Effects of Production by Microwave Heating After Conventional Baking on Moisture Gradient and Product Quality of Biscuits (Cookies)[1]

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ABSTRACT

After conventional (forced-convection heating) baking at 240°C for 4 min, biscuits (cookies) were baked further in a microwave oven at medium and high settings (617.3 and 745.5 W, respectively) to study the effects of microwave baking on the moisture gradient and overall quality of the cookies. Microwave baking significantly ($P < 0.05$) reduced the moisture gradient and total moisture content of the cookies. Initially, a complete factorial design at baking times of 15, 20, 30, and 40 sec with microwave ovens at high and medium power settings was used to evaluate the moisture gradient and total cookie moisture content. Applying high and medium microwave settings for 30 or 40 sec, respectively, avoided cracking, although the products were slightly darker. Treatment at a high power setting for 20 sec resulted in a moisture gradient of 1.11%/cm and 2.8% cracking. Gradients >1.5%/cm produced significant levels of cracking. Cookies postbaked at a medium microwave power setting for 29 sec produced the same moisture gradient as a high microwave power setting for 23 sec, which was significantly ($P < 0.05$) lower than the control (cookies baked using the traditional process). The cookies were softer and the color did not differ significantly from that of the control. The expansion ratio of the control sample (11.3) was significantly higher than the combined process sample (10.7), showing a shrinkage effect attributed to the microwave treatment. The removal of the residual moisture during microwaving also increased product weight losses (from 0.912 to 0.956 g).

In conventional baking of biscuits (cookies), heat induces chemical and physical changes in the materials. Chemical changes include gas formation, protein denaturation and coagulation, starch gelatinization, and crust formation and browning. Physical changes include water evaporation, volume expansion, development of a porous structure, and alterations in dimensions (Smith 1972, Turhan and Ozilgen 1991).

Currently, the majority of cookies are baked by heat radiation from hot ceramic or insulated metal surfaces heated continuously by gas, oil, or electrical energy. Modern cookie ovens consist of heating tunnels through which the product travels on continuous conveyors that form the baking surface. The baking process can involve the transfer of heat from more than one energy source to the product. In conventional baking ovens, three mechanisms of heat transfer (conduction, radiation, and convection) are involved to varying degrees, depending on the design and adjustment parameters of the oven. Although these processes are satisfactory for baking cookies, they have some drawbacks, such as migration of moisture from areas within the cookie that have high concentrations to areas that have low concentrations, forming a moisture gradient. Also, the rapid drying of the surface causes differential shrinkage near the surface, which results in mechanical stress. When mechanical stress reaches a critical point, cracking occurs.

The use of microwave heating for final baking of cookies results in a more uniform moisture distribution than does forced convection (the conventional method) (Schifmann 1992). Microwave cooking is unique and has gained acceptance for food preparation because of its convenience, efficiency, speed, and low operating costs. Microwave heating of food materials is caused by molecular friction of electrical dipoles under an oscillating electric field of specific frequency. The great absorption of microwave energy by water molecules, which are the most abundant dipole component of foods, and other components (salt, fat, and proteins), which also act as dielectric components, results in food heating (Decareau and Peterson 1986, Mudgett 1986).

The principal differences between conventional and microwave ovens are that the products baked by microwave heating do not brown and have a poor crunchy texture (Mudgett 1989). However, microwave heating used in combination with other energy sources can obtain a desirable result (Decareau 1986). The use of microwave heating, pre- or postconventional baking process, has been successfully applied in breadmaking (Decareau 1967, Chamberlain 1973, Mudgett 1989). These combined processes decrease the system cost when compared to single heating systems (heated air, infrared, vapor, etc.) due to a synergistic effect (Schifmann 1992).

The objective of this research was to study the association of conventional and microwave heating processes for baking cookies, aiming at minimizing cookie cracking by reducing the moisture gradient and preserving the normal characteristics of the product, allowing development of adequate color, texture, flavor, and linear dimensions.

MATERIALS AND METHODS

Cookie Ingredients

A commercially milled, untreated, soft wheat flour (13.0% moisture, 11.56% protein, 0.99% ash, and 2.0% lipid content, wb) was obtained from Braswey Mill Sociedade Anônima (Campinas, Brazil). Semisweet cookies (5.18 cm diameter) were prepared using the formula: flour (200 g); corn starch (40 g); sugar (65 g); invert syrup (20 g); hydrogenated vegetable fat (22 g); soy lecithin (3.0 g); water (55 g); salt (2.5 g); sodium bicarbonate (1.1 g); ammonium bicarbonate (1.5 g); flavor (0.1 g) from Firmenich & Cia. Ltda. (São Paulo, Brazil); powdered milk (4.0 g); lactic acid (0.2 g); and sodium metabisulfite (1.5 g). The average particle size of sugar (0.196 mm) was determined using the method proposed by Henderson and Perry (1955). All ingredients, except flour, were obtained from established industries in São Paulo, Brazil.

Chemical Analysis of Flours

Moisture, ash, and protein contents were determined by Approved Methods 44-15A, 08-01, and 38-10, respectively (AACC 1995). Lipid content was determined according to the method of Bligh and Dyer (1959). Carbohydrate content was calculated as the difference from 100%. Results were expressed on a wet weight basis.

Flour Quality

The alkaline water retention capacity of the flour was 58.6%, determined according to Yamazaki et al (1953). The rheological test of the flour was done with a farinograph and extensigraph

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according to Approved Methods 54-21 and 54-10 (AACC 1995). Flour characteristics were: water absorption index 61.0%, dough development 4 min, dough stability 5.5 min, dough-mixing tolerance index 60 BU, dough resistance to extension 285 BU, and dough extensibility 160 mm.

The pH value and moisture content of the dough were determined according to Approved Methods 02-52 and 44-16 (AACC 1995). Flour distribution particle size (0.163 mm) was measured according to the method proposed by Henderson and Perry (1955).

Preparation of Cookies by Conventional Baking

Ingredients were blended in a farinograph mixer linked to a Brabender Do-Corder at 30 rpm for 7 min, followed by 8 min at 70 rpm, resting for 15 min, kneading with an electrical laminator with a gradual reduction of thickness by a standard steel matrix to 1.3 mm, and forming and baking. Baking was done on a carbon steel VC 1450 belt in an electric oven (Maq-Forno, São Paulo, Brazil) at 240°C for 4 min, followed by cooling (10 min) and packaging (in high-density polyethylene). During cookie preparation, dough temperature was maintained at an almost constant temperature (36–41°C) by controlling the temperature of the water added to the dough. Dough pH was ≈8.3, and dough moisture varied slightly from 21.9 to 22.4% (wb).

Conventional and Microwave Processes in Cookie Baking

Cookie samples were prebaked conventionally at 240°C for 4 min, followed by final baking in a microwave oven (Panasonic 7589B). The power output of the magnetron specified by the manufacturer was 800 W, and the operating frequency was 2,450 MHz. The microwave oven was used at high and medium power settings. The power setting of a microwave system is obtained from the mass caloric capacity at constant pressure (Kingston and Jassie 1988). Hence, the useful power setting of the magnetron can be determined indirectly by measuring the increase in temperature of a fixed quantity of water, enough to essentially absorb all the liberated energy provided by the magnetron to the microwave cavity (Collins and Neas 1988).

The useful power setting of the microwave oven was calculated according to the IMPI 2-L test described by Buffler (1993):

$$P = C_p K \Delta T m/t$$

where P = apparent power setting absorbed by sample watts (1 W = 1 J/sec), K = conversion factor for calories to joules (4.184 J = 1 cal); C_p = specific heat (J/kg °K); $\Delta T = T_f - T_i$ (final temperature – initial temperature [°K]); m = sample mass (kg); and t = time (sec).

For each treatment, 36 cookies were placed as a single layer on the circular rotating platform (360°) of the oven, as recommended by Kingston and Jassie (1988), to produce a more uniform absorption of energy. The cycling time and percentage of power setting provided from the magnetron to the microwave cavity were measured and calculated. At the levels applied, the energy provided to the cavity by the medium power setting was 82.8% of the energy provided at the high power setting. Microwave heating was applied after conventional baking to reduce the moisture gradient by removing the residual moisture from the center of the cookies.

Analysis of Cookies

The moisture content of the cooled baked cookies was determined according to Approved Method 44-15A. The moisture gradient was the difference between the moisture content of two parts of the baked cookie: the central core and outer ring. The percentage of cracking was determined by counting the number of cracked cookies in batches of 36 after one week of storage. A texture analyzer (TA-XT2, Texture Technologies, Scarsdale, NY) equipped with a 25-kg load cell, with a sensitivity of 1 g and a distance sensitivity of 0.0025 mm, was used for cookie texture evaluation. Ten cookies were evaluated by measuring the peak breaking force (kg), using a platform accessory with a circular opening. A cookie was fitted into the opening and tested with a stainless-steel spherical probe (1.27 cm diameter) at a loading speed of 3 mm/sec to a penetration depth of 2 mm. Color evaluation was accomplished with a lab system (CIE) with D65 light source, CIE standard and observation angle of 10°. The luminosity (L) parameter was measured on 30 cookies. Cookie width and thickness were measured for groups of 10 cookies, according to Approved Method 10-50D. Loss of weight was measured from the difference between raw, molded dough and cooled, baked cookie. The spread ratio obtained was the ratio between diameter and thickness; volume (cm^3) was determined by displacement of millet seed; density (g/m^3) was calculated as the ratio between the weight of the cooled, baked cookies and their volume (cm^3).

Statistical Analysis

Research was performed in three stages. A statistical analysis system (SAS Institue, Cary, NC) was used for data analysis. In the first stage of the experiment, a complete factorial design was used for the high and medium power settings (745.5 and 617.3 W, respectively) and microwave exposure time (15, 20, 30, and 40 sec), and each time and power setting combination for microwave exposure after conventional baking was evaluated. The adjusted model for moisture gradient was developed by multiple regression as a function of microwave power setting and exposure time:

$$y = 2.12 + 0.300p - 0.049t$$

where y = moisture gradient; p = power setting: 0 = high power setting and 1 = medium power setting; and t = time (sec). The significance of the adjusted model was $P = 0.0001$ and $R^2 = 0.96$.

During the second stage, using the results of the first stage, the adjusted model for moisture gradient had a moisture gradient zone

TABLE I
Moisture Gradient, Total Moisture Content, and Percent Cracking of Biscuits[a]

		Microwave Treatment Exposure Time[c]							
		Medium Power (sec)				High Power (sec)			
Characteristic	Control[b]	15	20	30	40	15	20	30	40
Total moisture content[d] (%)	3.31 (0.0424)[e]	2.43 (0.0384)	2.95 (0.0626)	1.87 (0.0611)	1.547 (0.0683)	2.158 (0.1171)	1.62 (0.0484)	1.75 (0.1675)	1.22 (0.0712)
Moisture gradient[f] (%)	2.38 (0.0434)	1.57 (0.0123)	1.49 (0.0639)	0.97 (0.0498)	0.52 (0.0406)	1.55 (0.0349)	1.11 (0.0717)	0.50 (0.0413)	0.19 (0.0419)
Percent cracking[g]	47.22	27.77	8.33	0	0	22.22	2.77	0	0

[a] Stage 1.
[b] Conventional process (240°C for 4 min).
[c] Combination conventional (240°C for 4 min) and microwave baking process.
[d] Mean and standard deviation of three measurements.
[e] Standard deviation.
[f] Central disk – outer rim. Mean of four measurements.
[g] Mean of 36 biscuits.

of ≈1% (central disk – outer rim), and the quality of the cookies (texture, color, moisture gradient, and percentage of cracking) was compared to that of the control. For the microwave treatments, a 2^2 factorial for times of 23 and 29 sec at high and medium power settings was used.

During the third stage of the experiment, the means of the physical characteristics of the control and selected sample of cookies baked using a combination of conventional and microwave heating processes were compared by the least significant difference test at $P < 0.05$.

RESULTS AND DISCUSSION

Moisture Gradient and Total Moisture Content (Stage 1)

The data presented in Table I show that the application of microwaves during the final baking process significantly ($P < 0.05$) reduced the moisture gradient in cookies. The longer the microwave exposure time, the smaller the moisture gradient. The smallest moisture gradients were obtained at the higher microwave power setting as compared to the same exposure times at the medium microwave power setting. Because cookies are more plastic at elevated temperatures, which occur immediately after the conventional baking step, cracking should be avoidable by allowing samples to equalize their moisture gradients while still warm, during final baking by microwave heating. Microwave heating after conventional baking produced a more even moisture distribution in the cookie than did convection heating alone.

The total moisture content of the cookies behaved similarly to the moisture gradient. Total moisture content decreased with moisture gradient with increasing microwave exposure at both microwave strengths. These results confirm the expectation that the decrease in moisture gradient due to the introduction of microwaves during the final baking process also would decrease the total cookie moisture content. The reduction in the moisture gradient and consequent decrease in moisture differential between the outer and inner parts of the cookies can be attributed to uniformity in heating resulting from application of microwave heating during postbaking compared to the conventional heating process. High correlations were found between the moisture gradient and total cookie moisture content ($r = 0.90$, $P \leq 0.0007$) and between the total cookie moisture content and percentage of cookie cracking ($r = 0.79$, $P \leq 0.010$).

The fact that moisture gradients exist in cookies at the end of the conventional baking process is important. The highest moisture content is in a thin lamella at the center of the product parallel to its surface, and the lowest moisture content is at the product surface and around the periphery (Wade 1988). Early research conducted by Dunn and Bailey (1928) demonstrated that the causes of spontaneous cracking of some cookies during storage were related to the presence of a moisture gradient between the center and outer rim of fresh, conventionally baked cookies. Dunn and Bailey (1928) also reported that the magnitude of the moisture gradient decreased with increasing baking time, and when exposed to atmospheres of controlled humidity for several hours, the moisture content of the different parts of the cookie came into equilibrium with the relative humidity of the atmosphere. Wade (1987) confirmed these findings using near-infrared radiation to bake cookies and observing that semisweet cookies baked by near-infrared had final moisture contents considerably lower than the normal level (≈1.5%), and when stored after cooling in sealed tins, they showed few, if any, signs of cracking.

In the current study, the application of microwave treatments during the final stage of cookie baking resulted in 0% cracking, and after applying high and medium microwave energy power settings for 30 or 40 sec, the corresponding moisture gradients were <1% (central disk – outer rim). The microwave treatment at a high power setting for 20 sec resulted in minimal cracking (2.8%) and a moisture gradient of 1.1% (central disk – outer rim). Gradients >1.5% resulted in significant levels of cracking. Cracking can occur in almost any type of cookie product but is most common in semisweet products and least common in high-fat products (Wade 1988). According to Somers (1974), residual moisture levels of <2% are more desirable in semisweet cookies to avoid cracking. On the other hand, Smith (1972) recommended moisture gradients of ≈0.5%, with a tolerance of 1% for efficiently baked cookies because higher moisture gradients cause cookie cracking. Similarly, Wade (1987) reported that the incidence of cracking in cookies baked in a forced-convection oven rose steeply with increasing product moisture content and that the moisture gradient within the product likewise increased with increasing total moisture content.

Figure 1 shows the relationship between moisture gradient and percentage of cookie cracking. As the moisture gradient increased, the percentage of cracking increased. Dunn and Bailey (1928) suggested that changes in dimensions (shrinkage at the center as the cookie loses moisture and expansion at the rim as it absorbs moisture) increase stresses within the product. If the stresses exceed the mechanical strength of the product, spontaneous breakage will take place. A high correlation ($r = 0.89$, $P = \leq 0.0012$) was observed between the moisture gradient and percentage of cracking.

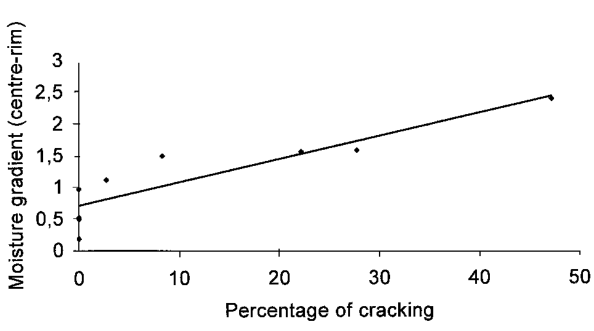

Fig. 1. Relationship between moisture gradient and percentage of cracking during baking of cookies using conventional and microwave heating.

Moisture Gradient, Total Moisture Content, and Percentage of Cracking (Stage 2)

The mean values for moisture gradient, total moisture content, and percentage of cracking during application of conventional and microwave heating to bake cookies for 23 and 29 sec at the high and medium microwave power settings are shown in Table II. All the microwave treatments produced significantly lower ($P < 0.05$) moisture gradients than the control sample baked by the conventional process. Treatments of 23 sec at the high power setting and 29 sec at the medium power setting produced statistically similar

TABLE II
Moisture Gradient, Total Moisture Content, and Percent Cracking of Biscuits[a]

		Microwave Treatment Exposure Time[c]			
		Medium Power (sec)		High Power (sec)	
Characteristic	Control[b]	23	29	23	29
Total moisture content[d] (%)	2.79 (0.0972)[e]	2.47 (0.0418)	1.90 (0.0806)	1.21 (0.0332)	1.90 (0.0757)
Moisture gradient[f] (%)	2.16a (0.0800)	1.17b (0.1272)	0.88cd (0.0672)	0.94c (0.0364)	0.71d (0.7148)
Percent cracking[g]	41.68	2.77	0	0	0

[a] Stage 2. Treatments with the same letter are not significantly different ($P < 0.05$) with respect to moisture gradient.
[b] Conventional process (240°C for 4 min).
[c] Combination conventional (240°C for 4 min) and microwave baking process.
[d] Mean and standard deviation of three measurements.
[e] Standard deviation.
[f] Central disk – outer rim. Mean and standard deviation of four measurements.
[g] Mean of 36 cookies.

moisture gradients of 0.9392 and 0.8854, respectively, as predicted by the model adjusted to the first experiment.

The microwave treatment of 29 sec at the high power setting produced an average moisture gradient 0.7148 lower than the treatment for the same time at the medium power setting but was not significantly different between the treatments. The treatment for 23 sec at the medium power setting resulted in an average moisture gradient of 1.17% (central disk – outer rim), predicted by the adjusted equation determined during the first stage of the research. The difference in cookie moisture gradient between the conventional and combined conventional and microwave baking can be related to the greater penetrating power of microwave heating, which sped up the baking process. Other heating systems (e.g., forced-convection heating) depend on the transfer of heat through the product from the surface. A carefully designed process tunnel in which the product is properly exposed to microwave fields can provide power utilization efficiencies of >70%. Also, microwave heating can do a more effective job without the size restriction usually imposed by other heating systems (Jeppson 1964).

A combination conventional and microwave cookie-baking process could be economically feasible. The use of microwave heating could have a favorable effect on space requirements. In combination with conventional heating methods, this process represents a low-microwave heating requirement and a 50% reduction in baking time (Decareau 1986). The use of microwaves and a conventional baking oven accelerated the breadbaking process, and only one-third of the normal baking time was required (Pei 1982). Similarly these processes can reduce the moisture gradient. The total moisture content of difficult products (e.g., particularly thick cookies) might be reduced to a satisfactory level by a postbaking treatment in a dielectric heater.

With respect to the percentage of cracking, the results obtained in the first stage were confirmed, with such products presenting a moisture gradient <1% (central disk – outer rim), a total moisture content <2%, and 0% cracking.

Cookies baked by near-infrared also had a slightly more even distribution of residual moisture than control products. This difference, although small, was sufficient to prevent spontaneous breakage in cookies during rapid cooling and subsequent storage (Wade 1988).

Color

The values for dimension *L*, luminosity scale, indicated that cookies baked at the medium microwave power setting were equal and did not differ significantly from the control cookies (Fig. 2). The cookies baked at the high microwave power setting were similar to each other but significantly ($P < 0.05$) different from the control ($r = 0.90$, $P \leq 0.0007$), which were lighter in color. The results of the medium power setting treatment were not significantly different than those of the high power setting treatment for 29 sec but were significantly ($P < 0.05$) different than high power for 23 sec, which produced a darker product. However, because the maximum difference in luminosity was of the order of 2%, the use of microwave heating at the levels tested resulted in minimal alterations in luminosity compared to the control; the differences were imperceptible to the human eye. This fact may be a consequence of temperature variations in the conventional oven (±2.5°C), which led to more and less darkening of the cookies, and also could be due to low moisture in the oven atmosphere during the early stages of conventional baking. The distribution of the cookies in the oven also could affect variation in the instrumental measurement of color. Even in relatively smooth products, such as semisweet cookies, the center of the docking holes and imprinted lettering are lighter in color than the surrounding material (Wade 1988).

Mudgett (1989) reported that the biggest difference between conventional and microwave ovens is the inability of microwave ovens to induce browning and crisping of foods. However, a control of the separate functions of convection-microwave baking proved to be useful in generating browning reactions. Microwave heating sysems are efficient at drying the wet centers of bakery foods, such as cookies and crackers, eliminating the need to conventionally bake the product all the way to the center, so the baker can concentrate on obtaining optimum product color and surface conditions (Mans 1991). For example, doughs could be baked partially by microwave heating and browned in a conventional oven to produce a desirable cookie color (Fetty 1966). As few as 3 min of microwave heating produced partially baked bread, and the volume and texture of finished products were equal to those of conventionally produced, partially baked products (Decareau 1967).

Hardness

The distinctly heterogeneous nature and variable structure of cookies and crackers complicate the instrumental measurement of texture. Cookie and cracker geometry causes heat to penetrate unevenly during baking, creating longer moisture residence at the center of the product and allowing greater amounts of starch to gelatinize there. The result is a more open crumb cell structure at the center (Burn and Fearn 1983). Measurement of hardness, which is related to the force necessary to break the cookie, showed that the control was harder and significantly ($P < 0.05$) differed from the other treatments (Fig. 3).

All of the microwave treatments resulted in cookies with the same hardness. When considering the moisture content of the samples, the control sample, which was harder, showed the highest moisture content. However, samples treated with microwaves had different moisture contents, suggesting no direct proportionality between moisture content and texture, as might have been supposed.

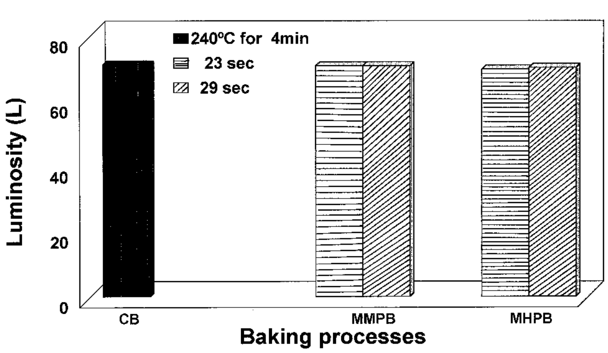

Fig. 2. Luminosity of cookies baked by a combination conventional and microwave baking process. CB = conventional baking; MMPSB = microwave medium power setting baking; MHPSB = microwave high power setting baking.

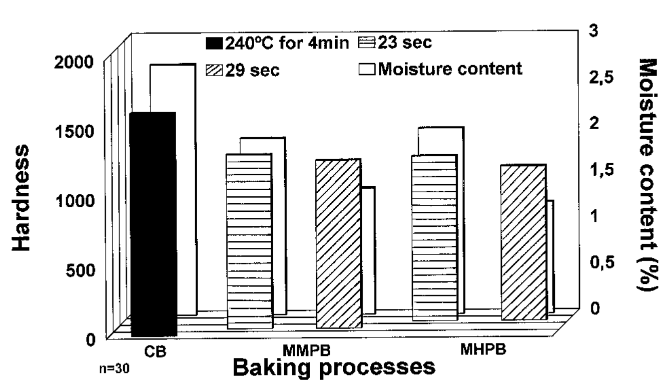

Fig. 3. Hardness of biscuits baked by a combination conventional and microwave baking process. CB = conventional baking; MMPSB = microwave medium power setting baking; MHPSB = microwave high power setting baking.

Although the difference in hardness between the control and microwave-treated samples was great, as far as the apparatus was concerned, it appeared to be below the limit of human detection. Wade (1988) noted that the use of temperatures lower than normal in the first part of the oven, which would reduce the rate of temperature rise in the dough, produced significantly thicker final cookies. Wheat hardness and flour particle size also affected the spread of short dough during baking.

Physical Measurements (Stage 3)

Combined conventional and microwave heating for 29 sec at a medium power setting baking treatment was selected. The physical characteristics of the cookies are shown in Table III. The value for the expansion factor (diameter/thickness, *D*/*E*) for the control cookies was significantly ($P < 0.05$) higher than for the cookies baked by the combined conventional and microwave processes, showing that microwave heating resulted in shrinkage of the product, although the difference was small. Because the cookies were still soft and flexible when they left the conventional oven and residual moisture was rapidly removed in the microwave oven, it is probable that movement of mass occurred. This theory is supported by the decrease in diameter and increase in the thickness of the cookies baked using microwave heating compared to the control.

The thickness of a cookie depends not only on the aerating agents present but also on the conditions in the oven. Wade (1971) demonstrated that increasing moisture in the first part of a continuous oven reduces the thickness of semisweet cookies and cream crackers. Changes also were found in the other linear dimensions of cream crackers with increasing oven moisture but not in semisweet cookies (Wade 1971, 1972). Wade (1988) reported that the greatest shrinkage occurred in semisweet cookies between the point of cutting and the time the dough piece entered the oven. Further shrinkage also could occur during the early stages of baking.

A high-quality soft wheat cultivar yields cookies of larger diameter with a uniform surface-cracking pattern. The level of soluble starch in different flours appears to cause differences in the spread rate of cookies made with hard wheat and soft wheat flours (Miller and Hoseney 1997). Final cookie diameter is controlled by cookie spread rate and set time. Cookie spread rate appears to be controlled by dough viscosity (Hoseney and Rogers 1994). Cookies made with soft wheat flour spread at a faster rate during baking than cookies made with hard wheat flour (Miller at al 1996).

In the current study, volume and density remained the same for both baking treatments (conventional and combined conventional and microwave baking). As occurred during conventional baking, the increase in the volume of dough during combined conventional and microwave baking can be attributed to the action of the aerating agents and to steam produced from the dough moisture.

With respect to weight loss, the results demonstrated that the residual moisture content removed by microwave heating increased the weight loss of the products. However the difference in weight loss was not sufficient to distinguish the samples (control and combination baking) with respect to their densities. The overall rate of moisture loss during baking depends on many factors, including the properties of the product. Denser cookies had a much harder eating texture than those with lower densities.

TABLE III
Physical Characteristics of Cookies[a]

Characteristics	Control[b]	Microwave Treatment[c]
Total moisture content	2.57	1.577
Diameter (mm)	51.47a	50.88b
Thickness (mm)	4.58b	4.75a
Expansion factor (*D*/*E*)[d]	11.35a	10.72b
Loss of weight (g)	0.91b	0.96a
Volume (cm^3)	6.73a	6.96a
Density (g/cm^3)	0.54a	0.53a

[a] Treatments with the same letter are not significantly different ($P < 0.05$).
[b] Conventional process (240°C for 4 min).
[c] Combination conventional (240°C for 4 min) and microwave (medium power setting for 29 sec) baking process.
[d] Diameter/thickness.

CONCLUSIONS

Cookies prebaked in a conventional oven (convection heating) at 140°C for 4 min and subsequently baked with a microwave oven set at 2,450 MHz and magnetron power output of 617.27 W for 29 sec showed significant reductions in moisture gradient, from 2.16 to 0.88% (central disk – outer rim), and incidence of cracking, from 41.7 to 0%. The introduction of microwave heating during conventional cookie baking significantly ($P < 0.05$) decreased the moisture gradient and total cookie moisture content. Applying high and medium microwave power settings for 30 or 40 sec, avoided the occurrence of cracking. The adjusted model for moisture gradient had a moisture gradient zone of ≈1% (central disk – outer rim), and selected microwave treatments of 23 sec at the high power setting and 29 sec at the medium power setting produced the same moisture gradients, which were significantly ($P < 0.05$) lower than those of the control. Instrumental measurement of the luminosity (*L*) of the experimental cookies (combined process) was similar to the control sample, and hardness was significantly ($P < 0.05$) less than that of the control. The use of microwave heating resulted in shrinkage of the product; however, volume and density were not significantly affected. The expansion factor (D/E) of the control was significantly ($P < 0.05$) higher than that of the samples exposed to final microwave baking. The residual moisture removed by microwave heating increased the weight loss of the products. Microwave heating could be introduced successfully in the final stages of cookie baking, producing products with excellent physical properties and no cracking.

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