Effects of Microwave Radiation and Storage on Hard Red Spring Wheat Flour[1]

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ABSTRACT

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A pilot-milled hard red spring wheat flour was subjected to microwave radiation (625 W) for up to 480 sec and stored at room temperature for a total of six months. Physical dough properties and baking characteristics were examined immediately and at definite time intervals after radiation treatment. Analysis of the flour and bread indicated that important qualities were adversely affected after 240 sec of microwave exposure. Exposing the flour to high levels of microwave radiation produced an abnormal farinograph curve exhibiting two peaks, whereas low levels produced bread with loaf volumes and overall bread characteristics equal to or better than those of the control flour. In general, storage improved all samples. The influence of radiation on certain biochemical components was also investigated. When starch pasting characteristics were examined, radiation appeared to have had no adverse effect on paste stability; however, the rate of retrogradation decreased as radiation treatment increased. Decreasing starch intrinsic viscosity and total sugar values were observed with increased radiation levels after storage of the flour for six months.

Microwave radiation occupies a narrow section of the electromagnetic spectrum comprising the radio frequency band. Microwaves are nonionizing energy that causes a rise in temperature within a penetrated medium as a result of rapid electromagnetic field changes at high frequency. Over the past 30 years, use of microwave energy has become increasingly popular as a food processing technique and, out of this, much interesting research has developed.

Early investigators claimed that various chemical reactions could be induced by microwave energy. However, in recent years controlled experiments to elucidate the effects of microwave energy on biological and biochemical components have been conducted. Experiments by Goldblith et al (1968) showed that thermal destruction accounted for loss of thiamine in phosphate buffer (pH 6.8) irradiated for 50 min at 102.8° C, whereas no effect of radiation treatment was observed when thiamine solutions were held at 0° C for 45 min or at 33° C for 30 min. Some structures in biological materials, ie, hydrogen-bonded structures, may be affected by very low energies, however, according to Takashima (1962).

Although numerous studies have been conducted on microwave irradiation of meat, vegetables, and fruit, little has been reported on its effect on cereal grains. Edwards (1964) and Aref et al (1972) investigated the effects of microwave energy on sprout-damaged whole grain and flour in two related studies. They concluded that microwave treatment reduced α-amylase activity in the flour but not without detrimental effects on other flour performance characteristics. Doty and Baker (1977) found that microwave conditioning of a hard red spring wheat for more than 270 sec before milling adversely affected physicochemically important qualities of the flour and of the bread baked from this flour.

The objective of the present investigation was to ascertain what effect various levels of microwave radiation have on certain qualities and on specific biochemical components of flour immediately after radiation treatment and over a period of six months of storage.

MATERIALS AND METHODS

Flour Samples

The flour used for this investigation was obtained from the hard red spring wheat variety Waldron, grown at Casselton, ND, during the 1978 crop year. The flour, obtained after milling on a Miag pilot mill (Shuey et al 1968), was untreated and unbleached and contained 13.1% protein and 0.39% ash (14.0% mb).

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Radiation Source

Experiments were conducted in a Gereral Electric Jet 90 countertop microwave oven (General Electric Co., Louisville, KY) equipped with a Tashiba 2M53 magnetron as the microwave source. The unit operated on 120-V, 60-Hz alternating current and emitted radiation at a frequency of 2,450 MHz.

Radiation Treatments

Separate 2,000-g flour samples were placed in a 2.5-qt Pyrex bowl (15-cm diameter) and irradiated for designated periods of time from 0 to 480 sec on high power (625 W). The flour depth at the center of the bowl measured 9.0 cm. The bowl was rotated by hand one quarter turn every 60 sec to avoid hot spots. The temperature of the flour was recorded as an average of three readings taken immediately after radiation treatment. The flour samples were allowed to cool, then stored in airtight containers at room temperature for future analyses.

Analytical Measurements

Moisture, ash, and protein contents were determined on the control flour by AACC standard methods (1976).

Amylograph Data

Maximum viscosity of the various irradiated flours and of the control was determined with the Brabender Visco/Amylograph according to the AACC procedure.

Physical Dough Properties

Physical dough properties of the irradiated flour samples and the control were determined at designated time intervals from 0 to 150 days of storage, using the farinograph (50-g bowl) and the standard AACC constant flour weight procedure.

Baking Procedure

Bread was baked in duplicate one day after irradiation and at three-month intervals up to 150 days of storage, using a straight dough procedure. Baking absorption was estimated from the farinograph absorption, and optimum mixing time was obtained by visual examination of the dough. Mixing was performed in a National 100–200 g mixer (National Mfg. Co., Lincoln, NE). The baking formula was: flour, 100% (14% mb); salt, 2%; sugar, 5%; shortening 3%; compressed yeast, 3%; barley malt, 0.125%; and water, variable.

After a 2-hr fermentation period with two punches, the doughs were sheeted, molded, proofed for 55 min, and baked for 25 min at 230° C. The bread was allowed to cool for 1 hr, and the volume was measured by rapeseed displacement. The bread was stored overnight and judged for grain, texture, and crumb color the following day.

Starch Isolation

Starch was isolated by the dough kneading procedure described by Walden and McConnell (1955).

Starch Pasting Properties

Pasting properties of the starches subjected to various degrees of irradiation as well as starches isolated from the irradiated flours were examined using the Brabender Visco/Amylograph as described by Medcalf and Gilles (1966).

Intrinsic Viscosity

Intrinsic viscosity was determined only on the irradiated starches and not on the starches isolated from the irradiated flour. The irradiated starches were dissolved in 1 *N* soidum hydroxide solution as described by Lansky et al (1949), and the intrinsic viscosity was determined at 25°C as described by Leach (1963), using an Ubbelohde (Cannon Fenske) viscometer, capillary size 75, equipped with a Wescan automatic viscosity timer (Wescan Instruments Inc., Santa Clara, CA).

Total Sugar Content

Total sugar content was measured by the phenol-sulfuric acid method of Dubois et al (1956) on an aliquot of extract obtained using the ternary solvent system described by Ponte et al (1969) and modified by MacArthur and D'Appolonia (1979).

RESULTS AND DISCUSSION

Radiation Treatment

Table I shows the duration of microwave radiation used in this investigation, microwave energy absorbed for the various times utilized, and temperature and moisture changes of the flour after irradiation.

Microwave energy was calculated from the total watt input (625 W) multiplied by time in seconds and divided by sample weight (2,000 g). Temperature increased linearly according to the amount of time the sample was irradiated and the amount of microwave energy absorbed. Moisture content decreased as irradiation increased, particularly for those samples receiving higher radiation treatments. Loss of moisture during microwave irradiation has been reported (Apgar et al 1959) to be caused by a greater rise in post oven temperature, causing more dehydration.

TABLE I
Effects of Irradiation Time and Energy on Flour Temperature and Moisture Content

Irradiation Time (sec)	Microwave Energy[a]	Temperature[b] (°C)	Moisture (%)
0	0.00	22	14.3
90	2.81	44	14.3
120	3.75	47	14.2
240	7.50	61	14.0
360	11.25	75	13.6
480	15.00	100	13.0

[a] Calculated by multiplying watt input by seconds of radiation divided by weight of sample.
[b] Average of three readings per sample.

Amylograph Data

Amylograph peak viscosities of the irradiated flour samples at 0 and 150 days of storage are shown in Table II. Peak viscosity values remained constant for increasing irradiation times up to 360 sec, these values being slightly higher after six months of storage. The 360-sec and 480-sec irradiated samples for both storage periods showed considerably higher peak viscosities. The higher values obtained for these two samples are probably not a result of α-amylase inactivation because the flour was derived from sound wheat having virtually no amylase activity. However, other possibilities exist: 1) some type of alteration in the starch components could have taken place during the radiation treatment as a result of the increase in flour temperature or 2) the gluten proteins could have been altered in such a way that they became more absorbent with increased radiation treatment, removing free water from the slurry, thus increasing the starch/water ratio and causing a more viscous paste. Storage time also had an effect on the peak viscosity of the samples. The peak viscosity of the sample measured after 150 days of storage was higher than the corresponding sample measured immediately after irradiation. The higher viscosity after the storage period may be attributed to flour maturation. Although the effects of aging on pasting characteristics have not been investigated extensively, Loney and Meredith (1974) found peak amylograph viscosities to increase with the natural aging of two commercial flours during four years of storage. They attributed the increased viscosities not to a decline in amylase activity, but to changes in other components such as the starch. Hirohashi (1979) reported similar results.

Physical Dough Properties

Although farinograms were obtained every 30 days during the 150-day storage period, only the results for the samples immediately after irradiation and after 150 days of storage are shown (Table II).

Farinograph absorption remained essentially the same for the samples irradiated up to 360 sec at 0 days of storage. With the higher levels of irradiation (360 and 480 sec), absorption decreased. With the same samples, but after 150 days of storage, the decrease in absorption for the samples exposed to 360 and 480 sec of irradiation was not as pronounced. The initial decrease might be related to a temporary alteration or denaturation of the gluten proteins by the heat produced by irradiation, with an apparent recovery after 150 days of storage.

A gradual increase in dough development time was observed as the level of irradiation was increased at 0 days of storage, particularly for the samples receiving more than 120 sec of

TABLE II
Amylograph Peak Height and Farinograph Data of Irradiated Flours at 0 and 150 Days of Storage

Irradiation Time (sec)	Amylograph Peak Height,[a] BU		Farinograph Absorption,[b] %		Farinograph Dough Development Time, min		Farinograph Mechanical Tolerance Index, BU	
	0 Days	150 Days	0 Days	150 Days	0 Days	150 Days	0 Days	150 Days
0	3,260	3,830	63.4	63.2	8.0	10.5	35	30
90	3,330	3,840	63.2	63.8	9.0	10.0	35	25
120	3,280	3,875	63.6	63.4	9.5	10.0	30	25
240	3,290	3,835	63.2	63.4	10.5	11.0	30	20
360	3,420	3,965	61.6	63.8	14.0	17.5	25	20
480	3,840	4,000	60.2	62.4	...[c]	...[c]	...[c]	...[c]

[a] 100 g of flour, 14% mb.
[b] Expressed on 14% mb.
[c] Abnormal curve exhibiting two peaks.

radiation treatment. With storage, dough development time was constant up to 240 sec of irradiation, but at 360 sec of irradiation it increased dramatically.

Mechanical tolerance index, a measurement of the breakdown of the dough structure following attainment of maximum dough development, decreased as the level of radiation was increased and also as the time of storage was increased. Thus, a strengthening or toughening effect was observed in the dough from highly irradiated flour.

At 480 sec of irradiation, abnormal farinograph curves exhibiting two peaks were obtained. Figure 1 shows the curves obtained for the control flour and the flour subjected to 480 sec of irradiation at 0 days of storage. This phenomenon did not change as storage time increased, but the values for the two peaks increased with storage time from 2.25 and 29.50 min to 2.50 and 32.00 min at 0 and 150 days of storage, respectively.

Bread-Baking Properties

Baking absorption remained essentially constant over the six-month storage period for the different levels of radiation except for the 360-sec and 480-sec samples (Table III). These two samples, which showed a decrease in absorption initially, showed a lesser decrease after 150 days of storage. Mixing time for the control and for the samples receiving 90, 120, and 240 sec of irradiation remained essentially the same at 0 and 150 days of storage. As the level of irradiation was increased further, the mixing time increased. However, the mixing time required for the 480-sec sample stored for 150 days showed a lesser increase than did that for the sample evaluated after no storage. Doty and Baker (1977) found baking absorption to decrease in all wheat samples that had been microwave-conditioned before milling. These workers also found mixing time to decrease after 180 sec of conditioning.

Figure 2 shows the effect of microwave irradiation at 150 days of storage on internal and external bread appearance. With radiation treatments of 90 and 120 sec, loaf quality remained as good as, or improved slightly over, that of the control, particularly as storage time increased. With low levels of irradiation, a trend toward larger loaf volume, and improved grain and texture values was apparent as storage time increased. Irradiation for 240 sec resulted in loaf quality slightly below that of the control, and irradiation times beyond 240 sec reduced loaf quality significantly. A definite decrease in loaf volume and a more compact grain and texture was noted with these samples. In general, crumb color scores of the bread baked from the flours irradiated for 90 and 120 sec and, in some instances, the flour irradiated for 240 sec were slightly better than or equal to the control and appeared whiter upon visual observation. The crumb color of the bread baked from the flours receiving the higher irradiation treatments was definitely yellower in appearance. All crumb color scores for the bread baked at 150 days of storage were better than those baked at the corresponding level of irradiation after 0 days of storage. Such results would suggest a maturation effect.

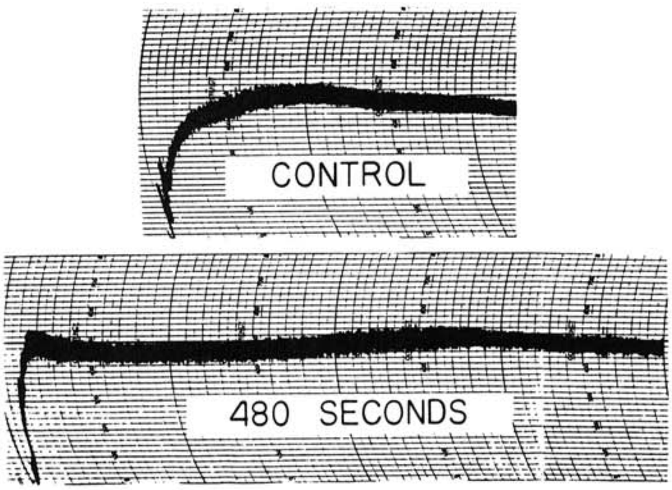

Fig. 1. Farinograms of control and irradiated flour.

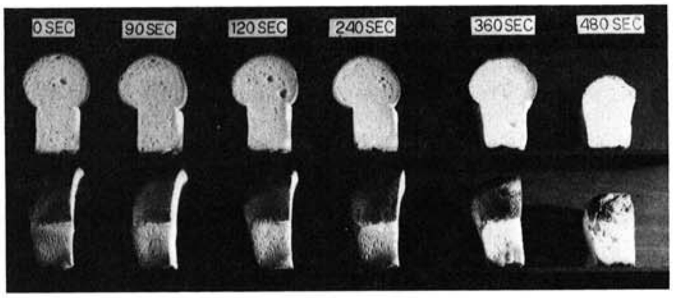

Fig. 2. Effect of microwave radiation on internal and external bread appearance.

Starch Pasting Properties

Initially, starch was isolated from flour irradiated for 0, 120, and 360 sec. Starch pasting properties were examined immediately after irradiation treatment and again after 30 and 120 days of storage. The results of this study are shown in Table IV. Temperature of initial pasting was similar for all samples. A slight decrease in peak height and the height after 15 min at 95° C was observed after 30 days of storage for all the samples. After 120 days storage, the control flour showed a pronounced increase whereas the irradiated samples remained constant. Upon cooling, the peak height at 50° C showed more fluctuation. The control flour showed a possible maturation effect not as evident with the irradiated samples. The complete separation of starch from other flour components with

TABLE III
Baking Absorption and Mixing Time of Bread Made from Irradiated Flour and Stored for 0 and 150 Days

Irradiation Time (sec)	Absorption,[a] %		Mixing Time, min	
	0 Days	150 Days	0 Days	150 Days
0	62.2	62.2	2.75	3.00
90	62.2	62.8	2.75	3.00
120	62.4	62.4	2.75	3.00
240	62.1	62.4	2.75	3.50
360	61.8	62.8	4.50	6.00
480	60.4	61.4	22.00	14.75

[a] Expressed on 14% mb.

TABLE IV
Amylograph Measurement of Starches Isolated from Flour Samples Irradiated 0, 120, and 360 Sec and Stored for 0, 30, and 120 Days

Amylograph Measurement/ Storage, days	Irradiation Time, sec		
	0	120	360
Pasting temperature,[a] °C			
0	83.5	83.5	84.5
30	83.5	83.5	83.5
120	83.5	83.5	84.0
Peak height, BU			
0	345	320	320
30	305	310	315
120	440	310	315
15-min height, BU			
0	350	335	335
30	295	315	320
120	440	315	320
50° C height, BU			
0	700	740	650
30	690	755	725
120	840	690	690

[a] Taken when the curve initially rises 10 BU.

TABLE V
Starch Pasting Properties of Starch Irradiated at Various Levels

Amylograph Measurement	Microwave Irradiation Time, sec					
	0	90	120	240	360	480
Initial pasting temperature, °C	85.0	85.0	85.0	85.0	85.0	85.0
Peak height, BU	290	300	315	295	300	290
15-min height, BU	300	315	325	305	310	300
50°C-height, BU	710	675	675	645	620	685
Rate of retrogradation, BU/min	13.6	12.0	11.7	11.3	10.3	12.8

TABLE VI
Intrinsic Viscosity Values of Isolated Starch Irradiated at Various Levels

Irradiation Time (sec)	Intrinsic Viscosity (η)
0	1.9
90	1.8
120	1.7
240	1.5
360	1.3
480	1.8

TABLE VII
Total Sugar Content of Irradiated Flour Samples[a]

Irradiation Time (sec)	Total Sugar, %		
	0 Days	30 Days	150 Days
0	1.5	1.5	1.7
90	...	...	1.5
120	1.6	1.6	1.4
240	...	...	1.4
360	1.6	1.4	1.1
480	...	...	1.1

[a] Average of two determinations, expressed in terms of sucrose (dry basis).

the irradiated samples was very difficult. Therefore, the results obtained may have been influenced by minute particles of gluten and "sludge" material adhering to the starch.

To eliminate possible contaminants, starch was isolated from the control flour and subjected to the same levels of microwave radiation as had been used on the flour. The pasting properties of the irradiated starches were determined immediately after microwave treatment (Table V). Pasting temperature, peak height, and height after 15 min at 95°C were similar for all starches. Therefore, irradiation did not alter the stability of the pastes. The values for the height at 50°C showed a decrease with irradiation up to 360 sec, indicating that irradiation has a tendency to slow down the rate of retrogradation. This can also be noted by calculating the rate of increase in Brabender Units from the height at 15 min to the end of the 30 min cooling cycle. The results obtained for this investigation are not in agreement with those of Doty and Baker (1977), who reported an increase in rate of retrogradation with increasing radiation. These workers, however, used flour instead of starch. Their observations may have been influenced by the interaction of other components present in the flour. Microwave energy might induce the formation of crystalline regions within the starch gel, which has important implications on the rate of bread staling according to D'Appolonia et al (1971).

Intrinsic Viscosity

Intrinsic viscosity values for the various irradiated starches are shown in Table VI. A progressive decrease in intrinsic viscosity was observed as irradiation increased, except for the 480-sec sample. The decrease in intrinsic viscosity suggests a possible alteration in starch structure as a result of the radiation treatments, even though peak viscosity as measured by the amylograph did not differ. The reason why the starch sample irradiated for 480 sec showed an increase in intrinsic viscosity is not clear; however, the increase might be related to thermal effects.

Total Sugar Content

As microwave radiation of the flour increased, total sugar content at 0 and 30 days of storage (Table VII) showed little change. As the length of storage time was extended to 150 days, the sugar content for the control flour showed a slight increase, which could be a result of flour maturation. However, with the remaining samples stored for 150 days, a trend toward a reduction in sugar content with increased radiation was seen. The exact reason for such results is unknown.

Although the effects shown in this study can be explained in part as thermal and/or maturation-related, some alteration of the starch structure could possibly occur during the microwave radiation of wheat flour. Studies on the effects of microwave energy on the amylose and amylopectin starch fractions would be helpful to further elucidate the precise effects of microwave-generated heat on the starch pasting characteristics and intrinsic viscosity. The effects of microwave radiation on the nonstarchy polysaccharides of wheat flour are presently being examined in our laboratory.

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