RESEARCH ARTICLE

Microwave versus convective processing: Characterization of baking conditions and cake quality

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This work purpose was to compare convective and microwave processing effects on cake quality. The centre temperature profile, weight loss, final height, CIE Lab colour, firmness and sensory attributes were determined. Statistical analysis revealed that baking conditions had significant impact on all the studied parameters. Experimental data indicated that microwave power settings increase allowed an important decrease in baking time (85% time reduction). Moreover, baking at 850 W induced high weight loss rate, and it recorded the highest final height. However, microwave baking has no significant difference on cakes color. Firmness was negatively affected by high microwave power level, consistently with sensory results. Although baking cake at 850 W could be considered a good alternative to save time and energy, sensory scores confirmed that panellists appreciated cakes baked at 250 W.

Key Words: *Baking; Cake; Microwave; Convective; Quality*

Cooking process and quality development need to be understood predicted and controlled [1]. As a matter a fact, conventional baking methods have several downsides on food quality that's why there is a raising need to more sophisticated alternatives. Microwave heating was emerging [2] to reach high quality requirements. Microwave food processes offer a lot of advantages as compared with conventional surface heating; indeed, microwaves can generally provide less start-up time, faster heating, energy efficiency, space savings, precise process control, selective heating and food with high nutritional quality [3-5].

Microwave is a promising technique in food baking. Recently, the use of microwave energy in baking is of interest [6]. Therefore, quality traits assessment, mainly physical properties (temperature, moisture, colour and texture), is crucial. Indeed, changes in one physical property are closely related to changes in others and to the thermal processing condition [7]. The main advantages of microwave baking are shorter drying time and improved product quality [8]. In fact, it seemingly reduces the thermal impact on food functional properties which allows for an overall food quality improvement [9]. The use of microwave heating for baking results in a more uniform moisture distribution than does forced convection [10]. Breads baked in an electrical resistance had interior characteristics and shelf-life superior to those of products baked in a conventional oven [11].

A current challenge facing food technologists and engineers is that of improving the quality of microwave-baked products [12]. Microwave baking quality problems are mainly pale color, temperature non-uniformity and low power efficiency. On the one hand, the biggest disadvantage is the inability of the microwave ovens to induce browning [13]. On the other hand, due to inherent nature of standing wave patterns of microwaves inside a cavity and dielectric properties of different components in a food, microwave heating leaves non-uniform distribution of energy inside the food volumetrically [14]. For that reason, to overcome these problems, studies dealing with microwave and the improvement of baking conditions are of a great interest.

In this paper, the main concern is to assess the effect of convective and microwave processes on the major physical, textural and sensory attributes of cake. In furtherance of this purpose, temperature profiles, weight loss rate, final heights, color components, firmness and sensory analysis of cakes baked at microwave and convective ovens were performed.

MATERIAL AND METHODS

Materials

Sugar, eggs, sunflower oil, vanilla yogurt, flour, vanilla sugar and yeast were purchased from a local market in Tunis.

Cake formulation

The cake formulation was a white-layer homemade cake formulation. The batter, which contained (based on a 330 g batch), 132 g sugar and two eggs, was mixed at high speed (level 3) using a standard kitchen mixer (150 W) (Molinex, China) until it became fluffy (approximately 5 min). Then the wet-blended mixture consisting of 5 cl sunflower oil and 32 g vanilla yogurt was added with continued mixing at high speed (level 3 for 3 min). A dry-blended mixture consisting of 234 g flour, 3 g vanilla sugar and 3 g yeast was added, and agitated (level 4) until stiff peaks were formed (approximately 3 min).

Baking process

Convective baking

Convective baking was performed in an electrical oven (AXELL, China) at 180°C. Three samples were baked at a time.

Microwave baking

A domestic microwave (MW86N, China) was used in this study with several output settings (100, 180, 300, 450, 600 and 850 W) at 2450 MHz. A water load (approximately 50 ml) was placed in the microwave cavity to provide a heating load sufficient to protect the magnetron from overheating, especially when samples reached low moisture contents during the latter stages of baking. Energy uniformity was improved by positioning the sample in the centre of the microwave cavity and rotating the load on the turntable [6].

Cake quality measurements

Microwave baking was carried out a at five power output settings (100, 180, 300, 600, 850 W). As a control baking system, a standard fan assisted convective oven (Genlab, Model MF75) was used. The temperature was measured using a Type 'K' thermocouple (1 mm diameter). Experimental baking curves were carried out to determine the effect of baking time on temperature in both baking systems. The internal temperature of the cake was measured three times for each sample. One batter sample (100 g), placed in an aluminium dish (39 mm inside diameter, 109 mm height), and was positioned in the centre of microwave oven under specific conditions. Weight loss measurements were in different times during baking and calculated by subtracting the weight of cake after baking from weight of dough and dividing this term by the weight of dough and given in percentage [15]. The height across the sample cross-section was measured at three locations; the center; the right and the left after baking. Surface color of the cake samples was measured using a Minolta colour reader (CR-10, Japan) using the CIE L*, a* and b* colour scale. Triplicate readings were carried out at different positions on the cake surface, and the mean value was recorded. Total colour change (DE) was calculated from Eq. (1) [16].

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$$Eq(1): \Delta E = \left[\left(L^* - L_0\right)^2 + \left(b^* - b_0\right)^2 + \left(a^* - a_0\right)^2 \right]^{1/2}$$

Texture analysis

Firmness analysis was carried out following the method of Sowmya et al. [17]. The instrument used was a TA.XT plus texture analyzer (Stable Micro Systems) with 2 and 5 kg load cells. The samples (4.0 × 4.0 × 2.5 cm) were compressed using an aluminum 80 mm diameter circular disc probe. The texture parameters were determined with a cross head speed of 50 mm/min, compression distance 50% of cake's height and 5 s delay between two bites.

Sensory analysis

Hedonic sensory assessment was carried out with ten panel members. Sensory attributes were colour, flavour, firmness, tenderness, elasticity and overall acceptance of cakes baked in the microwave at six different powers settings. The control cake was baked at 180°C in convective oven. Samples were presented on plastic dishes coded and served in randomized order. Intensity of sensory attributes was scored on a verbal hedonic scale of nine points (1 – disliked extremely; 5 – neither liked nor disliked; 9 – liked extremely) [18].

Statistical analysis

Analysis of variance (ANOVA) was carried using SPSS Software version 13, with a confidence level of 95% ($p<0.05$). Duncan's test was applied to evaluate the differences between mean values among the different treatments. Three replications were used for each treatment.

RESULTS AND DISCUSSION

Effect of baking conditions on experimental baking curves

Once the internal cake temperature reached 101-102°C, the baking process was stopped and baking time was recorded [19]. Figure 1 presented the centre temperature profile of cakes baked in convective and microwave ovens (six microwave power outputs and convective oven at 180°C) as a function of baking time. Similar trends in the shape of the experimental thermal curves were observed in microwaves different powers outputs and convective oven. These curves could be divided in three stages; In stage I, temperature increased sharply at the start of baking until approximately 1/3 to halfway through the baking, and then the heating rate started to decrease until a final internal temperature of around 100°C was [20]. In stage II, temperature increased linearly with time, independently of the power used up to around 100°C, consistently with Tong and Lund (1993) because the air helped to remove heat from the sample [21]. In stage III, the sample temperature was kept almost constant around 100°C.

Further, ANOVA results revealed a significant effect of baking conditions on baking time. Microwave baking at 850 W enabled a reduction of 85% in the time needed to complete the baking process as compared to convective oven (at 180°C). In fact, heating from the interior of a food product leads to the build-up of an internal vapor pressure that drives the moisture out of the product [22], leading to baking time reduction (Table 1).

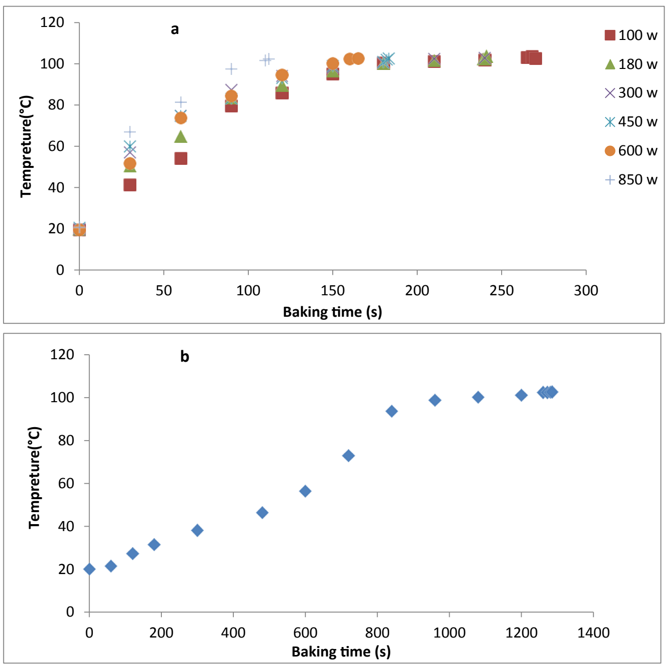

Figure 1) *Temperature profiles during microwave (a) and convective baking (b) as a function of baking time.*

Effect of baking conditions on weight loss rate

Weight loss rate versus baking time was presented approximately by a straight line for both baking methods (Figure 2). According to ANOVA, baking conditions significantly affected weight loss rate. The rate of weight loss was the highest during microwave baking as compared to convective baking (14.27 %). The high weight loss during microwave baking might be attributed to high pressure and moisture gradients in microwave baked products [23]. Cakes baked at 850 W power output had the highest final weight loss (24.13%). Indeed, weight loss rate increased as microwave power increased, consistently to Sumnu et al. [15] works. In fact, larger amount of interior heating during microwave baking result in significant internal pressure which increases the loss of moisture from the baked product [24].

Effect of baking conditions on cakes final height

The final height of cakes was the result of the balance between the setting of the product by thermal denaturation of the gluten network and expansion of the dough by the action of aerating agents and steam [6]. Figure 3 showed the cakes final height profile at three different locations. Similarities in final height shapes were recorded among the studied samples. Cakes baked in microwaves had less final height than conventionally baked ones. Nevertheless, Duncan's test showed no significant difference between final heights of cakes baked at 850 W and conventionally baked. Additionally, results showed that as microwave power output increased, the final height increased which might be explained by the significant internal pressure

TABLE 1

Baking time at different baking conditions.

Baking condition	Baking time (s)
Convective oven 180°C	1285
100 W	270
180 W	240
300 W	180
450 W	150
600 W	140
850 W	110

Data are expressed as mean from three replicates. Means of same column followed by different letters differ significantly (p<0.001).

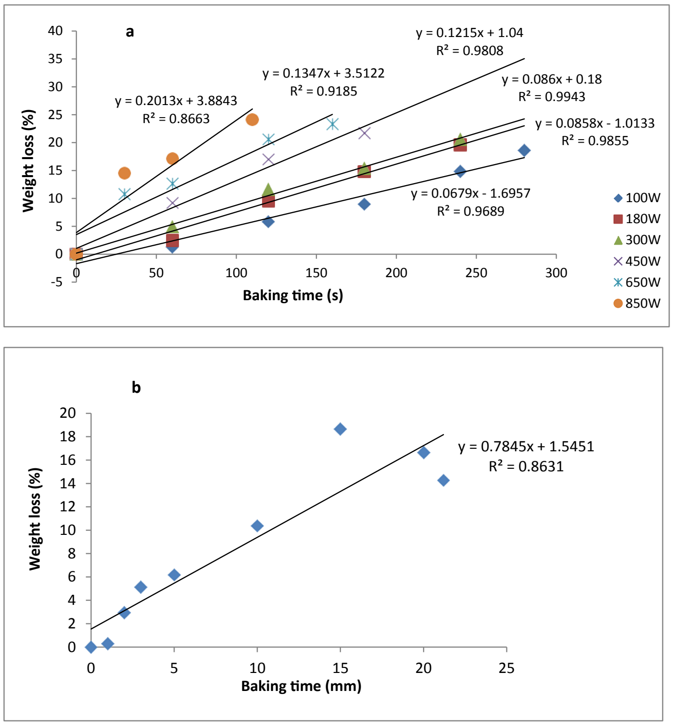

Figure 2) *Weight loss rate of cakes baked at different microwave powers (a) and convective baking (b) as function of baking time.*

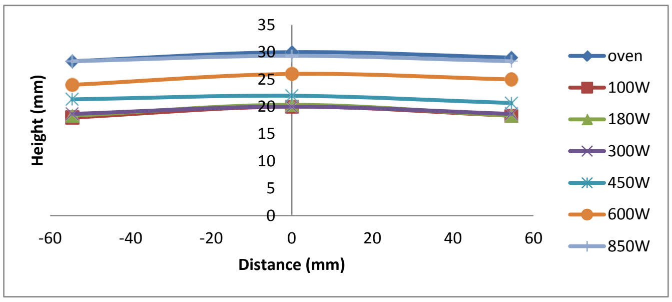

Figure 3) *Height final profile of cakes baked at six different microwave power settings and oven at 180°C.*

TABLE 2

Microwave and oven baked cakes final color parameters.

	(180°C)	100 W	180 W	300 W	450 W	600 W	850 W
a*	17.46	0.43	0.48	0.48	0.48	0.49	0.52
b*	21.85	33.03	33.02	33.67	33.75	33.57	33.77
L*	46.39	83.13	83.03	80.70	79.33	81.40	82.91
ΔE	14.65	39.92	40.73	38.07	37.18	38.49	39.98

Data are expressed as mean from three replicates. Means of same row followed by different letters differ significantly ($p<0.001$).

which might result in a puffing effect and high volume [25]. ANOVA results showed a significant effect of baking conditions on final heights. Microwave baking at 850 W allowed 85% baking time reduction as compared to baking in a convective oven. Thus, microwave baking provided faster processing by accelerated heat transfer and moisture migration [26].

Effect of baking conditions on cake's final colour

ANOVA results revealed that CIE a*, b*, L and ΔE values were significantly ($p \leq 0.001$) affected by baking conditions. Although microwave baking increased the yellow index, luminosity and ΔE value, it decreased red index, in concordance with correlation matrix results. High correlations between colour components and baking time confirmed that baking time enhanced red index (r=0.990), whereas it worsened yellow index (r =-0.986), luminosity (r=-0.974) and ΔE (r=-0.970). Thus, long baking time in conventional ovens allowed cakes browning unlike microwave baked cakes. Indeed, during microwave baking, cakes are not heated long enough to proceed to the point where brown pigments and flavor compounds are produced [13]. Consequently, as expected, it was not possible to observe any significant colour change during microwave baking (Table 2). Indeed, Duncan's test results showed that there was no significant difference in red and yellow indexes of samples baked in microwave oven. According to Aghilinategh et al. [27], the fundamental decrease in Millard reaction is due to short baking time, and consequently, it does not proceed beyond the initial stages [28]. Further, baking temperature might not be high enough to enhance browning reaction, Maillard and caramelization [29].

Effect of baking conditions on cake's firmness

Figure 4 presented the influence of baking conditions on the baked cakes firmness. Statistical results revealed that baking conditions had a significant impact on firmness. Firmness values varied from 0.52 N (Oven) to 2.84 N (850 W). In fact, convective cakes showed the lowest firmness due to homogeneous bubble distribution and a finer air cell structure as mentioned by Al-Muhtaseb et al. (2013). Further, it could be explained by the low weight loss and the high moisture. Indeed, a high correlation was found between firmness and weight loss (r=0.95). Regarding microwave baked cakes, firmness was significantly affected by the increase in microwave power setting. Cakes baked at 100 W showed a firmness value (0.63 N) slightly higher than cakes baked in convective oven. However, cakes baked at 850 W had the highest hardness. The increase of hardness could be correlated to baking time. Actually, baking time greatly influenced the firmness of cakes as confirmed by their correlation coefficient (r=-0.63). It could be concluded that the increase of baking time allowed an improved texture. Thus, as microwave output power increased, weight loss increased and cakes hardness increased suggesting low microwave power baking as a good option to obtain cake with tender texture. Otherwise, correlation between height and firmness was weak and insignificant (r=0.25). In contract, Stauffer (1999) suggested that cake with high volume usually had low firmness. Additionally, Demirekler et al. [30] works established that baking time and microwave power were the most significant factors in increasing the firmness.

Sensory assessment

Sensory scores were presented in Figure 5. Sensory attributes were color, firmness, tenderness, elasticity, flavor and overall acceptance. Conventionally baked cakes were the most appreciated regarding all attributes. On the other side, microwave baked cakes at 250 W had the highest overall acceptance because panelists did appreciate their tenderness and flavor. However, they assigned the lowest overall acceptance to cakes baked at 100 W for its weak flavor. Besides, no significant differences were observed between microwave color scores. Cakes baked at 450 W had the highest flavor. Baking at maximum power (650 and 850 W) resulted in cakes with high firmness and elasticity which explained its lowest overall acceptance score. Comparing microwaves cakes to the control cake indicated that baking at medium microwave power (250 W) could produce a cake with good flavors and tenderness.

Correlation between sensory and instrumental analyses

Correlation between sensory and instrumental analysis was carried out. In fact, Table 3 presented linear regression models relating sensory scores to instrumental measurements. The sensory firmness and tenderness had high linear correlations with instrumental results (determination coefficients (R^2) were 0.829 and 0.895, respectively) confirming that texture can be measured by means of objective (instrumental) and intrinsic subjective (sensory) tests [31-33]. The sensory colour score was also linearly correlated to the instrumental red index (R^2=0.886). Hence, it could be concluded that sensory evaluation was efficient differences identification, in consistent with instrumental assessment.

CONCLUSION

Based on this work, several conclusions could be drawn. Firstly, microwave baking allowed an important baking time reduction in comparison with convective baking at 180°C. Secondly, temperature profile had similar trends for the six-power settings of microwave. Then, as the microwave power increased, baking time decreased. However, weight loss and final height was adequately increased with microwave power output. Then, it was not possible

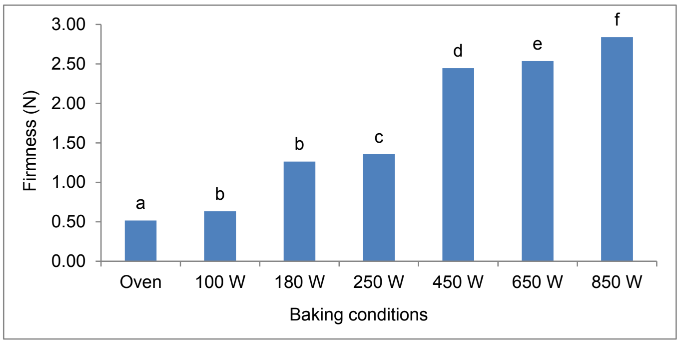

Figure 4) *Effect of baking conditions on cakes firmness.*

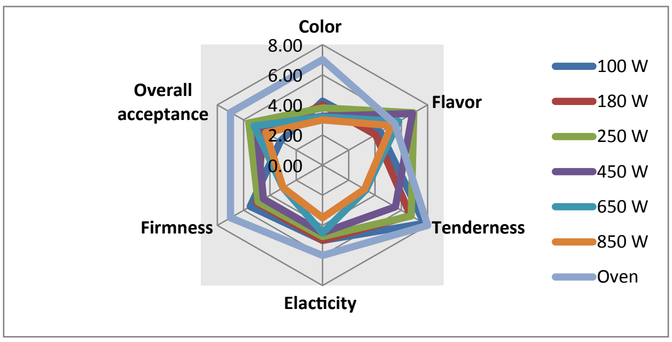

Figure 5) *Effect of baking conditions on sensory scores of baked cakes.*

TABLE 3

Relationships between cake sensory and instrumental attributes.

y: sensory	x: instrumental	Regression model	Determination coefficient
Firmness	Firmness	y=-1.3514x+6.9381	R^2=0.829
Tenderness	Firmness	y=-1.9695x+9.1548	R^2=0.895
Color	Red index	y=0.201x+3.487	R^2=0.886

to detect a significant difference in red and yellow indexes of microwaves baked cakes [34-36]. Furthermore, firmness was highly influenced by weight loss, baking time and microwave power setting. Finally, cake sensory attributes were valuable tools for cakes quality assessment that could be instrumentally predicted.

REFERENCES

1. Datta AK, Rakesh V. Principles of Microwave Combination Heating. Compr Rev Food Sci Food Safety. 2013;13:24-39.
2. Abbas KA, Abdulkarim SM, Ebrahimian M, et al. The Drawbacks and Superiorities of Using IR-Microwave System in Cake and Bread Baking: A Review. Modern Applied Science 2010;4:1852-1913.
3. Decareau RV, Peterson R. Microwave Processing and Engineering. Chichester: Ellis Horwood. 1986;18-21.
4. S Saltiel C, Datta A. Heat and mass transfer in microwave processing. Adv Heat Trans 1999;33:1-94.
5. Regier M, Schubert H. Dielectric Properties at Microwave Frequencies Studied in Partially Filled Cylindrical TE011 Cavities. J Microw Power Electromagn Energy 2000;35:25-33.
6. Megahey EK, MCminn WAM, Magee TRA. Experimental study of microwave baking of Madeira cake batter. Food Bioprod Proces 2005;83:277-87.
7. Yong YP, Emery AN, Fryer PJ. heat transfer to a model dough product during mixed regime thermal processing. Trans IChemE. 2002;80:183-92.
8. Hangi AK, Amanifard N. Analysis of heat and mass transfer during microwave drying of food products. Braz J Chem Eng 2008;25:491-501.
9. Marra F, De Bonis MV, Ruocco GG. Combined microwaves and convection heating: A conjugate approach. J Food Eng 2010;97:31-9.
10. Chavan RS, Chavan SR. Microwave Baking in Food Industry: A Review. Int J Dairy Sci 2010;5:113-27.
11. Yin Y, Walker CE. A quality comparison of breads baked by conventional versus nonconventional ovens: A review. J Sci of Food Agri. 1995;67:283-91.
12. **Al-Muhtaseb A,** McMinn W, Megahey E, et al. Textural Characteristics of Microwave-Baked and Convective-Baked Madeira Cake. J Food Proc Technol 2013;4:2-8.
13. Ibrahim GE, El-Ghorab AH, El-Massry KF, et al. Effect of microwave heating on flavour generation and food processing, Chapter 2, InTech, 2012;20.
14. Pitchai K, Birla S, Subbiah J, et al. Heating Performance Assessment of Domestic Microwave Ovens. Paper 55 in Conference Presentations and White Papers: Biological Systems Engineering, 2010.
15. Sumnu G, Ndife MK, Bayındırlı L. Temperature and weight loss profiles of model cakes baked in the microwave oven, J Microw Power Electromagn Energy 1999;34:221-6.
16. Keskin SO, Sumnu G, Sahin S. Bread baking in halogen lamp-microwave combination oven. Food Res Int 2004;37:489-95.
17. Sowmya M, Jeyarani T, Jyotsna R, et al. Effect of replacement of fat with sesame oil and additives on rheological. Food Hydrocol 2009;23:1827-36.
18. Volpini-Rapina LF, Sokei FR, Conti-Silva AC. Sensory profile and preference mapping of orange cakes with addition of prebiotics inulin and oligofructose. LWT-Food Science and Technology 2012;48:37-42.
19. Sani NA, Taip FS, Kamal SM, et al. Effects of temperature and airflow on volume development during baking and its influence on quality of cake. J Eng Sci Technol 2014;9:303-13.
20. Baik OD, Marcotte M, Castaigne F, et al. Cake baking in tunnel type multi-zone industrial ovens Part I. Characterization of baking conditions. Food Res Int 2000;33:587-98
21. Feng H, Tang J. Microwave finish drying of diced apples in a spouted bed. J Food Sci 1998;63:679-83.
22. Feng H, Yin Y, Tang J. Microwave drying of food and agricultural materials: Basics and heat transfer modeling. Food Eng Rev 2012;4:89-106.
23. Sumnu G, Turabi E, Oztop MH. Drying of carrots in microwave and halogen lamp-microwave combination ovens. LWT-Food Science and Technology 2005;38:549-53.
24. Seyhun N, Sumnu G, Sahin S. Effects of different starch types on retardation of staling of microwave-baked cakes. Food Bioprod Proces 2005;83:1-5.
25. Kocer D, Karwe MV, Sumnu SG. Alternative Baking Technologies. In Food Engineering Aspects of Baking Sweet Goods by Sahin S and Sumnu SG. CRC Press, USA, 2008;215-44.
26. Sumnu G, Sahin S. Recent Developments in Microwave Processing. In Emerging Technologies for Food Processing by Sun D. Elsevier, UK, 2005.
27. Aghilinategh N, Rafiee S, Gholikhani A, et al. A comparative study of dried apple using hot air, intermittent and continuous microwave: evaluation of kinetic parameters and physicochemical quality attributes. Food Sci Nutr 2015;3:519-26.
28. Risch SJ. Flavors and colors for microwave foods. In Development of Packaging and Products for Use in Microwave Ovens by Lorence MW, Pesheck PS. Woodhead Publishing, UK, 2009;176-91.
29. Tanvarakom T, Therdthai N. Effect of Egg and Microwave Baking on Quality of Rice-Flour Bread. Food App Biosci J 2015;3:59-68.
30. Demirekler P, Sumnu, G, Sahin, S. Optimization of bread baking in a halogen lamp–microwave combination oven by response surface methodology. Eur Food Res Technol 2004;219:341-7.
31. Paula AM, Conti-Silva AC. Texture profile and correlation between sensory and instrumental analyses on extruded snacks. J Food Eng 2014;121:9-14.
32. Demirkesen I, Sumnu G, Sahin S, et al. Optimization of formulations and infrared-microwave combination baking conditions of chestnut-rice breads. Int J Food Sci Technol 2011;46:1809-15.
33. Hu LX, Yang QX, Jia ZG. Effective Optimization of Temperature Uniformity and Power Efficiency in Two-ports Microwave Ovens. J Microwave Power and Electromagnetic Energy 2014;48:261-8.
34. Stauffer CE. Bakery products. In Emulsifiers. Eagan Press, USA, 1999;47-66.
35. Sumnu G. A review on microwave baking of foods. Int J Food Sci Technol 2001;36:117-27.
36. Tong CH, Lund DB. Microwave heating of baked dough products with simultaneous heat and moisture transfer. J Food Engineering 1993;19:319-39.