EFFECT OF GAMMA IRRADIATION OF WHEAT ON BREADMAKING PROPERTIES[1,2]

S. R. RAO[3], R. C. HOSENEY[4], K. F. FINNEY[5], and M. D. SHOGREN[5]

ABSTRACT

Physicochemical studies on flours milled from irradiated samples of Tascosa and Shawnee wheats indicated no adverse effects on quality at the dose level required for disinfestation of wheat (20 krad). As the irradiation dose increased, height of amylogram peak and dough stability decreased. At 1000 krad, the mixing requirement was reduced about 30% and loaf volume and crumb grain were impaired. Tascosa was impaired more than Shawnee wheat. Fractionating and reconstituting studies indicated that the gluten fraction was largely responsible for the impaired loaf volume potential of flour milled from irradiated (1000 krad) wheat. Because the gluten protein fraction also contains considerable lipid material, total free lipids were extracted from an irradiated sample (1000 krad) and found to be completely functional when reconstituted with RBS-70A defatted flour. Apparently the detrimental effect of γ-irradiation was largely on the gluten proteins.

Irradiation of wheat (20–25 krad) prevents the growth and development of most infesting species of insects (1). Most studies on wheat irradiation deal with doses much higher than those required for disinfestation. Reports are conflicting on the baking qualities of wheat after irradiation at low-dose levels.

Using lean, straight-dough formulas, several workers have reported (2-5) increased loaf volume at dose levels below 200 krad. However, other workers, using a rich formula, have reported (6-8) no difference in the baking performance of wheat irradiated at those dose levels. For wheat irradiated at low-dose levels, Lai *et al.* (3) found that loaf volume increased when using a lean baking formula, and decreased when using a rich formula. At doses above 500 krad, irrespective of the baking formula used, loaf volume and baking quality deteriorated (3,5,9,10).

The purpose of the present study was to determine the effect of irradiation on rheological and baking properties of wheat and to determine the fraction or fractions responsible for changes in those properties.

MATERIALS AND METHODS

Wheat Samples

Two hard winter wheat varieties were irradiated. Tascosa had a medium-

[1]Cooperative investigations, Agricultural Research Service, North Central Region, U.S. Department of Agriculture, and the Department of Grain Science and Industry, Kansas State University. Contribution No. 815, Kansas Agricultural Experiment Station.

Mention of a trademark name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

[2]Presented at the 57th Annual Meeting, Miami Beach, Oct.-Nov. 1972.

[3]Present address: Bhabha Atomic Research Center, Trombay, Bombay 85, India.

[4]Associate Professor, Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506.

[5]Research Chemist and Research Cereal Technologist, respectively, Hard Winter Wheat Quality Research Unit, U.S. Grain Marketing Research Center, Agricultural Research Service, U.S. Department of Agriculture, Manhattan, KS 66502.

mixing time and contained 12.3% protein (N × 5.7). Shawnee had a medium-long mixing time and contained 11.5% protein. Both samples had a good loaf volume potential.

Regional Baking Standard (RBS-70A) flour, used as a reference, was a composite flour from many wheat varieties harvested at many locations throughout the Southern and Central Great Plains of the U.S. in 1969. It had a good loaf volume potential, a medium-mixing time, and contained 12.3% protein.

Irradiation of Wheat

Samples (2 lb) of each variety of wheat (9.9% moisture) were irradiated at doses of 20, 200, and 1000 krad in a ^{60}Co γ-experimental cell at a rate of 1920 rad per min. Samples, after irradiating, were stored for 3 weeks at 25°C and then milled on an Allis experimental mill. Flours, after milling, also were stored for 3 weeks at 25°C. Thereafter, aliquots of flours were obtained from the bulks stored at 2° to 5°C.

Analytical Methods

Protein (N × 5.7), moisture, amylograms, and farinograms were determined as described in AACC Approved Methods (11). Mixograms were obtained on a 10-g mixograph as described by Finney and Shogren (12). The samples were baked by a rich, straight-dough (100 g flour) procedure as described by Finney and Barmore (13-15). For reconstitution studies (16), a microbaking procedure (10 g flour) was used. Standard deviations for the average of duplicate loaf volumes were 12 cc and 1.75 cc for the 100-g and 10-g methods, respectively. Loaf volume was measured by dwarf rapeseed displacement.

Fractionation of Flour

Flour was fractionated into gluten, water-solubles, and starch (17). All the

TABLE I
Amylogram, Farinogram, and Mixogram Data for Flours Milled from Tascosa and Shawnee Wheat Irradiated at 0, 20, 200, and 1000 krad

γ-Irradiation krad	Gelatinization Viscosity BU	Farinogram: Water Absorption %	Farinogram: Development Time min	Farinogram: Dough Stability min	Mixogram Mixing Time min
TASCOSA					
0 (control)	1000	60.6	4-1/2	4-1/2	3-5/8
20	960	60.8	4-1/2	4	3-5/8
200	670	61.3	4-7/8	2-1/2	3-3/8
1000	480	62.8	3	1-1/2	2-1/2
SHAWNEE					
0 (control)	800	63.4	8	3-3/4	4-3/8
20	530	63.1	8-3/8	2-3/8	4-3/8
200	480	63.0	8-1/2	1-1/2	4-1/8
1000	140	64.8	8-1/2	1-1/2	3

fractions were lyophilized, ground, and stored at −18° C. Flour was extracted with petroleum ether (bp 30°−60° C) for 18 hr in a Soxhlet apparatus to obtain total free lipids.

Reconstitution of Flour

Flours (10 g, 14% mb) were reconstituted to the protein content of the original flour. Additionally, gluten, starch, water-solubles, and total free lipid fractions from irradiated (1000 krad) and control samples were interchanged. Thereby, the particular fraction or fractions damaged by irradiation and affecting baking performance could be determined. Lipids were reconstituted with the flour by grinding in a mortar and pestle.

RESULTS AND DISCUSSION

Rheological Properties

Gelatinization viscosity (amylogram peak) decreased as irradiation dose

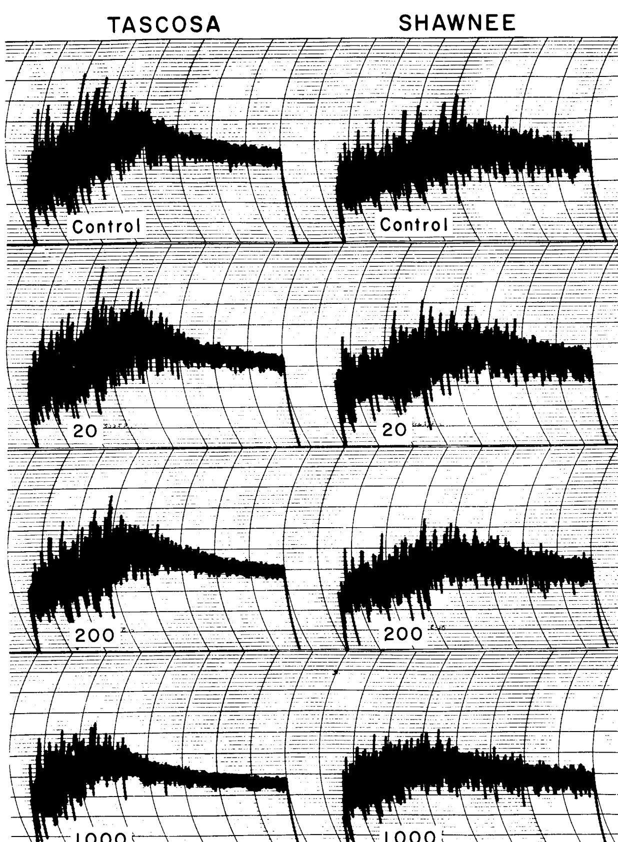

Fig. 1. Mixograms of flours milled from Tascosa and Shawnee wheats irradiated at 0, 20, 200, and 1000 krad of γ-irradiation.

increased (Table I). Similar results have been reported (2,4). Apparently starch susceptibility to amylolysis is increased by irradiation. Farinograph water absorption increased for flours from wheat irradiated at 1000 krad. In addition, farinograph dough stability decreased as irradiation dose increased. Similar results were reported by Fifield *et al.* (8). Mixograms (Fig. 1) showed a similar decrease in dough stability; mixing time, in general, decreased with increasing irradiation for both varieties.

Thus, physical dough tests indicated that 200 and 1000 krad of irradiation adversely affected the rheological properties of flours, but only at 1000 krad was the damage sufficient to impair baking absorption.

Breadmaking Properties

Loaf volume and crumb grain of bread baked from flour milled from irradiated wheat decreased as the dose of irradiation increased from 200 to 1000 krad (Table II). Irradiation impaired Shawnee only at the 1000 krad level. Optimum mixing time decreased, in general, as the irradiation level increased in samples of both wheat varieties, especially at 1000 krad. The bake mixing times were similar to those obtained from the mixograph.

Flours milled from irradiated wheat (1000 krad) had lower baking absorptions and higher bromate requirements than control flours and those receiving low levels of irradiation. Loaf crumb grains were satisfactory at 20 krad, but at higher levels were somewhat impaired. Bread from wheat irradiated with 1000 krad had a dark crust and crumb color and a peculiar flavor.

Both baking and farinograph absorptions generally increased as the irradiation level increased, except that baking absorption decreased materially at 1000 krad. Flour from irradiated wheat required more bromate than the control. That could have been because of shortened mixing time; generally, as the mixing time decreases, the bromate requirement increases (12). In the irradiated samples, mixing requirement decreased as the irradiation level increased, thereby resulting in an increased bromate requirement.

TABLE II
Baking Data (100 grams) for Flour Milled from Tascosa and Shawnee Wheat Irradiated with 0, 20, 200, and 1000 krad γ-Irradiation

γ-Irradiation krad	Bake Mixing Time min	Baking Absorption %	$KBrO_3$ Requirement ppm	Loaf Vol cc	Crumb Grain[a]
TASCOSA					
0 (control)	3-3/4	62.7	5	1008	S
20	3-3/4	61.2	5	1005	S
200	3-1/4	63.4	10	983	Q-S
1000	2-1/2	60.8	15	903	Q
SHAWNEE					
0 (control)	4-3/8	64.7	0	955	S
20	4-1/4	65.9	0	963	S
200	3-3/4	66.0	5	963	S
1000	2-3/4	63.5	10	898	Q

[a]S = satisfactory; Q-S = questionable to satisfactory; and Q = questionable.

Fractionating and Reconstituting Studies

To determine what fraction or fractions of wheat flour were affected by irradiation, Tascosa samples (0 and 1000 krad) were fractionated, reconstituted, and micro baked into bread. Data obtained by reconstituting the flours and interchanging the water-solubles, starch, and gluten fractions from certain of the flours are shown in Table III.

Gluten, Starch, and Water-Solubles

Mixing times for the reconstituted flours were not equal to those of the control flours. Similar results have been reported (17). The loaf volumes and bromate requirements for reconstitutes of flours milled from Tascosa wheat (control and irradiated) were the same as those of the original flours from which the fractions

TABLE III
Baking Data for Reconstituted Fractions of Untreated and Irradiated (1000 krad) Tascosa Flours

Source of Fractions			Mixing	$KBrO_3$	
Gluten	Starch	Water-Solubles	Time min	Requirement ppm	Loaf Vol cc
	Unfractionated Flour				
	Not Irradiated (N)		3-3/8	10	80
	Irradiated (I)		2-3/8	20	74
	Reconstituted Flour				
N	N	N	3-1/4	10	80
I	I	I	2-7/8	20	74
N	I	N	3-1/4	10	78
N	N	I	3-1/8	10	79
I	N	I	2-5/8	20	73
I	I	N	3	20	76
N	I	I	2-7/8	10	78
I	N	N	2-7/8	20	76

TABLE IV
Baking Data for Defatted RBS-70A and for Irradiated (1000 krad) and Defatted Tascosa Flours Reconstituted with Total Free Lipid (TFL)

Flour and Treatment	Mixing Time min	$KBrO_3$ Requirement ppm	Baking Absorption %	Loaf Vol cc
RBS	3-5/8	20	67	80
RBS defatted	3-3/4	20	68	72
RBS defatted + TFL[a]	3-1/8	20	67	82
Tascosa (I)	2-3/8	20	66	75
Tascosa (I) defatted	2-5/8	20	64	69
Tascosa (I) defatted + TFL	2-1/2	20	66	75

[a]TFL = 0.8% total free lipid from Tascosa flour milled from wheat irradiated at 1000 krad.

were prepared. Thus, the procedure used to fractionate and reconstitute the flours did not affect the baking performance of the samples.

Reconstitution of the gluten and water-soluble fractions from the control (not irradiated) flour with the starch fraction from irradiated (1000 krad) Tascosa produced a loaf volume (78 cc, NIN) somewhat, but not significantly, lower than that from the original flour (Table III). When the water-soluble fraction from irradiated wheat was reconstituted with the starch and gluten fractions from flour milled from control wheat, the loaf volume (79 cc, NNI) was nearly equal to that of the control flour. However, when the gluten from flour milled from irradiated Tascosa wheat was reconstituted with the water-soluble and starch fractions from control flour, the loaf volume was significantly lower (76 cc, INN) than that from nonirradiated control (80 cc, NNN), and somewhat, but not significantly higher than that from the completely reconstituted irradiated sample (74 cc, III). Those data, together with the results for the other reconstitutes in Table III, indicate that the gluten fraction was damaged to a greater extent than the starch or water-soluble fractions. No difference was noted in the starch-gel electrophoretic patterns of protein fractions from unirradiated and irradiated (1000 krad) samples.

Flour Lipids

The gluten fraction, as isolated in this study, contained a major part of the wheat flour lipids. Those lipids, particularly the total free lipids, have been shown (18) to be important in the baking performance of a flour. Therefore, the lower loaf volume potential of the gluten fraction of flour from irradiated wheat was possibly attributable to the lipids, instead of the protein, in that fraction. To check that possibility, we extracted the total free lipids from flour milled from Tascosa wheat irradiated at 1000 krad and reconstituted them with defatted flours (both the irradiated and a nonirradiated, standard flour, RBS-70A). Chung *et al.* (19) demonstrated that total free lipid content (0.8%) of flour was unchanged when irradiation doses varied from 1000 to 10000 krad.

Both defatted flours had reduced loaf volumes and slightly increased mixing times (Table IV). When the total free lipid (TFL) from the irradiated sample was reconstituted with control (RBS-70A) defatted flour, loaf volume was fully equal to the unfractionated RBS flour. When defatted flour prepared from irradiated (1000 krad) Tascosa wheat was reconstituted with its TFL, loaf volume was equal to that of the unfractionated Tascosa (I) flour.

Those data indicate that the lipid fraction of the flour was not responsible for the decreased loaf volume of flours milled from irradiated wheat (1000 krad). The total free lipids from irradiated flour were fully as functional as those from RBS-70A control. Therefore, the major part of the decrease in loaf volume potential of irradiated wheat can be attributed to damaged gluten proteins.

Literature Cited

1. MAYER, E. L. Irradiation treatment of grain and grain products. 6th Annual report U.S. At. Energy Comm.; published by NRC (1969).
2. LEE, C. C. The baking quality and maltose value of flour irradiated with Co^{60} gamma rays. Cereal Chem. 36: 70 (1959).
3. LAI, S. P., FINNEY, K. F., and MILNER, M. Treatment of wheat with ionizing radiations. IV. Oxidative, physical, and biochemical changes. Cereal Chem. 36: 401 (1959).

4. MILNER, M. Some effects of γ-irradiation on the biochemical storage and breadmaking properties of wheat. Cereal Sci. Today 2: 130 (1957).
5. NICHOLAS, R. C. Radiation induced changes in bread flavor. Food Technol. (Chicago) 12: 52 (1957).
6. WEBB, N. L., RUTHERFORD, B. E., and WIANT, D. E. Effect of ionizing radiation on cakes and biscuits made with milled irradiated wheat. Food Technol. (Chicago) 15: 386 (1961).
7. BROWNELL, L. E., HARLIN, H. A., and NEHEMIAS, J. V. A preliminary study of the effect of gamma irradiation on the baking quality of wheat. Food Technol. (Chicago) 9: 620 (1955).
8. FIFIELD, C. C., GOLUMBIC, C., and PEARSON, J. L. Effects of gamma irradiation on the biochemical storage and breadmaking properties of wheat. Cereal Sci. Today 12: 253 (1967).
9. MILLER, B. S., KOENIG, V. L., TRIMBO, H., and OGRINS, A. Effects of Co^{60} γ irradiation and mechanical damage on soft wheat flours. J. Sci. Food Agr. 15: 701 (1964).
10. MILLER, B. S., YAMAHIRO, R. S., TRIMBO, H. B., and LUKE, K. W. Organoleptic quality of cake and bread made with Co^{60} irradiated flour and flour from irradiated wheat. Cereal Sci. Today 10: 80 (1965).
11. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Approved methods of the AACC. The Association: St. Paul, Minn. (1962).
12. FINNEY, K. F., and SHOGREN, M. D. A 10-gram mixograph for determining and predicting functional properties of wheat flours. Baker's Dig. 46(2): 32 (1972).
13. FINNEY, K. F., and BARMORE, M. A. Yeast variability in wheat variety test baking. Cereal Chem. 20: 194 (1943).
14. FINNEY, K. F., and BARMORE, M. A. Varietal responses to certain baking ingredients essential in evaluating the protein quality of hard winter wheat. Cereal Chem. 22: 225 (1945).
15. FINNEY, K. F., and BARMORE, M. A. Optimum *vs.* fixed mixing time at various potassium bromate levels in experimental bread baking. Cereal Chem. 22: 244 (1945).
16. SHOGREN, M. D., FINNEY, K. F., and HOSENEY, R. C. Functional (breadmaking) and biochemical properties of wheat flour components. I. Solubilizing gluten and flour protein. Cereal Chem. 46: 93 (1969).
17. HOSENEY, R. C., FINNEY, K. F., SHOGREN, M. D., and POMERANZ, Y. Functional (breadmaking) and biochemical properties of wheat flour components. III. Characterization of gluten protein fractions obtained by ultracentrifugation. Cereal Chem. 46: 126 (1969).
18. DAFTARY, R. D., POMERANZ, Y., SHOGREN, M. D., and FINNEY, K. F. Functional breadmaking properties of wheat flour lipids. 2. The role of flour lipid fractions in breadmaking. Food Technol. (Chicago) 22 (3): 79 (1968).
19. CHUNG, O., FINNEY, K. F., and POMERANZ, Y. Lipids in flour from gamma-irradiated wheat. J. Food Sci. 32(3): 315 (1967).

[Received September 16, 1974. Accepted December 20, 1974.]