

# Textural Characteristics of Microwave-Baked and Convective-Baked Madeira Cake

Ala'a H Al-Muhtaseb<sup>1\*</sup>, Wendy McMinn<sup>2</sup>, Emma Megahey<sup>2</sup>, Gerry Neill<sup>2</sup>, Ronnie Magee<sup>2</sup> and Umer Rashid<sup>3</sup>

<sup>1</sup>Department of Petroleum and Chemical Engineering, Faculty of Engineering, Sultan Qaboos University, Oman

<sup>2</sup>School of Chemistry and Chemical Engineering, Queen's University Belfast, Belfast, UK

<sup>3</sup>Institute of Advanced Technology, Universiti Putra Malaysia, Serdang-43400, Selangor, Malaysia

## Abstract

The textural properties (hardness, cohesiveness, springiness, gumminess, chewiness) of microwave-baked (250, 900 W) and convective-baked (200°C) Madeira cake were examined. Experimental texture profile analysis data revealed Madeira cake microwave-baked at 250 W to have the most favourable textural properties in terms of springiness and cohesiveness. In contrast, cake microwave-baked at 900 W exhibited the least favourable hardness, gumminess and chewiness characteristics. Modification of the batter formulation to include additional margarine improved the textural characteristics of the cake in terms of increased springiness and decreased hardness. However, an increase in the flour component was found to increase the cake hardness, gumminess and chewiness, and decrease the springiness and cohesiveness.

**Keywords:** Baking; Madeira cake; Texture; Microwave; Convective

## Introduction

Texture is one of the major quality attributes of foods, and is determined from the response of tactile senses to the food product. It is generally acknowledged as a multi-parameter attribute [1]. Szesniak [2] divided textural characteristics into three categories namely, mechanical, geometrical and other characteristics. Mechanical characteristics, which are examined in this work, refer to the reaction of food to an applied force and consist of both primary (hardness, adhesiveness, cohesiveness) and secondary (chewiness, gumminess) characteristics.

A current challenge facing food technologists and engineers is that of improving the quality of microwave-baked products. Textural problems associated with microwave - baked cake include reduced volume, reduced moisture content and crumb toughness. In order to develop formulations appropriate for use in microwave heating, numerous authors have considered the functions of individual recipe components. Baik [3] suggested that an approximate estimation of cake texture could be achieved based on the type and quantity of the ingredients used. Each ingredient can be categorised by its functional role, for example shortening is a tenderiser, flour is a toughener and egg proteins help build a stable cell structure [4]. High quality cake has a large volume and high tenderness resulting from a balanced formula [5]. Sumnu [6] studied the effects of emulsifier, water, shortening and starch on microwave-baked cake quality and developed a cake formulation which produced cake with comparable quality to convective-baked cake. Sumnu [7] assessed the effect of starch type (wheat, rice) on the volume and tenderness of microwave-baked cake. Wheat cake was found to have a greater volume than rice cake, and although the latter generally showed a greater weight loss, they were significantly tenderer. The use of low gluten flour in microwave-baked bread was shown, by Ozmutlu [8], to produce cake with higher volume and softer texture.

Sumnu [9] compared the quality of microwave, infrared and infrared-microwave combination baked cake. The weight loss, specific volume and firmness of the white layer cake were found to increase with increasing baking time during microwave baking at 50% power

level (approx. 350 W). To apply microwave energy during baking, strict control over power output must be maintained in order to avoid notable water loss. Sumnu [6,7] observed that the weight loss of microwave-baked cake increased and the tenderness decreased, with an increase in microwave oven power. Sevimli [10] showed that the textural properties (weight loss, specific volume, firmness) of cake baked in a halogen lamp microwave oven for 5 mins at 60% upper halogen lamp power, 70% lower halogen lamp power, and 30% microwave power were comparable with those of conventionally baked cake.

The aim of this work was to examine the effect of baking mode (Microwave and convective), baking time, and batter formulation on the textural properties (hardness, springiness, cohesiveness, gumminess, chewiness) of microwave - baked and convective - baked Madeira cake.

## Materials and Methods

### Cake batter preparation

Madeira cake batter was prepared based on the ingredients and procedures used in a local bakery. The batter (control), which contained (based on a 330 g batch), 94.5 g castor sugar and 40.5 g margarine, was mixed at high speed (level 3) using a standard kitchen mixer (Kenwood, Model KM199) until it became fluffy (approx. 5 min). A wet - blended mixture consisting of 61.3 g eggs and 38.1 g water was then added in small increments with continued mixing at high speed (level 3 for 3 min). A dry blended mixture consisting of 32.1 g flour and 63.3 g American Crème Cake Concentrate (ACC) (Macphie of

\*Corresponding author: Dr. Ala'a H Al-Muhtaseb, Department of Petroleum and Chemical Engineering, Faculty of Engineering, Sultan Qaboos University, Oman, E-mail: [muhtaseb@squ.edu.om](mailto:muhtaseb@squ.edu.om)

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Glenbervie Ltd., UK) was added, and agitated (level 4) until stiff peaks were formed (approx. 3 min).

### Baking procedure

The microwave oven used in this work is a standard domestic microwave oven (Panasonic, Model NNT543W) with variable power output settings (100, 250, 440, 600 and 900 W) at 2450 MHz. Microwave ovens typically use 'duty cycle' control, i.e. oven turns on and off at full power automatically to vary the power. The 'duty cycle' represents the fraction of time that microwave power is applied to the load. In contrast, the oven used in this work utilizes an 'Inverter System' for 'variable power' control, which steps down the power to provide a constant flow of specified magnitude. A water load (approx 50 ml) was placed in the microwave cavity during operation. This provided a heating load sufficient to protect the magnetron from overheating, especially when the samples reached low moisture contents during the latter stages of baking. As a control baking system, a standard fan assisted convective oven (Genlab, Model MF75) was used.

For each experiment,  $30 \pm 0.1$ g of freshly prepared batter was placed in a glass dish (47 mm inside diameter, 71 mm height, which is a representative of an individual cake), positioned in the centre of the appropriate oven and then baked at the specified conditions for a pre determined time period. In the case of convective drying, samples were dried at 200°C which represent the bake temperature used by the local bakery.

The moisture of the samples was determined at the beginning and end of each experiment by drying representative triplicate samples in a convective oven at 105-110°C for 8-10 hr.

### Texture profile analysis

Texture Profile Analysis (TPA) was carried out in order to determine the effect of baking time and heating mode and recipe modification on the textural properties of Madeira cake. Batter samples, of compositions shown in table 1, were prepared according to the procedure previously outlined, and then baked in either the microwave or convective oven for a specified baking time (Table 2).

On the basis of results from previous research, the cake was considered to be 'fully' baked when the centre temperature had reached 100°C, and the moisture content was less than 0.333 kg.kg<sup>-1</sup>, dry basis [11]. Therefore, cakes microwave baked at 250 W and 900 W

and convective baked at 200°C were deemed to be 'fully' baked after a minimum of 70 s, 40 s and 10 min, respectively. However, on the basis of external appearance, the cake microwave baked at 250 W and 900 W and convective baked at 200°C could still be considered to be 'adequately' baked after a time of 90-115% of optimum baking time. It should be noted that previous work considered only the mass transfer which occurred during the baking period and did not account for changes in the sample during cooling to room temperature. Moreover, errors induced by interruptions during the baking process for sample analysis were considered negligible [11].

The TPA test involved subjecting the sample to a multi - compression force and recording the associated force-distance curve. Again the TA-XT2 texture analyser was used, with a 25 kg load cell. The cake was tested under vertical compression, at a constant speed, until the sample was compressed to 75% of its original height. The compression level was selected on the basis of preliminary experiments; the very soft nature of Madeira cake necessitated medium compression. It was not possible to ensure a consistent sample height throughout the experiment, therefore high deformation was also avoided in order to minimise experimental error. During the experiment, the compressive force was instantly withdrawn and after a 3 s pause the second compression initiated. A cylinder probe (36mm diameter) was used and test conditions were: pre-set speed 2.0 mm.s<sup>-1</sup>; test speed 5.0 mm.s<sup>-1</sup>; post-test speed 5.0 mm.s<sup>-1</sup>; strain 25%; force 100 g; time 3 s; count 5; trigger type: auto; trigger force 20 g. Five replicate samples were baked at each baking condition and then allowed to cool to room temperature (approx 20°C) before testing.

Analysis of Variance (ANOVA) and a post-hoc Tukey Honest Significant Difference (HSD) test were performed on the TPA data.

### Digital photo analysis

Batter samples were prepared, according to the procedure previously outlined, and then baked in either the microwave or convective oven for the optimum baking time. The sample was then cooled to room temperature (approx 20°C) before a slice (approx 3 mm thickness) was carefully removed from the centre of the cake using a scalpel. Digital images were taken and image analysis software (Algo Lab Raster to Vector Conversion Toolkit, Ontario, Canada) was used to convert the original digital image to a black and white outline, which further facilitated the identification of bubbles within the cake structure.

## Results and Discussion

### Texture profile analysis

Eight textural parameters may be extracted from experimental Texture Profile Analysis (TPA) data namely hardness, fracturability, adhesiveness, cohesiveness, springiness, gumminess, chewiness and resilience. Figure 1 shows a typical experimental force-time graph for texture profile analysis performed on Madeira cake. No initial peak could be identified on the graph from which fracturability can be determined. Furthermore, the adhesiveness values obtained were inconclusive; adhesiveness is the force required to pull the plunger away from the sample ( $A_3$ )-area under TPA curve (Figure 1).

**Hardness:** Hardness, or firmness, is the force (N) required to compress the product by a pre-set distance and is determined directly from the experimental data ( $F_D$ ) (Figure 1). As shown in table 3, the hardness values for Madeira cake ranged from 2.75 - 4.02 N for cake microwave-baked at 250 W, 2.71-4.89 N for cake microwave - baked

Ingredients	Mass (g)		
	Control	Additional Flour	Additional Margarine
Sugar	137.5	137.5	137.5
Margarine	58.9	58.9	70.7
Cake concentrate	92.0	92.0	92.0
Flour	46.6	56.0	46.6
Egg	89.1	89.1	89.1
Water	55.4	55.4	55.4

Table 1: Cake formulations used for texture profile analysis experiments.

% Optimum baking time	Heating Mode		
	Mw 250 W (s)	Mw 900 W (s)	Conv 200°C (min)
90	63	36	9.0
100	70	40	10.0
115	80	46	11.5

Table 2: Experimental baking conditions used for texture profile analysis experiments.

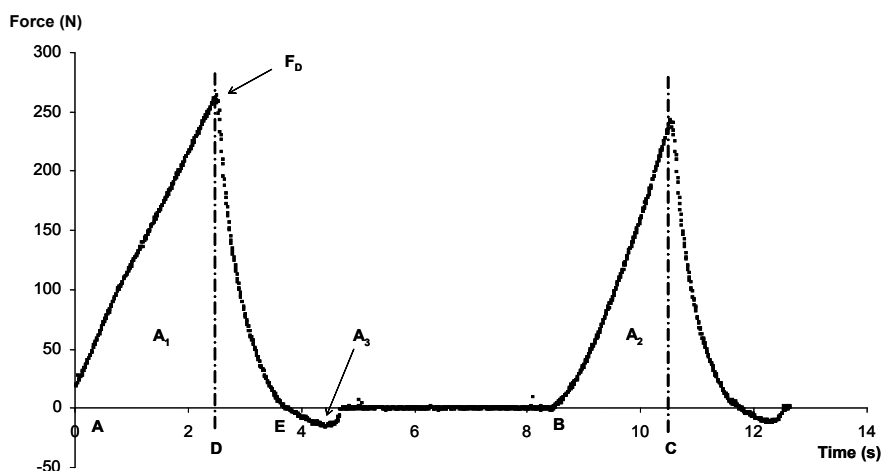


Figure 1: Typical experimental data from texture profile analysis (TPA) on Madeira cake sample (Microwave 250 W, 70 s).

Recipe	Baking mode	115 % Optimum baking time		100 % Optimum baking time		90 % Optimum baking time	
		Mean	SD	Mean	SD	Mean	SD
Control	Mw 250 W	3.42	0.25 <sup>ab</sup>	2.92	0.26 <sup>ab</sup>	3.32	0.37 <sup>ab</sup>
	Mw 900 W	4.08	0.35 <sup>ac</sup>	3.53	0.07 <sup>c</sup>	2.71	0.25 <sup>a</sup>
	Conv 200°C	3.20	0.24 <sup>ab</sup>	2.84	0.22 <sup>ad</sup>	3.06	0.22 <sup>ab</sup>
+ 20% Flour	Mw 250 W	3.91	0.54 <sup>abc</sup>	3.24	0.22 <sup>acd</sup>	2.75	0.40 <sup>a</sup>
	Mw 900 W	4.74	0.83 <sup>c</sup>	4.89	0.18 <sup>e</sup>	3.51	0.38 <sup>b</sup>
	Conv 200°C	3.52	0.41 <sup>ab</sup>	3.47	0.40 <sup>c</sup>	3.03	0.21 <sup>ab</sup>
+ 20% Margarine	Mw 250 W	4.02	0.78 <sup>abc</sup>	3.26	0.28 <sup>acd</sup>	2.97	0.06 <sup>ab</sup>
	Mw 900 W	3.76	0.24 <sup>abc</sup>	2.94	0.29 <sup>bd</sup>	2.78	0.52 <sup>a</sup>
	Conv 200°C	3.06	0.26 <sup>b</sup>	2.74	0.21 <sup>bd</sup>	2.98	0.29 <sup>ab</sup>

\*Tukey HSD; n = 5; p < 0.05; mean values followed by a common letter within the same column are not significantly different; mean values followed by a common numeral within the same row are not significantly different.

Table 3: Effect of baking time, baking mode and recipe modification on the hardness (N) of Madeira cake.

at 900 W, and 2.74 - 3.52 N for cake convective-baked at 200°C. Although cake baked at 900 W for 90% of optimum time showed the lowest hardness value, it was not significantly different from that of cake microwave - baked at 250 W or convective - baked (irrespective of baking time). The highest hardness values for Madeira cake were observed after baking for 100% and 115% of optimum time at 900W. Convective-baked cakes showed the lowest hardness after 100% and 115% of optimum time, however, this was only significantly different from cake (control and additional flour recipes) baked at 900 W. Irrespective of recipe and baking time, the hardness of cake microwave - baked at 250 W was not significantly different from the corresponding convective-baked cake.

The high degree of internal heating, which occurs during microwave processing, results in the formation of significant pressure and concentration gradients, thereby causing rapid moisture loss [12]. Previous research revealed that the drying rate constant of cake microwave-baked at 900 W ( $k=0.209 \text{ s}^{-1}$ ) was 1.5 times greater than that of cake microwave-baked at 250 W ( $k=0.140 \text{ s}^{-1}$ ) and 15 times greater than that of cake convective-baked at 200°C ( $k=0.014 \text{ s}^{-1}$ ) [11]. This may contribute to the production of cake with increased hardness. Although cake microwave-baked at 250 W had a drying rate constant 10 times that of convective-baked cake, the respective products attained

comparable final moisture contents (Mw 250 W, 0.334  $\text{kg.kg}^{-1}$  db; Conv, 0.320  $\text{kg.kg}^{-1}$  db) following baking for the optimum time. This may account for the cakes exhibiting comparable hardness properties (Mw 250 W, 2.92 N; Conv, 2.84 N), as shown in table 3. Sumnu [9] also found a positive correlation between the moisture loss of cakes during microwave baking and the firmness.

The overall cake texture was further assessed qualitatively in terms of bubble distribution and crumb cell structure (Figures 2a, 2b and 2c). The convective - baked cake was observed to have a more homogeneous bubble distribution and a finer air cell structure (Figure 2a), in comparison to the microwave - baked cakes (Figures 2b and 2c). This may, in part, attribute to the production of a softer texture cake, as also reported by Arunepanlop and Alava [13,14].

Irrespective of recipe, the hardness of cake microwave-baked at 900 W was most sensitive to variation in baking time, with this textural parameter significantly decreasing with a decrease in baking time. The hardness of cake baked at 250 W also decreased with baking time, however, to a lesser extent. In contrast, convective-baked cake did not show a significant change in hardness with baking time, irrespective of recipe. Such behaviour can be explained in terms of moisture loss. The greater the baking time and microwave output power, the greater

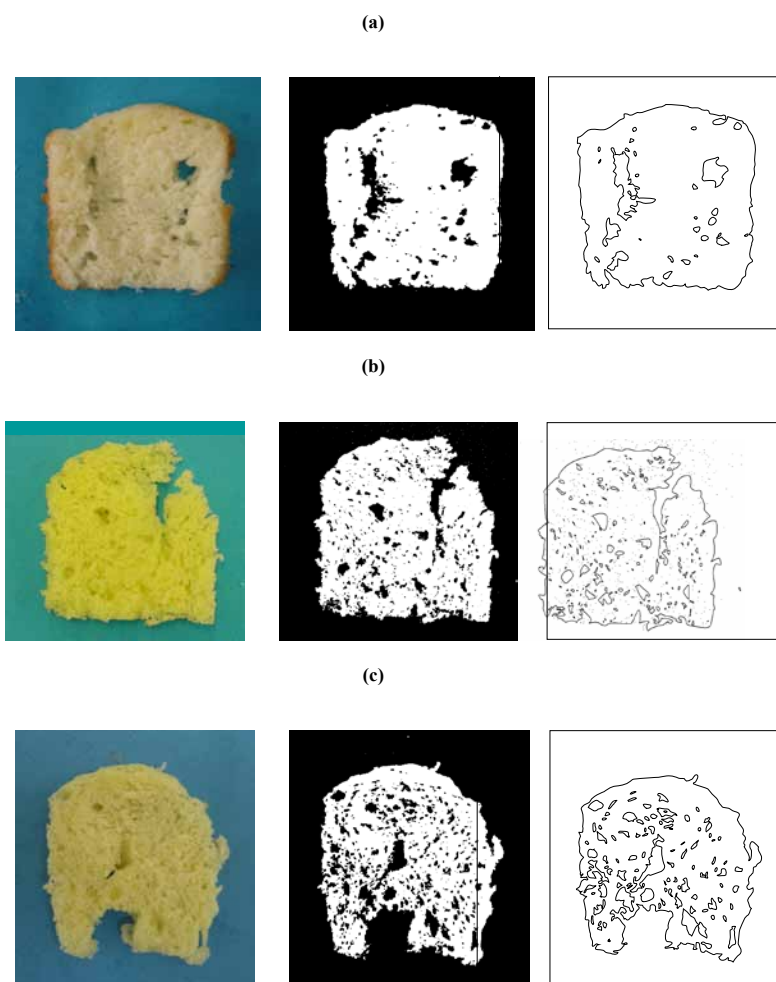


Figure 2: (a) Convective-baked Madeira cake at 200 °C (10 min); (b) Microwave-baked Madeira cake at 250 W (70 s); (c) Microwave-baked cake at 900 W (40 s).

the moisture loss from the cake and therefore, the greater the cake hardness. Clarke and Farrell [15] found the hardness of microwave-reheated pizza bases to increase when the heating time was increased from 120 to 180 s. The firmness of white layer cake increased with increasing baking time during microwave baking at 50% power. Pan and Castell-Perez [16] also found that the texture of microwave-baked cakes were more sensitive to changes in baking time than that of convective - baked cake.

The most significant effect of recipe alteration on the hardness of cake microwave-baked was observed at 900 W. The hardness of samples baked for 100 and 90% of optimum time significantly increased with the addition of flour, while the hardness of samples baked for 90% of optimum time significantly decreased with the addition of margarine. Shortening is known to tenderise, while flour is known to toughen cake crumb [4,17]. However, cakes microwave-baked at 250 W were not significantly affected by additional flour or margarine in the batter recipe. Addition of flour to samples convective-baked for 100% of the optimum time significantly increased the hardness. Ozmutlu [8] also found that increasing the fat content decreased the firmness of microwave-baked bread.

**Springiness:** Springiness describes how the crumb reacts following

removal of a compressing force. It is, therefore, related to the strength of the crumb cell network and is considered to be a reliable indicator of the onset of staling [18]. Springiness can be determined by Eq. (1) (Figure 2).

$$\text{Springiness} = \frac{t_{B:C}}{t_{A:D}} \quad (1)$$

where:  $t_{B:C} = t_B - t_C$  = time to reach B - time to reach C (refer to Figure 1)

$$t_{A:D} = t_A - t_D = \text{time to reach A - time to reach D (refer to Figure 1)}.$$

Table 4 summarises the springiness data for Madeira cake. As shown, the springiness values ranged from 0.764-0.914 for cake microwave-baked at 250W, 0.711- 0.861 for cake microwave-baked at 900 W, and 0.781 - 0.876 for cake convective - baked at 200°C. Irrespective of baking time and recipe, cake microwave - baked at 250 W had the highest springiness. The magnitude of the springiness was significantly higher in comparison to samples (with additional flour and margarine) convective-baked for 100% of optimum baking time and samples (with additional flour) microwave-baked cake for 100% of optimum baking time at 900 W. The microwave system adopted in this work uses 'Inverter Technology', which steps down the power to expose the cake sample to a continuous flow of microwave energy at 250 W. Thus it would appear that this method of microwave heating

is advantageous for the baking of Madeira cake, producing a springier product.

The larger bubbles observed within the coarse structure of cake microwave-baked at 250 W may also be responsible for a springier product, as compared to convective - baked cake (Figures 2a and 2b). Moreover, the less homogeneous, and more distorted, bubbles present within the structure of cake microwave - baked at 900 W (Figure 2c), as compared to cake baked at the other baking conditions, and may account for the less springy product. Large air bubbles were often observed to form at the base of the glass dish during microwave baking at 900 W. This can be explained by the large pressures exerted by leavening vapour and gases as the temperature increases rapidly during microwave baking [19].

In general, as the cake lost moisture it became less springy. For control recipe samples, and those with additional margarine, springiness increased with decreasing convective baking time. Moreover, samples with additional margarine baked in the convective oven exhibited a significant increase in springiness when the baking time was reduced from 100 to 90%. For samples with additional margarine microwave-baked at 250 or 900 W, a significant increase in sample springiness was observed on reducing the baking time from 115 to 100%. Conversely, Clarke and Farrell [15] found the springiness of microwave-reheated pizza bases to increase with increasing heating time.

In general, cake with additional flour showed the lowest springiness, irrespective of baking time. However, only cake microwave-baked

at 900 W showed significantly lower springiness as compared to the corresponding control recipe sample. Flour is known to act as a toughener [4], therefore, the more flour present in the batter recipe the less springy the cake. All other samples with modified recipes did not show significantly different springiness characteristics from their respective control samples.

**Cohesiveness:** Cohesiveness is determined from the strength of the internal bonds in the food structure and is affected by moisture content. It can be determined by Eq (2) (Figure 1).

$$\text{Cohesiveness} = \frac{A_2}{A_1} \quad (2)$$

where:  $A_1$  and  $A_2$  are areas under TPA curve (refer to Figure 1).

Table 5 summarises the cohesiveness data for Madeira cake. As shown, cohesiveness values ranged from 0.613 - 0.730 for cake microwave - baked at 250 W, 0.595-0.681 for cake microwave-baked at 900 W, and 0.592-0.691 for cake convective-baked at 200°C. The highest cohesiveness was observed in the control cake microwave-baked at 250 W for 90% of optimum time. For a given baking time and recipe formulation, cake microwave-baked at 250 W had the higher cohesiveness. However, the cohesiveness was only shown to be significantly higher than that of cake (with additional flour or margarine) microwave-baked at 900 W for 90 and 100% of optimum time, and for cake (with additional flour or margarine) convective-baked for 100% of optimum time. In general, for all recipes and baking times, cake microwave-baked at 900 W had the lowest cohesiveness.

Recipe	Baking mode	115 % Optimum baking time		100 % Optimum baking time		90 % Optimum baking time	
		Mean	SD	Mean	SD	Mean	SD
Control	Mw 250 W	0.836	0.05 <sup>a</sup>	0.867	0.05 <sup>ab</sup>	0.910	0.01 <sup>a</sup>
	Mw 900 W	0.817	0.02 <sup>ab</sup>	0.822	0.03 <sup>ac</sup>	0.861	0.04 <sup>a</sup>
	Conv 200 °C	0.818	0.02 <sup>ab</sup>	0.825	0.02 <sup>ac</sup>	0.846	0.02 <sup>a</sup>
+ 20% Flour	Mw 250 W	0.808	0.05 <sup>a</sup>	0.874	0.04 <sup>ab</sup>	0.830	0.10 <sup>ab</sup>
	Mw 900 W	0.711	0.06 <sup>b</sup>	0.790	0.04 <sup>cd</sup>	0.748	0.05 <sup>b</sup>
	Conv 200 °C	0.791	0.03 <sup>ab</sup>	0.781	0.04 <sup>cd</sup>	0.822	0.03 <sup>ab</sup>
+ 20% Margarine	Mw 250 W	0.764	0.11 <sup>ab</sup>	0.914	0.04 <sup>b</sup>	0.899	0.02 <sup>a</sup>
	Mw 900 W	0.754	0.04 <sup>a</sup>	0.856	0.03 <sup>ab</sup>	0.845	0.05 <sup>a</sup>
	Conv 200 °C	0.806	0.02 <sup>ab</sup>	0.829	0.02 <sup>ad</sup>	0.876	0.03 <sup>a</sup>

\*Tukey HSD; n = 5; p < 0.05; mean values followed by a common letter within the same column are not significantly different; mean values followed by a common numeral within the same row are not significantly different.

Table 4: Effect of baking time, baking mode and recipe modification on the *springiness* of Madeira cake.

Recipe	Baking mode	115 % Optimum baking time		100 % Optimum baking time		90 % Optimum baking time	
		Mean	SD	Mean	SD	Mean	SD
Control	Mw 250 W	0.699	0.04 <sup>a</sup>	0.680	0.03 <sup>ab</sup>	0.730	0.01 <sup>a</sup>
	Mw 900 W	0.647	0.02 <sup>ab</sup>	0.659	0.01 <sup>ac</sup>	0.681	0.01 <sup>ab</sup>
	Conv 200 °C	0.639	0.03 <sup>ab</sup>	0.677	0.02 <sup>ab</sup>	0.691	0.01 <sup>ab</sup>
+ 20% Flour	Mw 250 W	0.613	0.08 <sup>b</sup>	0.696	0.01 <sup>ad</sup>	0.677	0.06 <sup>ab</sup>
	Mw 900 W	0.595	0.02 <sup>b</sup>	0.646	0.02 <sup>bc</sup>	0.618	0.02 <sup>c</sup>
	Conv 200 °C	0.592	0.02 <sup>b</sup>	0.635	0.02 <sup>c</sup>	0.666	0.01 <sup>bcd</sup>
+ 20% Margarine	Mw 250 W	0.659	0.02 <sup>ab</sup>	0.718	0.01 <sup>d</sup>	0.713	0.01 <sup>ad</sup>
	Mw 900 W	0.627	0.01 <sup>b</sup>	0.660	0.01 <sup>abc</sup>	0.660	0.03 <sup>bc</sup>
	Conv 200 °C	0.641	0.01 <sup>ab</sup>	0.677	0.02 <sup>ab</sup>	0.688	0.02 <sup>ab</sup>

\*Tukey HSD; n = 5; p < 0.05; mean values followed by a common letter within the same column are not significantly different; mean values followed by a common numeral within the same row are not significantly different.

Table 5: Effect of baking time, baking mode and recipe modification on the *cohesiveness* of Madeira cake.

Again this highlights the advantage of the use of ‘Inverter Technology’ at 250 W. It facilitates the formation of a cake with a more stable air cell network as compared to cake microwave-baked at 900 W. It also emphasises the critical nature of the magnitude of the microwave power used for the preparation of acceptable microwave-baked products. Cohesiveness was also dependent on moisture content, which was found to be the highest in cakes microwave-baked at 250 W (Table 5); the greater the moisture content the greater the cake cohesiveness.

In general, irrespective of baking mode or batter recipe, as baking time was reduced the cohesiveness of the cake increased, and this was particularly evident when time was reduced from 115 to 100% of optimum baking time. A decrease in baking time resulted in less moisture loss and therefore, greater cake cohesiveness. In comparison, Clarke and Farrell [15] found the cohesiveness of microwave-reheated pizza bases to decrease with decreasing heating time.

The highest value of cohesiveness for each baking condition was exhibited by the control cake baked for 90% of optimum time, and the lowest value when the batter formulation with additional flour was baked for 115% of optimum time. The lowest cohesiveness values, for a given baking time, were exhibited by cake (with additional flour) microwave (900 W) and convective baked, and the highest value by cake microwave-baked at 250 W (irrespective of recipe and baking time). Cake with additional flour had a significantly lower cohesiveness than the respective control sample following microwave baking at 900 W for 100 and 90% of optimum times and convective baking for 100% of optimum time. Cake with additional margarine had significantly higher cohesiveness than the respective control sample when microwave-baked at 250 W for 100% of optimum time. Flour is known to possess toughening properties whereas margarine has tenderising properties. Thus, the more flour presents in the cake formula the less cohesive the resulting cake product, while the more margarine presents the more cohesive the cake.

**Gumminess:** Gumminess is the force required to disintegrate a semi-solid food before it is ready for swallowing [20]. It can be determined by Eq. (3) to the experimental data (Figure 1).

$$\text{Gumminess} = F_D \frac{A_2}{A_1} = (\text{Hardness} \times \text{Cohesiveness}) \quad (3)$$

Where, F is the force (N).

Table 6 summarises the gumminess data for Madeira cake. As shown, gumminess values ranged from 1.88-2.66 N for cake microwave-baked at 250 W, 1.84-3.16 N for cake microwave-baked at 900 W, and 1.86-2.21 N for cake convective-baked at 200°C. The highest gumminess value was obtained from cake with additional flour microwave-baked at 900 W for 100% of optimum time, with this being significantly higher than those exhibited by all other cakes baked for

100% of optimum time. The lowest gumminess value was found for the control recipe cake microwave-baked at 900 W for 90% of optimum time however, this was only significantly lower than the control cake microwave-baked at 250 W. Although, in general, convective-baked cake showed the lowest gumminess, irrespective of baking time and recipe, it was not significantly lower than that of cake baked using the other baking conditions. The gummy texture often associated with microwave-baked products is thought to be the result of microwave induced gluten changes [21]. However, the results indicate this problem is more limited in cake microwave-baked at 250 W, which shows comparable gumminess to convective-baked cake.

In general, the gumminess of cake convective-baked and cake microwave-baked at 250 W were not significantly affected by changes in baking time. At 900 W baking conditions, the gumminess of control and additional margarine batter formulations decreased with decreasing baking time (115 - 90%), however, the magnitude was only significant for the 100 to 90% interval. A reduction in baking time resulted in less moisture loss and therefore, a less gummy textured cake. Clarke and Farrell [15] found the gumminess of microwave-reheated pizza bases to decrease when the heating time was decreased. In general, recipe modification did not significantly affect the gumminess parameter, with the exception of cake (with additional flour) microwave-baked at 900W for 100% of optimum time.

**Chewiness:** Chewiness is the force required to chew a solid food until it is ready for swallowing. It can be determined by Eq. (4) to the experimental data (Figure 1).

$$\text{Chewiness} = F_D \frac{A_2}{A_1} \frac{t_{B:C}}{t_{A:D}} = (\text{Gumminess} \times \text{Springiness}) \quad (4)$$

Table 7 summarises the chewiness data for Madeira cake. As shown, chewiness values obtained ranged from 1.59-2.21 for cake microwave-baked at 250W, 1.58-2.50 for cake microwave-baked at 900 W, and 1.54-1.80 for cake convective-baked at 200°C. The highest value of chewiness was exhibited by cake (with additional flour) microwave-baked at 900 W for 100% of optimum time, with this being significantly higher than that exhibited by all other cakes baked for 100% of optimum time. The lowest value was obtained for cake (with additional margarine) convective baked for 100% of optimum time. In general, microwave-baked cakes were chewier than those convectively baked. This may also be due to the microwave-induced gluten changes which occur during microwave baking [21].

Cake microwave-baked at 900 W showed an overall decrease in chewiness as baking time was reduced from 115 to 100%. However, the chewiness was only significantly reduced for the control cake in the time interval 115 to 90% of optimum time, and for cake (with additional flour) from 100 to 90% of optimum time. As baking time was reduced,

Recipe	Baking mode	115 % Optimum baking time		100 % Optimum baking time		90 % Optimum baking time	
		Mean	SD	Mean	SD	Mean	SD
Control	Mw 250 W	2.39	0.27 <sup>ab</sup>	1.99	0.23 <sup>abc</sup>	2.43	0.31 <sup>a</sup>
	Mw 900 W	2.64	0.28 <sup>ab</sup>	2.33	0.04 <sup>bc</sup>	1.84	0.19 <sup>b</sup>
	Conv 200 °C	2.04	0.08 <sup>a</sup>	1.92	0.16 <sup>ad</sup>	2.11	0.15 <sup>ab</sup>
+ 20% Flour	Mw 250 W	2.39	0.41 <sup>ab</sup>	2.26	0.19 <sup>abc</sup>	1.88	0.39 <sup>ab</sup>
	Mw 900 W	2.83	0.57 <sup>b</sup>	3.16	0.19 <sup>e</sup>	2.18	0.29 <sup>ab</sup>
	Conv 200 °C	2.08	0.19 <sup>a</sup>	2.21	0.32 <sup>bcd</sup>	2.02	0.11 <sup>ab</sup>

\*Tukey HSD; n = 5; p < 0.05; mean values followed by a common letter within the same column are not significantly different; mean values followed by a common numeral within the same row are not significantly different.

**Table 6:** Effect of baking time, baking mode and recipe modification on the gumminess (N) of Madeira cake.

Recipe	Baking mode	115 % Optimum baking time		100 % Optimum baking time		90 % Optimum baking time	
		Mean	SD	Mean	SD	Mean	SD
Control	Mw 250 W	<sup>2</sup> 2.01	0.33 <sup>a</sup>	<sup>1</sup> 1.73	0.29 <sup>ab</sup>	<sup>2</sup> 2.21	0.30 <sup>a</sup>
	Mw 900 W	<sup>2</sup> 2.16	0.25 <sup>a</sup>	<sup>1</sup> 1.91	0.08 <sup>ab</sup>	<sup>1</sup> 1.59	0.21 <sup>b</sup>
	Conv 200 °C	<sup>1</sup> 1.67	0.05 <sup>a</sup>	<sup>1</sup> 1.59	0.14 <sup>a</sup>	<sup>1</sup> 1.79	0.16 <sup>ab</sup>
+ 20% Flour	Mw 250 W	<sup>1</sup> 1.94	0.43 <sup>a</sup>	<sup>1</sup> 1.98	0.23 <sup>ab</sup>	<sup>1</sup> 1.59	0.47 <sup>b</sup>
	Mw 900 W	<sup>2</sup> 2.04	0.54 <sup>a</sup>	<sup>2</sup> 2.50	0.25 <sup>c</sup>	<sup>1</sup> 1.64	0.32 <sup>ab</sup>
	Conv 200 °C	<sup>1</sup> 1.64	0.11 <sup>a</sup>	<sup>1</sup> 1.73	0.30 <sup>ab</sup>	<sup>1</sup> 1.66	0.10 <sup>ab</sup>
+ 20% Margarine	Mw 250 W	<sup>2</sup> 2.08	0.65 <sup>a</sup>	<sup>2</sup> 2.14	0.26 <sup>bc</sup>	<sup>1</sup> 1.91	0.10 <sup>ab</sup>
	Mw 900 W	<sup>1</sup> 1.77	0.05 <sup>a</sup>	<sup>1</sup> 1.66	0.14 <sup>a</sup>	<sup>1</sup> 1.58	0.42 <sup>b</sup>
	Conv 200 °C	<sup>1</sup> 1.59	0.15 <sup>a</sup>	<sup>1</sup> 1.54	0.12 <sup>a</sup>	<sup>1</sup> 1.80	0.23 <sup>ab</sup>

\*Tukey HSD; n = 5; p < 0.05; mean values followed by a common letter within the same column are not significantly different; mean values followed by a common numeral within the same row are not significantly different.

**Table 7:** Effect of baking time, baking mode and recipe modification on the *chewiness* (N) of Madeira cake.

there was no significant change in the chewiness of convective-baked cake or microwave - baked cake at 250 W.

For a given baking time, the lowest chewiness values were found for cake with additional margarine. Addition of flour caused a significant increase in the chewiness of microwave-baked cake at 900 W for 100% of optimum time; however, additional flour also resulted in a significant reduction in the chewiness of microwave-baked cake at 250 W for 90% of optimum time. In general, however, recipe modification did not have a significant effect on cake chewiness. The work of Gelinias [5] stated that a sensory panel considered cakes with low hardness and high cohesiveness values to be of best texture. Moreover, it is desirable to produce a cake with high springiness, low gumminess and low chewiness characteristics. In general, irrespective of recipe and baking time, the hardness of all cake samples microwave-baked at 250 W was not significantly different from those baked convectively. The springiness and cohesiveness were highest for cake microwave-baked at 250 W, and lowest gumminess and chewiness values were observed for convective-baked cake. In terms of hardness, cakes microwave-baked at 900 W were most sensitive to changes in baking time. For all baking conditions, with a decrease in baking time, sample springiness and cohesiveness generally increased, whereas sample gumminess decreased. Cake microwave-baked at 900 W showed a decrease in chewiness with decreasing baking time. Additional flour had a more significant influence on the hardness of cake microwave-baked at 900 W as compared to the other baking conditions. Recipe alteration also had a significant influence on cake cohesiveness, exhibiting the lowest values in samples with additional flour, for all baking conditions, and the highest values in microwave-baked samples with additional margarine.

## Conclusions

On the basis of this work the following conclusions can be drawn.

- Madeira cake microwave-baked at 250 W showed the most favourable textural properties in terms of springiness and cohesiveness. Cake microwave-baked at 900 W showed the least favourable hardness, gumminess and chewiness characteristics.
- In general, increasing the flour component of the batter formulation resulted in an increase in cake hardness, gumminess and chewiness, and a decrease in cake springiness and cohesiveness.

- In general, increasing the margarine component of the batter formulation resulted in an increase in cake springiness and a decrease in cake hardness.

## Nomenclature

- $A_{1,2,3}$  Areas under Force vs. Time TPA graph (refer to Figure 1)
- $F_D$  Firmness (N)
- $k$  Drying constant ( $s^{-1}$ )
- $n$  Number of samples
- $p$  Probability level
- $t_{A,B,C,D}$  Time to reach point A, B, C, D, E (refer to Figure 1) (s)

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