MICROWAVE CONDITIONING OF HARD RED SPRING WHEAT. I. EFFECTS OF WIDE POWER RANGE ON FLOUR AND BREAD QUALITY[1]

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ABSTRACT

Waldron hard red spring wheat was conditioned in a closed system with up to 450 sec of microwave energy (625 watts) before experimental Buhler milling and baking. The temperature of conditioned samples ranged from 22° C (0 sec) to 105° C (450 sec). Analysis of the flour and bread indicated that physicochemically important quality parameters were adversely affected after 270 sec (+20.2 cal/g) of microwave conditioning. Most noteworthy among the reduced quality parameters were: a) decreased extraction, b) increased ash, c) increased dough strength, d) decreased β-amylase activity, e) increased retrogradation, f) increased flour viscosity, g) decreased loaf volume, and h) decreased external and internal loaf characteristics. Starch damage decreased up to 360 sec of conditioning. Falling number values indicated that the low initial dextrinogenic activity was essentially unchanged throughout the 450-sec time of irradiation. Overall, flour and bread quality were highest after 90 sec (+6.7 cal/g) of microwave exposure.

Various conditioning procedures (1,2) have been applied to wheat to control milling behavior and quality characteristics of intermediate and finished products. Conditioning, the process of adding or removing water and/or heat, alters the amount and distribution of moisture within the kernel. Warm conditioning techniques decrease the time required for moisture redistribution. In general, flour quality is not adversely affected after conditioning up to 46° C (1–4). Above 46° C, wheat moisture (5,6) and length of conditioning (7) are critical, as heat-induced physicochemical changes occur within the grain during hot conditioning (1). Specific hot conditioning procedures are required to improve hard wheat milling and baking characteristics (1,8) and durum wheat milling and pasta quality (9), as different grades and different lots of wheats may respond variably to heat treatments (1,2).

The use of microwave power in the food (10) and baking (11) industries is well

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established. Techniques for the microwave drying of apples and potatoes (12), cottonseed (13), field corn (14), pasta (15), and rice (16) have been reported. Okabe *et al.* (17) and Gorakhpurwalla *et al.* (18) discussed the implementation of microwave energy to determine the moisture content of grain. A microwave energy source has been used to monitor moisture levels during wheat conditioning (19,20).

Little information is available on the use of microwave power for conditioning wheat. Direct exposure of tempering grain to microwave energy (21) shortened the time required for conditioning. The production of enzyme-inactivated flours with microwave energy has been reported (22). Loaf volumes were increased and decreased with relative ease by controlling the microwave treatment applied to hard winter and soft wheats (23). Proper microwave treatment of durum wheat (22) resulted in a pasta product whose quality was superior to that of a nonirradiated control. The effects on semolina and spaghetti quality produced from durum wheat conditioned with a wide range (24) and an optimal level (25) of microwave power have been recently reported.

This study was undertaken to evaluate the effects of conditioning hard red spring (HRS) wheat with microwave energy. The level of microwave power at which milling performance and product quality begin to deteriorate must be determined before application to open commercial systems is possible. Therefore, the precise alterations induced by microwave conditioning in a closed system on HRS milling behavior, flour quality, baking characteristics, and bread quality must be detailed. The parameters examined were selected on the basis of their recognized relationships to HRS milling (2), flour (26), and baking (27) quality.

MATERIALS AND METHODS

Sample Preparation

The HRS wheat (*Triticum aestivum*) variety Waldron, grown at Langdon, N. Dak., in 1975, was used throughout this study. Samples were cleaned with an Emerson Kicker and Dockage Tester (Hart-Carter Co., Minneapolis, Minn.) in conjunction with a Forster Scourer, Model 6 (Forster Manufacturing Co., Ada, Okla.).

Conditioning and Milling

Cleaned samples were tempered to 12.5% moisture for 48 hr and then to a final moisture of 15.5% 24 hr prior to milling. Randomly selected, duplicate samples (replicates) were sealed in polyethylene containers and irradiated up to 450 sec, in 90-sec increments, 45 min before milling. Sample temperature was recorded directly after irradiation. Total sample weight was 2000 g.

All conditioned samples were milled (28) on a Buhler laboratory mill (Buhler-Miag, Minneapolis, Minn.). The mill was equipped with three corrugated break rolls, three smooth reduction rolls, and appropriate sifting apparatus to produce flour. All stock was handled pneumatically. The three break and three reduction flour streams were combined and considered as flour. Extraction rates were calculated on a total products basis.

Microwave energy at 2450 MHz was generated by a General Electric Jet 90

Microwave Oven (General Electric Co., Louisville, Ky.). All irradiations were performed at the high power setting (625 watts).

Each replicate was analyzed in duplicate for each physical and chemical test, and baked in duplicate.

Physical Tests

Farinograms were obtained with AACC method 54-21 (29). The 50-g small bowl, constant flour weight procedure was followed. Maximum consistency was centered at the 540 BU line.

Extensigrams were obtained by a modified AACC method 54-10 (29). Doughs were prepared by combining 100 g of flour (14% mb), 20 ml of water containing 1.0 g of sodium chloride and 0.003 g of potassium bromate, and additional water to equal the flour farinogram absorption. Doughs were mixed in a National mixer (National Mfg. Co., Lincoln, Nebr.) using a 100–200-g bowl. Mixing time was based on peak dough development time.

The dough was scaled off to 150 g, rounded 16 revolutions in the extensigraph rounder, centered and molded into a cylinder in the molding unit, and stored on a greased dough holder in a humidified chamber (80% RH) for a 45-min rest period. An extensigram was obtained after the 45-min rest period. The dough was remolded and rested an additional 135 min prior to obtaining a second extensigram.

Flour pasting data were obtained (30) with a Brabender Visco-Amylograph® (Brabender Instruments Inc., South Hackensack, N.J.) using the 700 cm-g cartridge. Rate of retrogradation was defined as the increase in viscosity in BU of the suspension per min of cooling (BU/min).

Wet gluten weights were determined according to AACC method 38-11 (29). Dry gluten weights were determined after drying the wet gluten balls at 105° C for 24 hr.

Falling number values were measured according to AACC method 56-81B (29).

A straight-dough formula was used for analyzing bread-baking characteristics. The formula was as follows:

Flour (unmalted)	100.0% (14% mb)
Salt	2.0%
Sugar	5.0%
Shortening	3.0%
Yeast	3.0%
Water	Variable

Baking absorption was estimated from the farinogram absorption. Ingredients were mixed on a National Mixer using a 100–200-g bowl. The dough was fermented at 30° C for 3 hr, with the first punch at 105 min and the second punch at 155 min. After fermentation, the dough was sheeted first at 0.56 cm and then at 0.40 cm with a National sheeter. The sheeted dough was rolled by hand, panned, proofed for 55 min at 30° C, and baked for 25 min at 220° C. Loaf volume (rapeseed displacement) was determined 1 hr after removal from the oven. External and internal loaf characteristics were judged separately by three experienced individuals the following day. Crust color, break and shred, crumb color, and crumb grain and texture were scored on a scale of 1 to 10, where 10 was the best score in each category.

Chemical Tests

Moisture, ash, and protein were determined by AACC methods 44-15, 08-01, and 46-10, respectively (29). Ash and protein were expressed on a 14% mb.

Starch damage was determined colorimetrically according to the method

TABLE I
Effect of Time of Microwave Irradiation on Energy Increase and Temperature of Randomly Selected Waldron HRS Samples[a]

Duration sec	Energy Increase Δ cal/g	Temperature °C[b]
0	0.0	22
90	6.7	38
180	13.4	52
270	20.2	66
360	26.9	85
450	33.6	105

[a]Duplicate 2000-g samples at 15.5% moisture.
[b]Average of three readings per sample.

TABLE II
Milling, Gluten, Extensigram, and Farinogram Data of Flour Derived from Waldron HRS Wheat after Microwave Conditioning[a]

	Microwave Time, sec					
	0	90	180	270	360	450
Milling						
Extraction[b,c], %	66.1	67.2	65.0	65.8	65.5	63.2
Ash[b], %	0.433	0.437	0.432	0.436	0.451	0.468
Protein[b], %	14.9	14.8	14.8	14.8	14.6	14.5
Moisture, %	13.6	13.5	13.4	13.2	13.0	12.7
Gluten weight						
Wet, g	4.99	5.06	4.96	4.29	3.37	1.88
Dry, g	1.66	1.67	1.68	1.48	1.24	0.72
Extensigram						
45-min extension, cm	22.9	23.9	23.9	19.4	11.8	6.8
45-min resistance, BU	508	538	496	700	633	623
180-min extension, cm	23.6	24.2	23.2	16.8	10.1	6.1
180-min resistance, BU	673	703	728	971	999	850
Farinogram						
Absorption, %	63.3	62.9	62.5	60.5	60.1	60.1
Dough development time, min	8.9	9.3	10.3	11.0	2.0	1.5
Stability, min	20.3	19.9	19.8	22.3	4.3	3.6

[a]Each entry is the average of four observations, except where noted.
[b]14% Moisture basis.
[c]Average of two observations.

proposed by Williams and Fegol (31). Starch damage was expressed in terms of absorbance units at 550 nm (A_{550}).

β-Amylase activity of flour extracts was determined by measuring the colorimetric reaction (32) between the β-maltose liberated from a soluble starch substrate and 3,5-dinitrosalicylic acid. Extracts were prepared by mixing 1 g of flour with 10 ml of $0.02M$ acetate buffer at pH 6.0, previously cooled to 3°–5° C. The mixture was kept on ice for 1 hr, swirled 30 sec every 15 min, and centrifuged at $10{,}000 \times g$ for 10 min at 4° C. Absorbance at 540 nm was converted to activity by reference to a standard curve prepared with 0.3 to 3.0 mol of maltose. One unit of activity equaled the release of 1.0 μmol of β-maltose/min under assay conditions.

RESULTS AND DISCUSSION

Time of microwave application was used as the independent, causal variable. In this manner, microwave effects and data handling were facilitated. Graphical analyses were required to accurately determine the level of microwave power at which a particular parameter was altered significantly, as analysis of variance (ANOVA) did not completely describe the effects of microwave conditioning.

The effect of irradiation time on the increased energy level and sample temperature is listed in Table I. The change in temperature with time of

TABLE III
Analysis of Variance of Microwave Power on Flour, Baking, and Bread Quality

	Mean Square		Mean Square
Milling		Biochemical	
Extraction	3.545*	Starch damage	0.006**
Ash	0.001**	Falling number value	5306.933**
Protein	0.044**	β-Amylase	0.038*
Moisture	0.205**		
		Amylograph	
Gluten weight		Initial pasting temperature	1.600
Wet	3.181**	Peak height	7340.000**
Dry	0.284**	15-min height	7288.333**
Extensigram		50° C height	26540.000**
45-min extension	103.755**	Rate of retrogradation	8.710**
45-min resistance	10564.083**		
180-min extension	119.640**	Baking characteristics	
180-min resistance	39943.883**	Absorption	2.033**
		Mixing time	0.656**
Farinogram		Dough handling score	24.921**
Absorption	4.497**	Loaf volume	90234.883**
Dough development time	36.594**	External loaf scores	
Stability	148.834**	Crust color	26.083**
		Break and shred	23.133**
		Internal loaf scores	
		Crumb color	13.483**
		Crumb grain and texture	15.283**

irradiation was linear (r = 0.997**).

The milling, gluten, extensigram, and farinogram data of the flour derived from Waldron HRS wheat after microwave conditioning are presented in Table II. The ANOVA of these data is summarized in Table III.

There was no significant difference between duplicates and replicates of all reported data, except the replicate ash data. The difference between the ash replicates was significant at the 5% level ($F = 11.32$; Prob> $F = 0.020$). This level of significance probably reflects the 0.6% difference in the average extraction of each replicate, which was nearly significant ($F = 2.19$; Prob> $F = 0.198$).

There was a significant decrease in extraction, protein, and moisture as time of microwave conditioning increased. Extraction increased and then decreased in a unimodal fashion after 90 sec. The rate of moisture loss was nearly linear and probably influenced the majority, if not all, of the quality aspects of intermediate (flour) and finished (bread) products. The significant effect of microwave power on decreased flour protein is a result of decreased flour yield, and contrasts with the lack of significance on semolina protein (24). The significant increase in ash observed with increasing microwave power is opposite that observed with semolina (24) and that expected with decreased extraction. Detailed studies on the effects of microwave irradiation on HRS and durum wheat protein and mineral physicochemistry are required to accurately interpret milling data.

There was a significant overall effect of microwave power on flour gluten character (Table III). The gluten data of Table II show that gluten quality was unaffected up to 180 sec of microwave conditioning, decreased somewhat between 180 and 270 sec, but decreased drastically beyond 270 sec. The drastic reduction in gluten character beyond 270 sec is reflected in the extensigram and farinogram data. The more discriminative extensigram and farinogram data indicate that gluten quality was diminished after 180 sec of microwave conditioning and nearly destroyed after 270 sec. The influence of microwave power on the extensigram and farinogram data was highly significant (Table III). Farinograms of samples conditioned for 450 sec are strikingly similar to semolina farinograms. The trends observed in the gluten, extensigram, and farinogram data are similar to those attributed to heat effects after conventional hot conditioning (1). However, further studies are necessary before differentiation between conventional heat effects and other possible effects of three dimensionally microwave-generated heat (10) on these parameters is possible.

Starch damage, falling number, β-amylase, and flour pasting data are listed in Table IV. The ANOVA data of Table III show that only initial pasting temperature was not significantly influenced by microwave power.

Starch damage decreased up to 360 sec of microwave conditioning, but increased rapidly thereafter. Starch damage of HRS flour was significantly influenced by microwave power (Table III), while that of semolina was not (24), reflecting the differences between starch granule physicochemistry (33). Microwave conditioning up to 360 sec appears to induce granulation of the endosperm along its naturally existing fissures (33,34). Thus, less force is required to reduce particle size during milling, thereby reducing energy requirements and equipment wear. Beyond 360 sec, the endosperm is probably dried to the point that starch damage increased during milling.

Falling number values were constant through 270 sec of microwave conditioning, beyond which values decreased by 100 sec. Although significantly influenced by microwave power, this observed range indicates that the initial low level of dextrinogenic activity (29,35) was not altered during conditioning. Falling number values were probably influenced by starch damage, since these

TABLE IV
Biochemical and Amylograph Data of Flour Derived from Waldron HRS Wheat after Microwave Conditioning[a]

	Microwave Time, sec					
	0	90	180	270	360	450
Biochemical						
Starch damage, A_{550}	0.69	0.65	0.64	0.66	0.64	0.79
Falling number value, sec	750	765	769	799	685	654
β-Amylase, μmol maltose/min	1.14	1.07	1.03	0.96	0.80	0.82
Amylograph						
Initial pasting temperature, °C	59.0	58.0	60.0	60.0	58.0	59.0
Peak height, BU	595	628	660	670	723	760
15-min height, BU	523	563	593	585	658	685
50°C height, BU	953	983	1053	1115	1200	1238
Rate of retrogradation, BU/min	13.8	14.0	15.4	17.7	18.1	18.4

[a]Each entry is an average of four observations.

TABLE V
Baking Characteristics of Flour, and External and Internal Loaf Characteristics of Bread, Derived from Waldron HRS Wheat after Microwave Conditioning[a]

	Microwave Time, sec					
	0	90	180	270	360	450
Baking characteristics						
Absorption[b], %	62.7	61.7	61.5	60.5	60.2	60.2
Mixing time, min	3.3	3.4	3.4	2.8	2.5	2.0
Dough handling score[c]	9.0	9.0	10.0	7.8	4.0	1.0
Loaf volume, cc	743	754	721	671	430	230
External loaf scores[d]						
Crust color	9.5	9.6	10.0	10.0	6.0	1.0
Break and shred	9.5	10.0	9.0	8.5	4.5	1.5
Internal loaf scores[d]						
Crumb color	10.0	10.0	10.0	9.5	7.5	3.5
Crumb grain and texture	9.5	10.0	9.5	8.5	5.3	3.3

[a]Each entry is the average of four observations.
[b]14% Moisture basis.
[c]Ranges from 1.0 (poorest) to 10.0 (best).
[d]Ranges from 1.0 (poorest) to 10.0 (best); average of three judges.

data are inversely correlated (r = −0.611**). β-Amylase activity declined at a nearly constant rate throughout conditioning, with 70% of the activity lost after 360 sec. The observed stability of β-amylase probably reflects the effects of kernel temperature (36,37).

Initial pasting temperature was essentially constant, while peak height increased nearly 30% during the 450 sec of microwave conditioning. Since falling number data indicated no dextrinogenic activity, the increase in peak height reflected the lack of significant action by β-amylase on the damaged starch, especially after 360 sec of conditioning. The rate of microwave-induced retrogradation was sigmoidal, with maximum retrogradation occurring between 90 and 270 sec. Thus, relatively low levels of microwave power modify flour pasting properties by increasing the rate of retrogradation. Detailed studies on starch isolated from microwave-treated samples are required to elucidate the precise effects of microwave-generated heat on pasting characteristics. Microwave energy most likely induces increased formation of crystalline regions within the starch gel, which has important implications for the rate of bread staling (38).

The bread-baking characteristics of the flour and the external and internal loaf characteristics of the bread produced from the microwave conditioned HRS samples are shown in Table V. Table III shows that each quality parameter of

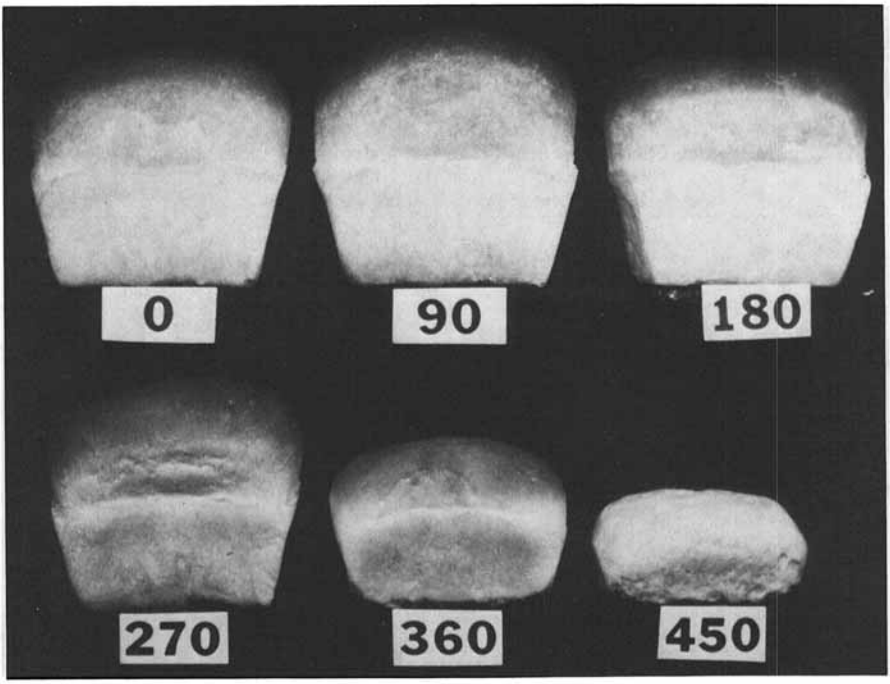

Fig. 1. Bread from Waldron HRS wheat after 0 (control), 90, 180, 270, 360, and 450 sec of microwave conditioning.

Table V is significantly influenced by microwave conditioning.

Baking absorption decreased throughout microwave conditioning, whereas dough mixing time decreased only after 180 sec of conditioning. The rates of decrease in absorption and mixing time are nearly parallel between 180 and 360 sec of conditioning. Dough handling characteristics were highest at 180 sec. Loaf volume was fairly constant up to 270 sec of conditioning but decreased rapidly beyond this time. Beyond 270 sec, doughs progressively slackened and were quite intractable.

External and internal loaf characteristics deteriorated rapidly beyond 270 sec of conditioning. Crust color was highest after 180 and 270 sec of microwave power, while crumb color was maximum between 0 and 180 sec of conditioning. However, there was little difference in either crumb or crust color through 270 sec. Break and shred and crumb grain and texture were maximum with those samples originating from grain conditioned for 90 sec. External loaf characteristics were reduced more than internal characteristics beyond 270 sec. It is noteworthy that loaf volume and the external and internal scores are negatively influenced to the same degree by microwave treatment.

Figures 1 and 2 show the effect of microwave conditioning on bread appearance. Loaf quality was improved after 90 sec, and was essentially equal to that of the control after 180 sec of microwave treatment. Irradiation for 270 sec resulted in loaf quality slightly below that of the control, while times beyond 270 sec reduced loaf quality drastically. These trends are consistent with the flour gluten, starch, and pasting data.

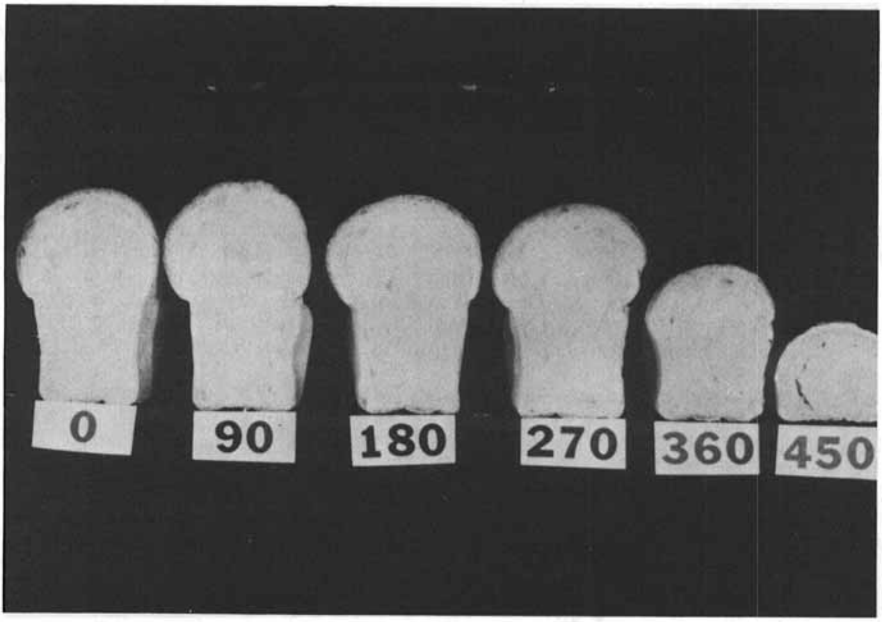

Fig. 2. Internal loaf characteristics of bread from Waldron HRS wheat after 0 (control), 90, 180, 270, 360, and 450 sec of microwave conditioning.

In summary, the rate of loss of endosperm moisture is probably the controlling influence on milling quality and starch damage. The changes in gluten quality, extensigram and farinogram characteristics, pasting properties, baking characteristics, and overall bread quality are most likely due to heat effects. Further studies are necessary to elucidate whether these effects are conventional or related to the nature of microwave energy. Application of up to 26.9 kcal (180 sec at 625 watts) of microwave energy is the limit for conditioning, as flour and bread quality was essentially equal to that of the nonirradiated control. Since application of up to 13.4 kcal (90 sec at 625 watts) of microwave energy increases overall flour and bread quality, microwave conditioning should be restricted to the lower energy levels. More data are necessary before widespread utilization of this potentially useful conditioning tool is possible.

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