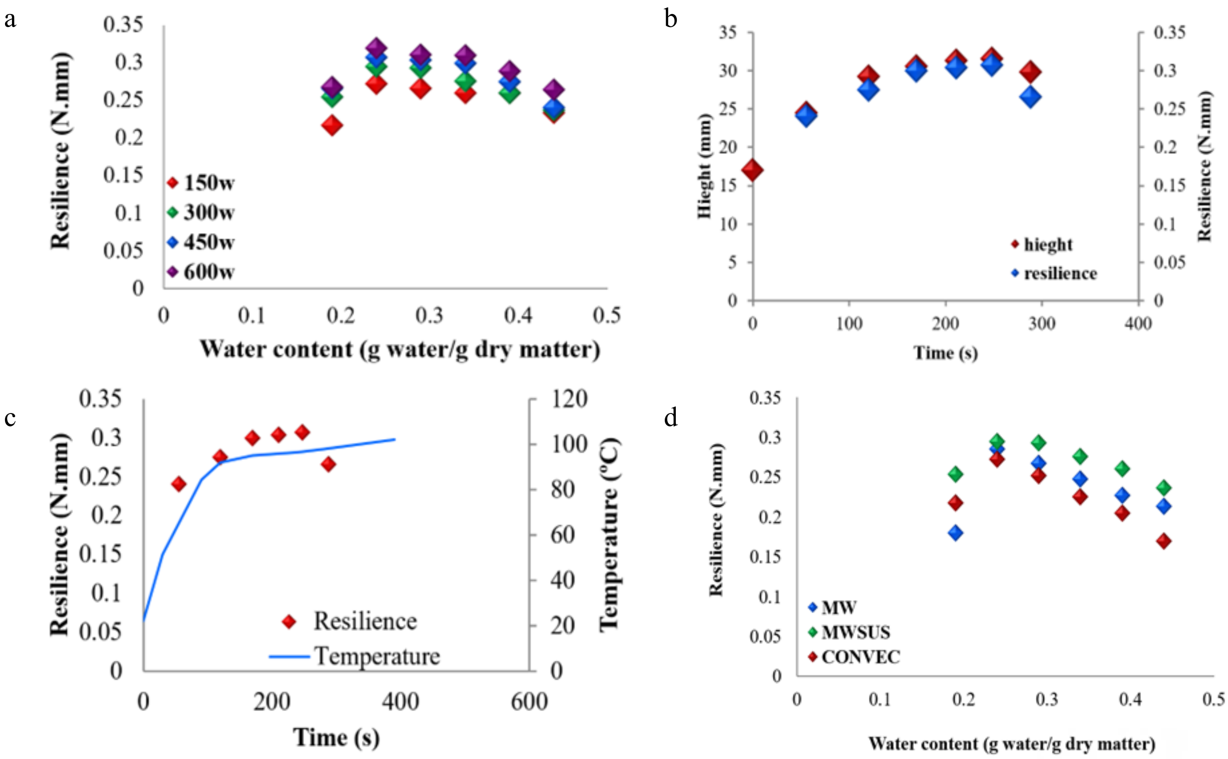


Fig. 6. The change in kinetic resilience at different powers (a); the relationship between resilience and height (b); and temperature (c) of cupcakes during microwave baking assisted by a microwave susceptor; and comparison of resilience for the three methods (d)

in chewiness as baking time increased. One reason for this was the increase in cake hardness with time and power, which led to an increase in the energy required to break down and chew samples. However, the final value of this parameter decreased with increasing power. The reduction in final hardness can be attributed to

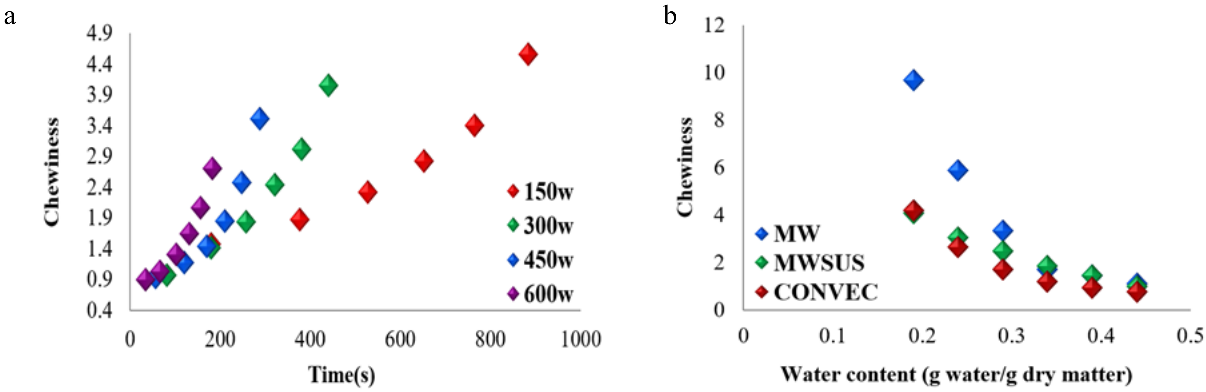


Fig. 7. The effect of baking time and power using the microwave susceptor (a); and the impact of baking mode on the chewiness of cupcakes (b)

the reduction in process time associated with an increase in power.

As Figure 7b shows, the highest degree of chewiness was produced by the microwave baking method. Microwaves generate heat inside the samples, and the internal vapor pressure consequently increases, leading to a harder structure compared to other methods. The susceptor absorbs the microwaves and converts them to heat faster than the samples. Thus, the majority of the heat is conductively transferred from the susceptor to the samples (Megahey et al., 2005; Yong et al., 2002). As a result, the parameter values obtained using susceptors were close to those obtained for conventional baking, indicating that the use of microwave susceptors for cake baking can improve this quality parameter.

CONCLUSIONS

The effects of a microwave, a microwave susceptor, and conventional baking on baking rate and textural properties were investigated. The results show that the time required to complete the baking process is affected by operational power as well as heating method. The lowest time was obtained when microwave susceptor baking was applied at the highest power. The results show that cohesiveness and resilience are increased when a higher operational power and microwave susceptor heating are used. They also show that the baking rate of cake is dependent on the process time. Investigation into the textural parameters of the samples showed that the final hardness, chewiness, and springiness decrease with power in all cases; microwave susceptor baking provides chewiness, crispiness and hardness similar to those of conventionally baked cakes, but increases weight loss and color parameters compared to other methods. In general, cakes with low hardness and high cohesiveness values have the best texture. Moreover, it is desirable to produce a cake with high springiness and low chewiness. The cakes baked in the microwave susceptor satisfied these criteria.

DATA AVAILABILITY

Datasets from the current study are available from the corresponding author upon request.

DECLARATIONS

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

OPEN ACCESS

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