Microwave Conditioning of Durum Wheat. 1. Effects of Wide Power Range on Semolina and Spaghetti Quality

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Crosby durum wheat was conditioned with microwave energy at 2450 MHz before experimental milling and processing. Randomly selected duplicate samples were irradiated at 625 W up to 600 s, in 120-s increments. The temperature of conditioned samples ranged from 22 °C (0 s) to 110 °C (600 s). Physicochemically important semolina and spaghetti quality parameters were adversely affected after 360 s (+25.9 cal/g) of microwave conditioning. Milling behavior and physical dough characteristics were reduced after prolonged irradiation. Most notable among the adverse biochemical effects were (1) increased dough strength, (2) increased starch damage during milling, (3) increased rate of starch retrogradation, (4) decreased α-amylase activity, (5) decreased β-amylase activity, and (6) loss of only 25% of total lipoxygenase activity after 600 s. Spaghetti color and cooked weight decreased, while cooking loss and firmness increased. In general, there were minimal effects on overall quality after 240 s (+17.3 cal/g) or less of microwave conditioning.

Wheat is conditioned before milling to improve product yield and quality. Conditioning involves a change in grain temperature and is performed with or without the removal or addition of water. As a result, the amount and distribution of moisture within the kernel are altered. Bradbury et al. (1960) have reviewed the literature on wheat conditioning.

Warm conditioning techniques shorten the time required for moisture redistribution. In general, product quality is not adversely affected after warm conditioning up to 46 °C (Wichser and Schellenberger, 1949; Bradbury et al., 1960). Wheat has been hot conditioned at temperatures over 46 °C (Geddes, 1929; Becker and Sallans, 1956). Specific hot conditioning procedures are required, as heat-induced physicochemical changes occur readily above 46 °C (Bradbury et al., 1960). Seyam et al. (1973) reported that durum wheat conditioned at 60 °C possessed increased milling performance without notable adverse effects on semolina and spaghetti quality.

The use of microwave power in the food (Tape, 1970) and baking (Lorenz et al., 1973) industries is well established. Techniques for the microwave drying of apples and potatoes (Huxsoll and Morgan, 1968), cottonseed (Welsey et al., 1974), field corn (Fanslow and Saul, 1971), pasta (Maurer et al., 1971), and rice (Calderwood, 1971) have been reported. Okabe et al. (1973) and Gorakhpurwalla et al. (1975) discussed the implementation of microwave energy to determine the moisture content of grains. Moisture levels during wheat conditioning have been monitored by microwave energy (Greer and Butcher, 1966; Butcher and Maris, 1973).

Little information is available on the use of microwave energy for conditioning wheat. Direct exposure of tempering grain to microwave energy (Watkins, 1971a) shortened the time required for conditioning. Proper microwave treatment of durum wheat (Watkins, 1971b) resulted in a pasta product, whose quality was superior to that of a nonirradiated control.

This study was undertaken to evaluate the effects of conditioning durum 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 durum wheat milling behavior, semolina quality, processing characteristics, and spaghetti quality must be detailed. The parameters examined were selected on the basis of their recognized relationships to durum, semolina, and pasta quality (Irvine, 1971).

MATERIALS AND METHODS

Sample Preparation. The durum wheat (*Triticum durum*) variety Crosby, 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% (w/w) moisture 48 h and then to 14.5% (w/w) moisture 24 h prior to microwave conditioning. Randomly selected, duplicate samples (replicates) were sealed in polyethylene containers and irradiated up to 600 s, in 120-s increments, 45 min before milling. Sample temperature was recorded directly after irradiation. Each irradiated sample was tempered to a final moisture of 17.5% (w/w) approximately 40 min before milling. Total sample weight was 2073 g.

All conditioned samples were milled on a Buhler laboratory mill (Buhler-Miag, Minneapolis, Minn.) specifically modified (Black and Bushuk, 1967) for producing durum wheat semolina. All semolina streams were blended together for 5 min in a Fluidizer Mixer (The Fluidizer Co., Hopkins, Minn.). 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 W).

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

Physical Tests. Semolina farinograms were obtained by the method of Irvine et al. (1961). Samples were tested at 33.0% (w/w) moisture for 8 min. Dough development time (DDT) and mechanical tolerance index (MTI) were defined according to Shuey (1972). Maximum consistency (MC) was defined according to Kent-Jones and Amos (1967).

Semolina extensigrams were obtained (Sibbitt, 1975) on 150-g doughs. Each dough was prepared by combining 110 g (14% moisture basis) of semolina, 10 mL of 10% (w/w)

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Table I. Effect of Time of Microwave Irradiation on Energy Increase and Temperature of Randomly Selected Crosby Durum Wheat Samples[a]

Duration, s	Energy increase, Δcal/g	Temp, °C[b]
0	0.0	22
120	8.6	39
240	17.3	57
360	25.9	80
480	34.6	95
600	43.2	110

[a] Duplicate 2073-g samples at 14.5% moisture. [b] Average of three readings per sample.

aqueous sodium chloride, and 40 mL of distilled water. Mixing was done in a National mixer (National Mfg. Co., Lincoln, Nebr.) using the 100–200 g bowl. Mixing time was based on the farinogram DDT of the semolina used.

Durum flour pasting data were obtained with a Brabender Visco-Amylograph (Brabender Instruments Inc., South Hackensack, N.J.) using the 700 cm-g cartridge. Durum flour was prepared by passing the semolina through a Brabender Quadrumat Jr. Laboratory Mill and using the material passing through a U.S. No. 70 Standard Sieve (Tyler). Amylograph procedure and data interpretation have been described (Medcalf and Gilles, 1965). The rate of retrogradation was defined as the increase in viscosity in Brabender Units of the suspension per minute of cooling (B.U./min).

Triplicate areas (6.45 cm^2) of semolina were scanned visually to detect the number of nonendosperm materials present. The average of the three readings was multiplied by 10. The speck count was reported as the number per 64.5 cm^2 (no./64.5 cm^2).

Semolina wet gluten weights were determined according to the AACC Approved Method 38-11 (1962). Dry gluten weights were determined after drying the wet gluten balls at 105 °C for 24 h.

Falling number values of durum flour, prepared as previously described, were measured according to the AACC Approved Method 56-81B (1962).

Semolina was processed into spaghetti by the method of Sibbitt and Harris (1946). A stiff dough was prepared by mixing semolina (30 g, 14% moisture basis) and approximately 10 mL of distilled water for 2.5 min, kneading for 3 min, and resting for 10 min in a humidity cabinet (98% RH). After the rest period, the dough was extruded with a continuous pressure laboratory microextruder (Research Products Co., St. Petersburg, Fla.). The processing absorption was adjusted to maintain extrusion pressure within the range of 425 to 525 lb/$in.^2$.

Spaghetti was dried in an experimental drier for 15 h. Relative humidity within the drier was decreased from 98 to 60% during the drying cycle, while temperature was maintained at 38 °C.

Spaghetti color scores were determined (Walsh et al., 1969) with a Model D-25 Hunter color difference meter (Hunterlab, Fairfax, Va.). The "L" and "b" color values were converted to a score ranging from 1 to 11, with 11 as the most yellow, desirable spaghetti, using a two-dimensional chromaticity diagram.

The method described by Dick et al. (1974) was used to determine the cooked weight of the processed spaghetti. Cooking loss was determined by the AACC Approved Method 16-50 (1962).

Spaghetti firmness was measured (Walsh, 1971) with an Instron Universal Testing Instrument, Type T (Instron Corp., Canton, Mass.). The area under the curve was calculated by an integrator. The average of three determinations was multiplied by 0.0199 to obtain the g-cm required to shear the cooked spaghetti.

Chemical Tests. Moisture, ash, and protein were determined by AACC Approved Methods 44-15, 08-01, and 46-10, respectively (1962). Ash and protein were expressed on a 14% moisture basis.

Starch damage was determined colorimetrically (Williams and Fegol, 1969). Damage was expressed in terms of absorbance units as 550 nm (A_{550}).

Lipoxygenase activity of freshly prepared semolina extracts was determined with linoleic acid (Lulai and Baker, 1976). The level of substrate autoxidation was determined by the method of MacGee (1959) prior to assaying. Substrate was discarded when its conjugated diene concentration was 3% or higher, as determined by the absorbance at 234 nm of 0.10 mL of linoleic acid plus 2.9 mL of deoxygenated distilled water against a distilled water blank.

β-Amylase activity of semolina extracts was determined by measuring the colorimetric reaction (Bernfeld, 1955) between the β-maltose liberated from a soluble starch substrate and 3,5-dinitrosalicylic acid. Extracts were prepared by mixing 1 g of semolina with 10 mL of 0.02 M acetate buffer at pH 6.0, previously cooled at 3–5 °C. The mixture was kept on ice for 1 h, swirling 30 s every 15 min, and centrifuged at 10000g 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 equalled 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 describe the overall 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 sample temperature with time of irradiation was linear ($r = 0.998^{**}$).

Table II. Effect of Microwave Conditioning on Milling Quality of Semolina Derived from Crosby Durum Wheat[a]

	Microwave time, s						
	0	120	240	360	480	600	F_{calcd}[b]
Extraction,[c,d] %	55.7	51.7	52.7	50.7	48.9	47.0	10.80
Ash,[c] %	0.616	0.603	0.612	0.548	0.537	0.565	16.59
Protein,[c] %	12.5	12.4	12.5	12.4	12.3	12.4	3.18
Mositure, %	13.2	13.8	13.7	13.3	12.9	12.6	15.63
Color score[e]	12.5	12.4	12.4	12.5	12.4	11.5	7.57
Specks, no./64.5 cm^2	20	14	14	13	14	16	0.39

[a] Each entry is the average of four observations except as noted. [b] $F_{0.05} = 5.05$; $F_{0.01} = 10.97$. [c] 14% moisture basis. [d] Average of two observations. [e] Ranges from 1.0 (poorest) to 14.0 (best).

Table III. Effect of Microwave Conditioning on Gluten Quality of Semolina Derived from Crosby Durum Wheat[a]

	Microwave time, s						
	0	120	240	360	480	600	F_{calcd}[b]
Gluten weight							
Wet, g	4.79	4.78	4.83	4.00	0.45	0.00	299.63
Dry, g	1.74	1.69	1.72	1.42	0.16	0.00	246.23
Extensigram							
Extension, cm	9.6	7.4	7.3	5.3	3.5	2.7	116.61
Resistance, B.U.	623	845	925	989	834	868	1.40
Farinogram[c]							
Dough development time, s	135	120	128	240	353	375	30.56
Mechanical tolerance index, B.U.	158	150	148	50	0	0	268.23
Maximum consistency, B.U.	630	578	585	542	130	90	792.87

[a] Each entry is the average of four observations. [b] $F_{0.05} = 5.05$; $F_{0.01} = 10.97$. [c] Farinograph absorption was 33.0% throughout.

Table IV. Effect of Microwave Conditioning on Pasting Properties of Semolina Derived from Crosby Durum Wheat[a]

	Microwave time, s						
	0	120	240	360	480	600	F_{calcd}[b]
Biochemical							
Starch damage, A_{550}	0.11	0.10	0.09	0.09	0.11	0.14	4.70
Falling number value, s	382	386	391	415	497	626	187.35
β-Amylase, μmol of maltose/min	0.49	0.42	0.30	0.33	0.26	0.15	36.73
Amylograph							
Initial pasting temperature, °C	71.5	72.0	72.0	69.0	67.0	67.0	29.14
Peak height, B.U.	200	198	218	318	478	713	523.06
15-min height, B.U.	100	103	120	208	535	738	699.21
50 °C height, B.U.	330	350	368	590	978	1465	584.24
Rate of retrogradation, B.U./min	7.7	8.3	8.2	12.8	14.8	24.2	193.92

[a] Each entry is the average of four observations. [b] $F_{0.05} = 5.05$; $F_{0.01} = 10.97$.

The semolina milling data are presented in Table II. The calculated F value is shown to indicate the level of significance that time of microwave conditioning exerted on each variable. There was no significant difference between duplicates and replicates of these data and all data reported in following tables.

There was a significant decrease in percent extraction and ash as time of microwave conditioning increased. As expected, semolina protein and speck count were not influenced by microwave power. Semolina moisture increased and then decreased in a unimodal fashion after 120 s of microwave conditioning. The decrease in moisture was significant. The rate of moisture loss is probably the controlling influence on milling behavior. The significant decrease in color reflected the loss of color occurring after 600 s. Color loss was probably due to destruction of the kernel matrix resulting from the interactive losses in moisture and gluten character.

The effect of microwave conditioning on semolina gluten quality is shown in Table III. Although extensigram and farinogram parameters are not normally applied to semolina quality of American durum wheats, these data are included to more accurately demonstrate the precise alterations undergone by the gluten during microwave irradiation. Microwave conditioning had a significant overall effect on semolina gluten character. Gluten quality was unaffected up to 240 s of microwave conditioning but decreased beyond this time, especially after 360 s. The drastic reduction in gluten quality beyond 360 s is reflected in the extensigram and farinogram data. The more discriminative extensigram and farinogram data indicate that gluten character was altered after 120 s of microwave conditioning. Loss of gluten strength and quality is shown in the abnormally long DDT and decreased MTI, MC, and extension of a semolina dough. Surprisingly, the large changes observed in extensigram resistance are not significantly influenced by microwave power. It is evident that further studies are required to elucidate whether the effect of microwave energy on gluten character is due to conventional or three dimensional microwave-generated (Tape, 1970) heat damage.

The effect of microwave conditioning on semolina pasting properties is shown in Table IV. Again, each starch-related variable is presented to give a more complete picture of pasting alterations induced by irradiation. Starch damage was not significantly influenced by microwave power. The examined range of microwave power evoked a minimum, unimodal response, with minimum damage occurring within the range of 240 to 360 s. This response is probably due to microwave-induced granulation of the endosperm along the naturally existing fissures and weak points (Greer and Hinton, 1950; Simmonds, 1974). Although not significant, decreased starch damage implies that particle size reduction achieved during milling would occur with less force, thereby reducing energy requirements and equipment wear. Conditioning beyond 480 s dried the endosperm to the point that starch damage increased dramatically.

Falling number values gradually increased up to 360 s of microwave conditioning, beyond which they increased at a rapid rate. This implies an equivalent rate of dextrinogenic (α-amylase) inactivation based on the inverse relationship between these variables (Perten, 1964). On the other hand, β-amylase activity declined throughout microwave conditioning, with nearly 80% of the activity destroyed after 600 s. The observed relative stabilities of α- and β-amylase are consistent with reported data (Kneen et al. 1943; Manners and Marshall, 1972). Both amylase activities were significantly altered during microwave conditioning.

The significant influence of microwave power on each amylograph parameter was the result of the changes observed after 240 s of conditioning. Initial pasting temperature decreased while peak height, 15-min height, 50 °C height, and rate of retrogradation increased beyond 240 s. In addition, the increased rate of retrogradation may

Table V. Effect of Microwave Conditioning on Processing of Semolina and Quality of Spaghetti Derived from Crosby Durum Wheat[a]

	Microwave time, s						
	0	120	240	360	480	600	F_{calcd}[b]
Processing							
Semolina absorption, %	34.0	34.0	33.7	33.3	34.3	36.2	4.11
Pressure, lb/in.^{2}	494	453	468	556	644	725	6.98
Spaghetti quality							
Color score[c]	10.0	10.3	10.0	10.0	8.9	4.5	167.89
Cooked weight, g	37.2	36.7	36.0	36.1	33.5	33.3	16.71
Cooking loss, %	6.0	6.0	5.6	6.1	9.0	14.1	38.52
Firmness scores, g-cm	3.92	3.76	4.15	4.38	4.44	3.36	4.19

[a] Each entry is the average of four observations. [b] $F_{0.05}$ = 5.05; $F_{0.01}$ = 10.97. [c] Ranges from 1.0 (poorest) to 10.5 (best).

be at least biphasic, with a rate change occurring at 480 s. Detailed studies on starch isolated from microwave-treated samples are required to elucidate the precise nature of microwave-generated heat on pasting characteristics. Microwave energy appears to induce increased formation of crystalline regions within the starch gel.

The sharp increase in amylograph peak height shows that the loss of dextrinogenic activity (Anker and Geddes, 1944) occurred after 240 s and not after 360 s as shown by the falling number data. The correlation (r = 0.983**) between these data was expected as both are routinely used for estimating α-amylase activity.

Lipoxygenase activity (ΔA_{234} min^{-1} mL^{-1}) changed from 7.0 to 5.3 after 0 and 600 s, respectively. Activity increased after 120 s of conditioning, which is consistent with the reported heat activation of cereal lipoxygenases (Franke and Frehse, 1953; Lulai and Baker, 1976). Beyond 120 s total activity was less than that of the 0-s sample. In general, total activity was fairly resistant to inactivation, as only a 25% reduction occurred after 600 s of conditioning. This level of stability was not observed in heat-treated wheat protein concentrates (Wallace and Wheeler, 1972).

Spaghetti processing and quality data are presented in Table V. The influence of microwave power on each processing and quality variable is shown. Semolina absorption decreased up to 360 s of conditioning but increased thereafter. These changes were not significant. Processing pressure increased after 240 s and, overall, was influenced by microwave power at the 5% level. This was expected and probably reflects the increased resistance and decreased extension of the gluten, the changes in starch damage, and/or the increased rate of retrogradation observed after 240 s of conditioning.

In general, spaghetti quality was not significantly reduced until after 360 s of conditioning. Some of the desirable yellow color was lost after 360 s, with a drastic reduction occurring after 480 s. The 480-s conditioned samples afforded irregularly colored, whitish spaghetti. Color loss is due, in part, to the relatively high level of semolina lipoxygenase remaining (Irvine, 1971). Although firmness decreased rapidly beyond 480 s of conditioning, the increase in firmness between 120 and 480 s did not parallel the trends observed with the other cooking quality data. This disparity may reflect the interaction of the microwave-altered gluten and starch during processing. However, further studies are required to elucidate the precise events responsible for the changes in firmness observed. In any case, since the changes in firmness were not significant, the al dente characteristics are not reduced by 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, pasting properties, processing characteristics, and overall spaghetti 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 35.9 kcal (240 s at 625 W) of microwave energy is the limit for conditioning, as semolina and spaghetti quality was essentially equal to that of the nonirradiated control. Since application of 53.8 kcal (360 s at 625 W) or more of microwave energy significantly reduces overall semolina and spaghetti 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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Microwave Conditioning of Durum Wheat. 2. Optimization of Semolina Yield and Spaghetti Quality

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Crosby durum wheat was conditioned with microwave energy at 2450 MHz before experimental macromilling to increase semolina yield and spaghetti quality. Randomly selected duplicate samples were irradiated at 625 W up to 90 s, in 15-s increments. Conditioning parameters were selected on the basis of quality data and grain temperatures observed during application of wide ranges of microwave power (Doty and Baker, 1977) and the results of a micromilling study. In the micromilling study, microwave conditioning was performed at 390 W in 2-s increments up to a maximum grain temperature of 65 °C. Semolina and spaghetti quality parameters of the micromilled samples were not influenced by conditioning time but selectively influenced by level of tempered moisture. Microwave conditioning for 60 s was optimum in the macromilling study. Semolina and semolina plus flour yield was increased 1.8 and 2.5 percentage points, respectively. Spaghetti color, cooked weight, and cooking loss were not altered by this conditioning treatment, while spaghetti firmness was increased significantly.

Procedures for conditioning wheat have been reviewed (Bradbury et al., 1960). Conditioning, the process of adding or removing water and/or heat, creates a moisture gradient within the kernel, which improves milling behavior and quality characteristics of intermediate and finished products. The time required for this internal moisture distribution is shortened when above ambient temperatures are used (Bradbury et al., 1960). The effects of conditioning temperatures above 46 °C have been studied (Geddes, 1929; Becker and Sallans, 1956). Durum wheat has been conditioned at 60 °C without adverse effects on milling and product quality (Seyam et al., 1973).

The use of microwave energy as a heat source would produce highly efficient conditioning, as water molecules distributed throughout the kernel reinforce the three-dimensional distribution of microwave-generated heat (Tape, 1970). The destruction of biologically active molecules following microwave irradiation is due to thermal effects (Goldblith et al., 1968), especially with molecules whose structural integrities result from extensive hydrogen bonding (Takashima, 1962). The biochemical functionings of various molecules are not destroyed under appropriate irradiation conditions (Goldblith et al., 1968; Takashima, 1966; Ward et al., 1975).

The present study was undertaken to optimize semolina yield and spaghetti quality from durum wheat conditioned with controlled, short periods of microwave power. The fact that short periods of microwave power does not lower semolina and spaghetti quality (Doty and Baker, 1977) suggested the possibility of quality optimization. The results of a micromilling study of microwave conditioned durum wheat, presented herein, suggested the potential of yield optimization.

MATERIALS AND METHODS

Sample Preparation. The sample used in this study was prepared in the same manner previously described (Doty and Baker, 1977).

Conditioning and Milling. Cleaned samples to be micromilled were tempered to 14.5% (w/w) moisture 48 h prior to a second tempering in sealed glass containers to a final moisture of 15.0, 15.5, or 16.0% (w/w) for 24 h. Randomly selected samples were irradiated in 2-s increments, up to a maximum grain temperature of 65 °C, 2 h before micromilling. Total sample weight was 200 g.

Cleaned samples to be macromilled were tempered to 12.5% (w/w) moisture 48 h prior to a second tempering to a final moisture of 17.0% (w/w) 24 h before milling. Randomly selected, duplicate sample (replicates) were sealed in polyethylene containers and irradiated up to 90

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