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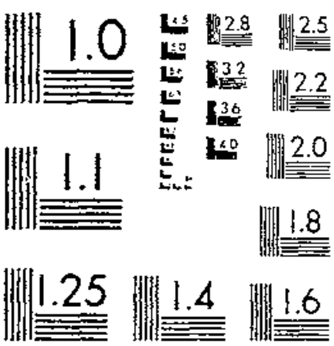

MICROCOPY RESOLUTION TEST CHART
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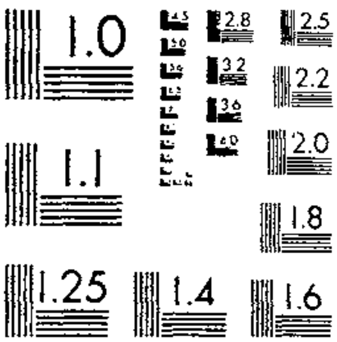

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

Quality Characteristics of Wheat Varieties Grown in the Western United States[1]

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CONTENTS

DEPOSITORY

SUMMARY

Data relating to the quality characteristics of winter and spring wheat are reported for 44 varieties grown in experimental plot and nursery trials in the western United States, mostly without but in some cases with irrigation. Included were the important commercial and a number of new and more promising varieties. The study was undertaken cooperatively by western agricultural experiment stations and the United States Department of Agriculture. It should be borne in mind that these samples have been grown under comparable conditions, whereas commercially some varieties, such as Baart and Turkey, are nearly always grown in the drier areas, while others, such as Hymar and Federation, are usually grown in the more humid areas.

The results for the field plot and nursery experiments are in excellent agreement as also are those for the irrigated and nonirrigated samples of the same varieties, except for dough-ball time and for the bread quality of the variety Baart. Irrigation tended to reduce materially the dough-ball time of most varieties but had

[1] Submitted for publication August 1944. The studies herein reported were made in the laboratories of the Grain Products Branch, Office of Distribution, War Food Administration, in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration. Credit is due B. B. Bayles, for planning the experiments and assisting in the interpretation of the data; to S. C. Salmon, for statistical advice and assistance in interpreting the data; and to A. Sallak, for most of the calculations. The experiments from which the grain for these studies was obtained were conducted in cooperation with the several State agricultural experiment stations in the region.

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little or no effect on those characterized by a very short dough-ball time. The loaf volume and the grain-and-texture scores of the bread from Baart grown under irrigation were materially less than when grown without irrigation and cannot be explained satisfactorily by differences in protein content. The irrigated and nonirrigated plots were not necessarily comparable in other respects, and hence such differences as were observed cannot with certainty be attributed to irrigation alone.

Of the 18 varieties of winter wheat tested, the 6 hard winters averaged slightly higher in protein content and test weight and lower in particle-size index, had a longer dough-ball time, and produced better bread but poorer cakes and cookies than the soft varieties. The differences in protein content generally were small. In general, more grain protein was retained in the flour of the hard wheats than of the soft.

Of the hard winter varieties, Turkey and Rio appeared to be best for bread.. Relief averaged slightly less than Turkey and Rio with respect to protein content and bread quality. Rio and Oro were relatively low and Relief high in carotenoid content of the grain and flour. Ridit, Turkey (Kharkof), and Rio were the lowest in flour ash.

All the soft winter wheats had a particle-size index of 22.7 or higher and all produced satisfactory cakes and cookies. Triplet produced the best cakes, with Goldcoin, Rex M1, and Athena only slightly inferior. The poorest cake was from Hymar, which had a relatively low particle-size index. Jenkin, Albit, and Hybrid 128 made the best cookies. The unusually high particle-size indexes for Rex, Rex M1, and Rex M2 may be related to the difficulties in separating the bran and flour and to the low yields of flour often complained of by commercial millers. With respect to test weight Triplet excelled all other soft wheats and averaged practically equal to the hard wheats.

Carotenoid content of the flour of the soft winter wheats ranged from 3.28 p. p. m. for Rex M2 to 1.66 p. p. m. for Elgin. All varieties bleached to what is generally regarded as a satisfactory level, but varietal differences in the color of the bread were still evident.

Among the spring wheats the general relation between hard and soft varieties was much the same as for the winter wheats, including a greater protein loss in milling the soft wheats.

Tests of the few spring varieties, which have hard vitreous grain, showed neither large nor important differences in bread quality. The variety Baart (which has semihard to hard grain), grown without irrigation, produced as good bread as any of the spring wheats. When grown with irrigation, the bread of Baart was poorer than others in relation to the protein content of the flour. The quality of bread and the dough-ball time of Fedawa, a soft wheat, approached that of the hard wheats, although the flour contained 1 to 3 percent less protein.

All the soft spring wheats produced satisfactory cakes and cookies. The best cakes were from Pacific Bluestem, Idaed, Union, Dicklow, Lemhi, and Jenkin. Jenkin and Union averaged best for cookies. Baart was equal to or superior to any of them for cakes though inferior for cookies.

Baart was among the highest in test weight. Fedawa and Ridit × Jenkin produced the highest yields of flour, averaging even higher than the hard wheats. The ash content of the flour of Fedawa, however, was relatively high.

Jenkin, Union, Federation, Onas, and Pilcraw averaged high in carotenoid pigments, and Baart, Lemhi, and Dicklow low. All bleached satisfactorily, but the differences tended to be carried over into the bleached flour.

The comparative results of the spring wheat varieties Baart, Federation, and White Federation grown for 3 years from fall seeding at Davis, Calif., were substantially the same as when grown elsewhere, except for dough-ball time of Federation. Of the varieties Ramona, Bunyip, and Poso, grown in California only, none appeared to be equal to Baart for bread and only Poso appeared to be equal to Baart for pastry purposes.

Scatter diagrams and correlation coefficients calculated only for the nursery tests showed some interesting relations. Yield of grain and protein content of the grain and flour were negatively correlated. Dough-ball time and flour protein appeared more useful than other determinations except the bread-baking test for predicting bread quality. Taken together they accounted for 93.5 percent of the variation in loaf volume in the irrigated spring wheat nurseries but only slightly more than 50 percent in the nonirrigated spring wheat and the winter wheat nurseries. The dough-ball time and loaf-volume relations appeared to be somewhat different for Baart in the nonirrigated nurseries and for Rex, Rex M1, and Rex M2, in the winter wheat nurseries as compared with other varieties. These results suggest that dough-ball time, in conjunction with protein analyses, may be a useful tool in breeding varieties of superior quality for bread when certain parents are used.

Particle-size index is highly correlated with cake grain-and-texture scores and also with the cooky factor. It appears to be more intimately associated with pastry qualities than is either flour protein or dough-ball time.

The correlations for bread-loaf volume on the one hand and cake grain-and-texture scores and cooky factors on the other were negative, but not always significant. The data and statistical computations show several exceptions to the assumed negative relation between bread and pastry qualities, thus indicating that it might be possible to produce varieties that are reasonably good either for bread or pastries, depending upon the protein content of a particular lot of the wheat.

INTRODUCTION [2]

The Western States produce more wheat than can be used locally. It is desirable therefore to make information available as quickly as possible concerning the varieties grown in the region, so that wheat of particular quality characteristics can be utilized for the purposes to which it is best adapted. This is particularly true under emergency conditions that involve a shortage of food and feed grains and the necessity to use rather large quantities of grain for the production of industrial alcohol.

This, the first comprehensive study on the quality characteristics of the wheat varieties grown in the region, will assist millers, bakers,

[2] Because of the need for conserving paper during the war, the presentation of data in this publication has been reduced to the bare essentials. Averages only are given in the tables and the discussion of methods is very brief. Additional information may be obtained on request addressed to the Division of Cereal Crops and Diseases, Plant Industry Station, Beltsville, Md.

and the grain trade in properly utilizing the wheat produced in the area and will guide agronomists in recommending varieties to be grown under the different environmental conditions.

A comparison of varietal quality is especially difficult when varieties are grown in areas having quite different soil and climatic conditions and different farming methods, as is true of grain reaching the commercial market in this region. This study is concerned with grain of varieties grown in experimental trial plots and, therefore, under nearly identical environment. The results supplement rather than replace those dealing with commercial lots of grain.

A large mass of data has been carefully summarized and interpreted, so that the tables occupy a minimum of space yet give an accurate picture of the results obtained.

Probably no other section of the United States grows wheat under such diverse conditions as those of the area west of the Rocky Mountains, and there is none in which a larger number of varieties so different in quality characteristics are produced. All the classes of wheat except durum and red durum are represented, including white, hard red winter, hard red spring, soft red winter, and the subclass white club. As would be expected, problems connected with their marketing and utilization are unusually complex.

In 1930 a closely coordinated program for the improvement of wheat in this region was undertaken by the State agricultural experiment stations and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture. Although this program was principally concerned with a comparison of the agronomic and pathologic characteristics of old and new varieties grown, provision was made for studies of grain-quality characteristics. The purpose of this publication is to present the pertinent data relating to these latter studies and to interpret them, especially in relation to the improvement of varieties for the region. The data are limited to the 5-year period 1935–39.

MATERIALS

The coordinated program provided for growing all the important commercial varieties of the region, both winter and spring, in uniform sets at several locations. These sets included 23 varieties of spring wheat grown in irrigated nurseries; 16 varieties of spring wheat and 18 of winter wheat in nonirrigated nurseries; 8 varieties of winter wheat in field plots; 7 varieties of spring wheat in irrigated and 5 in nonirrigated field plots; and 6 varieties of spring wheat seeded in the fall at Davis, Calif. Most of the varieties seeded in field plots also were included in the nurseries and all those grown without irrigation were included in the irrigated nurseries. A total of 44 distinct varieties were included in the study. These experiments are designated as uniform plot and nursery tests, because the same varieties in each case were grown at a number of locations and for several years.

The location in the region at which these varieties were grown include the State agricultural experiment stations, branch stations, and outlying experimental fields at or near Pullman, Lind, Prosser, Pomeroy, and Walla Walla, Wash.; Pendleton, Moro, and Union, Oreg.; Moscow, Aberdeen, Sandpoint, and Tetonia, Idaho; Bozeman, Mont.; Logan and Clarkston, Utah; Davis, Calif.; and Hesperus, Colo. The grain at Aberdeen, Bozeman, Prosser, and Logan was grown with irrigation.

As the primary purpose of the study was to characterize and evaluate varieties from the viewpoint of varietal improvement rather than to study the effect of environment on quality, composite samples of grain were used in those tests in most cases. These were made up by thoroughly mixing equal parts of grain of each variety from each station or location, so that all variety comparisons were strictly comparable.

It should be noted that varieties differ widely in their adaptation and that in practice they are grown under very different conditions of climate and soil. Differences in the quality characteristics of varieties, as received at the terminal markets, are related both to varietal characteristics as such and to climate and soil. For this reason the protein content and other quality characteristics of the varieties as received at the terminal markets may be quite different from that reported here. This is especially true of the varieties Baart and Turkey, which are grown most extensively in relatively dry areas.

METHODS

Quality characteristics of some varieties had been studied by the agricultural experiment stations and the United States Department of Agriculture previous to the inception of the present program. These, however, were limited in extent and usually included a few chemical determinations and bread-baking tests only. Quality characteristics in relation to pastry uses received little or no consideration. Since most of the varieties grown in the region are soft and the grain is relatively low in protein content, it appeared that attempts should be made to evaluate the varieties for pastry purposes as well as for bread. In setting up the new program, therefore, an attempt was made to develop adequate methods of characterizing varieties in relation to their suitability for specific purposes, including pastries, as well as to compare the quality characteristics of varieties by conventional bread-baking tests.

Determinations made included: Test weight of grain; flour yield; ash content of flour; protein content of grain and of flour; carotenoid content of grain, of unbleached flour, and of bleached flour; particle-size index; gassing power; dough-ball (wheat-meal fermentation) time; loaf volume and grain and texture of bread-, cake-, and cooky-baking tests.

All lots were cleaned, scoured, tempered, and then milled on an Allis-Chalmers experimental unit in such way as to obtain from each sample what was believed to be the maximum quantity of good quality flour. When milling was completed 5 percent of the lowest grade flour was discarded, the rest being used for all the flour determinations.

All chemical determinations, including protein and ash of the wheat and flour, were made according to the official method (*2*)[3] and are here reported on a 13.5-percent moisture basis. Carotenoid content of the grain and flour was determined by the method described by Ferrari (*7*) with some minor modifications as suggested by Geddes, Binnington, and Whiteside (*9*). Results are reported as parts per million (p. p. m.) of carotenoid pigment. The particle-size or granulation test developed by Cutler and Brinson (*5*) was used, except that the quantity of material that passed through the flour sieve into the pan, expressed as a percentage of the wheat meal, is reported as the particle-size index.

The dough-ball-time test was made by the method described by Cutler and Worzella (*6*) with certain modifications suggested by Bayfield (*3*) to avoid error due to the dough balls sticking to the sides of the beakers. Gassing-power tests were determined by the method described by Sandstedt and Blish (*10*).

Bread-baking tests were made in accordance with the methods of the American Association of Cereal Chemists (*2*), with such modifications as seemed necessary to bring out the potentialities of each lot of flour. What may be referred to as a commercial formula, including dried skim milk, shortening, sugar, salt, and yeast, was used. No bromate was used, as generally none is needed with low protein flours. Doughs were generally, though not always, mixed 2 minutes and then fermented, proofed, and baked in the usual manner.

Quality for cake was determined by baking yellow loaf cakes, the single-stage method being used with flour bleached with beta chlora (a mixture of nitrosyl chloride and chlorine) to a pH of 5.1 to 5.2. Cookies were made by the method described by Alexander (*1*) with slight modifications. Results are reported as the ratio of width to thickness and referred to as cooky factor.

EXPERIMENTAL RESULTS

The data consist of various physical and chemical determinations, as noted above, of the several varieties grown in uniform plot and nursery experiments in a number of locations and for several years. Carotenoid-pigment content of the flour and gassing-power determinations were not made in 1935, and the bread- and cake-baking tests for that year were considered unsatisfactory. The more pertinent data are presented in tables 1 to 6.

[3] Italic numbers in parentheses refer to Literature Cited, p. 35.

TABLE 1.—*Yield and quality characteristics of varieties of spring wheat grown in uniform irrigated nurseries; averages 1936–39, inclusive* [1]

Type and variety	C. I. No.[2]	Yield per acre	Test weight [3]	Flour yield [4]	Ash content of flour [5]	Protein content of [5]— Wheat	Protein content of [5]— Flour	Carotenoid content of [6]— Wheat	Carotenoid content of [6]— Unbleached flour	Carotenoid content of [6]— Bleached flour	Particle-size index	Dough-ball time	Gassing power	Absorption	Bread: Loaf volume	Bread: Grain and texture	Bread: Crumb color	Cake: Loaf volume	Cake: Grain and texture	Cooky factor
Hard red spring:		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P. p. m.*	*P. p. m.*	*Pct.*	*Min.*	*Mm.*	*Pct.*	*Cc.*	*Score*	*Score*	*Cc.*	*Score*	*W/T* [7]
Thatcher	10003	59.9	61.6	69.2	0.43	13.3	12.4	2.47	1.63	0.70	14.2	198	278	63	684	91	85	883	79	4.50
Marquis	4158	58.0	62.1	68.9	.46	13.0	12.1	2.26	1.51	.72	15.6	184	236	60	676	89	90	937	85	4.77
Ceres	6900	57.7	62.2	69.2	.46	13.0	11.9	2.49	1.75	.90	12.8	164	271	64	674	91	84	877	81	4.67
White:																				
Hard Federation 31	8255	55.9	62.0	69.7	.46	12.7	11.8	2.24	1.74	.75	19.4	165	292	62	644	71	78	855	76	4.41
Baart	1697	63.4	62.8	67.3	.46	12.5	11.0	2.10	1.43	.58	27.3	37	277	56	580	65	68	912	100	4.78
White Federation	4981	59.1	61.5	69.0	.46	12.2	10.9	2.41	1.64	.75	17.2	150	356	63	668	80	81	875	76	4.34
Idaed	11706	63.1	61.8	69.0	.40	11.9	10.3	2.35	1.73	.64	27.4	72	266	54	608	71	76	900	101	4.96
Pacific Bluestem	4067	56.3	61.5	69.5	.45	11.4	10.1	2.50	1.68	.70	27.6	49	168	55	529	49	59	923	103	5.11
Hard Federation × Dicklow	11623	70.3	61.0	68.9	.50	11.2	10.1	2.12	1.51	.73	19.0	51	247	57	565	70	76	905	91	4.80
Federation × Dicklow	11545	69.3	60.6	69.2	.54	10.9	9.5	2.58	1.79	.84	26.0	56	212	54	544	59	64	867	88	5.34
Baart × Hard Federation	11615	67.3	62.7	67.9	.43	10.8	9.4	2.04	1.34	.61	23.4	38	354	57	508	51	61	886	86	4.79
Lemhi	11415	69.6	60.2	68.3	.48	10.6	9.0	2.02	1.39	.69	27.4	44	213	55	568	71	76	901	100	5.06
Dicklow	8855	65.3	58.7	67.9	.48	10.5	9.2	2.04	1.40	.67	27.7	34	220	55	546	58	65	896	100	5.35
Hard Federation × Dicklow	11412	68.0	60.3	68.2	.42	10.5	8.8	2.74	1.86	.77	27.0	31	224	54	546	56	63	906	96	5.32
Fedawa	11795	64.1	60.9	70.4	.52	10.5	9.3	2.78	2.03	.78	22.3	108	238	54	586	64	68	902	85	5.00
Hard Federation × Dicklow	11427	68.6	59.5	68.9	.49	10.4	9.1	2.66	1.89	.80	25.3	51	249	54	533	58	69	917	94	5.16
Federation selection 47	11619	65.7	61.2	69.6	.47	10.4	8.7	2.77	1.91	.69	28.0	27	252	55	513	46	55	886	95	5.21
Federation	4734	63.7	60.4	69.4	.48	10.3	9.0	3.27	2.49	.75	26.5	67	241	55	585	64	64	905	98	5.10
Onas	6221	66.9	60.1	68.1	.51	10.3	9.0	2.86	2.03	.58	29.9	80	264	55	573	53	59	898	96	5.07
Pilcraw	10036	66.6	59.4	70.0	.48	10.3	9.0	2.81	2.32	.77	25.9	55	213	55	558	60	63	916	99	4.86
White club:																				
Union	11704	57.5	60.9	68.3	.45	11.3	9.5	3.41	2.71	.86	32.8	31	162	56	519	46	51	923	103	5.29
Jenkin	5177	58.5	61.5	69.5	.47	10.7	9.3	3.94	3.03	.87	26.0	32	158	56	531	50	50	916	100	5.54
Red club:																				
Jenkin × Ridit	11794	64.5	62.2	70.6	.45	11.5	10.3	2.82	2.22	1.01	17.4	76	255	57	586	69	70	891	84	4.99

[1] The grain of each variety used in these studies was grown at several locations each year and thoroughly mixed or composited by variety before milling. In each composite the quantity of grain from each location was the same for all varieties, but because of limited supplies not always the same for each location. The grain was grown at the following places: 1936, Aberdeen, Idaho, and Logan, Utah; 1937, Aberdeen, Idaho, and Bozeman, Mont.; 1938, Aberdeen, Idaho, Logan, Utah, Bozeman, Mont., Prosser, Wash., and Hesperus, Colo.; 1939, Aberdeen, Logan, Bozeman, and Hesperus.

[2] C. I. refers to accession number of the Division of Cereal Crops and Diseases.

[3] Dockage free.

[4] Moisture-free basis.

[5] 13.5-percent moisture basis.

[6] Carotenoid content expressed as carotene parts per million; naphtha-alcohol extract.

[7] W/T, ratio of width to thickness.

TABLE 2.—*Yield and quality characteristics of varieties of spring wheat grown in uniform nonirrigated nurseries; averages 1936–39, inclusive* [1]

Type and variety	C. I. No.[2]	Yield per acre	Test weight [3]	Flour yield [4]	Ash content of flour [5]	Protein content of [5]— Wheat	Protein content of [5]— Flour	Carotenoid content of [6]— Wheat	Carotenoid content of [6]— Unbleached flour	Carotenoid content of [6]— Bleached flour	Particle-size index	Dough-ball time	Gassing power	Absorption	Bread: Loaf volume	Bread: Grain and texture	Bread: Crumb color	Cake: Loaf volume	Cake: Grain and texture	Cooky factor
Hard red spring:		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P. p. m.*	*P. p. m.*	*Pct.*	*Min.*	*Mm.*	*Pct.*	*Cc.*	*Score*	*Score*	*Cc.*	*Score*	*W/T* [7]
Thatcher	10003	34.2	61.6	68.8	0.42	12.5	11.8	2.50	1.84	0.73	12.6	270	271	62	632	86	79	901	80	4.62
Marquis	4158	34.7	62.0	68.2	.42	12.0	11.2	2.19	1.76	.73	13.5	274	227	60	610	84	81	915	80	5.03
Ceres	6900	36.1	62.4	69.2	.42	11.9	11.1	2.45	1.90	.81	11.3	244	284	63	610	83	79	901	74	4.70
White:																				
Hard Federation 31	8255	36.5	62.9	69.3	.41	12.3	11.5	2.21	1.72	.72	17.8	294	296	62	626	85	81	883	75	4.52
Baart	1697	38.9	62.9	68.2	.47	11.7	10.3	2.39	1.63	.63	27.9	82	303	55	651	81	80	956	106	4.91
White Federation	4981	36.2	61.9	68.5	.42	11.4	10.4	2.44	1.81	.73	15.1	252	335	62	645	86	85	898	81	4.58
Pacific Bluestem	4067	37.3	61.0	68.5	.47	11.2	9.7	2.49	1.85	.69	32.9	73	160	54	547	64	68	974	101	5.33
Lemhi [8]	11415	42.3	59.8	67.7	.51	10.8	9.0	2.29	1.51	.58	28.6	45	218	54	568	71	77	928	101	5.50
Baart × Hard Federation	11615	40.0	62.9	69.2	.48	10.7	9.3	2.13	1.62	.69	22.8	61	337	56	539	65	69	937	86	4.84
Fedawa	11795	41.1	60.9	71.0	.48	10.5	9.3	2.63	2.13	.80	25.0	208	201	55	617	80	73	927	94	5.13
Idaed	11706	37.5	61.2	68.7	.42	10.4	9.5	2.69	2.05	.76	29.0	97	207	55	612	70	71	975	101	5.30
Federation × Dicklow	11545	41.1	60.3	68.9	.53	10.4	9.3	2.55	1.99	.69	28.5	94	191	55	563	64	68	929	91	5.50
Federation	4734	40.2	60.2	69.7	.50	10.2	8.9	3.35	2.67	.81	28.3	116	241	55	607	69	63	918	96	5.30
Onas	6221	42.9	60.4	70.0	.54	10.1	8.9	3.22	2.47	.94	30.1	166	253	55	593	69	64	920	93	5.33
White club:																				
Jenkin	5177	39.8	59.9	69.6	.54	11.1	9.7	4.10	3.50	.92	28.5	35	155	54	524	46	49	935	91	5.59
Union	11704	41.0	60.8	69.0	.50	10.5	9.1	3.41	3.05	.71	34.1	34	169	54	528	50	54	937	100	5.70

[1] The grain used in these studies was grown at several locations and composited by variety as noted for table 1. It was grown at the following places: 1936, Pullman, Wash., Pendleton and Union, Oreg., and Moscow, Idaho; 1937, Pullman, Pomeroy, and Walla Walla, Wash., Pendleton and Union, Oreg.; 1938, Pullman, Pomeroy, Walla Walla, and Lind, Wash., Pendleton and Union, Oreg., and Davis, Calif.; 1939, Pullman, Pomeroy, Walla Walla, and Lind, Wash., Pendleton and Union, Oreg., Sandpoint, Idaho, and Davis, Calif.

[2] See footnote 2, table 1.

[3] Dockage free.

[4] Moisture-free basis.

[5] 13.5-percent moisture basis.

[6] Carotenoid content expressed as carotene parts per million; naphtha-alcohol extract.

[7] W/T, ratio of width to thickness.

[8] Grown in 1937, 1938, and 1939 only. The data given are the averages for Federation for the full 4-year period, plus the algebraic differences between the averages for Federation and Lemhi for the 3 years in which Lemhi was grown.

TABLE 3.—*Yield and quality characteristics of varieties of winter wheat grown in uniform nonirrigated nurseries; averages 1936–39, inclusive*[1]

Type and variety	C. I. No.[2]	Yield per acre	Test weight[3]	Flour yield[4]	Ash content of flour[5]	Protein content of[5]— Wheat	Protein content of[5]— Flour	Carotenoid content of[6]— Wheat	Carotenoid content of[6]— Unbleached flour	Carotenoid content of[6]— Bleached flour	Particle-size index	Dough-ball time	Gassing power	Absorption	Bread: Loaf volume	Bread: Grain and texture	Bread: Crumb color	Cake: Loaf volume	Cake: Grain and texture	Cooky factor
		Bu.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P. p. m.*	*P. p. m.*	*Pct.*	*Min.*	*Mm.*	*Pct.*	*Cc.*	*Score*	*Score*	*Cc.*	*Score*	*W/T*[7]
Hard red winter:																				
Ridit[8]	6703	42.6	62.1	68.0	0.42	10.9	10.0	2.61	2.20	0.70	14.2	97	296	62	567	77	75	889	78	5.00
Turkey[9]	6175	42.9	62.3	68.0	.44	10.5	9.7	[8] 2.71	2.24	.70	15.6	06	308	[8] 62	[8] 561	[8] 73	[8] 72	884	75	4.81
Rio	10061	46.1	63.2	67.1	.42	10.5	9.4	2.28	1.88	.66	16.3	178	308	62	566	80	81	889	81	4.70
Oro	8220	46.9	63.3	68.4	.46	10.4	9.5	2.36	1.93	.77	14.6	186	292	60	520	73	74	885	81	4.59
Turkey (Kharkof)	1442	44.9	62.7	68.7	.42	10.1	9.3	2.76	2.31	.77	14.9	111	266	63	562	74	74	865	78	4.90
Relief	10082	46.2	62.4	67.9	.44	9.8	9.0	3.14	2.72	.97	14.6	132	259	61	533	69	64	900	84	4.87
Soft red winter:																				
Triplet	5408	47.8	62.7	66.6	.41	9.9	8.6	2.75	2.39	.64	27.9	54	222	57	558	65	71	947	104	5.42
White:																				
Rex M1	11689	46.8	62.0	67.5	.48	10.6	9.4	3.28	2.40	.66	34.3	170	252	55	595	68	71	964	100	5.14
Rex M2	11690	47.9	61.1	66.7	.46	10.4	9.2	3.71	3.28	.92	33.3	147	252	55	584	64	64	968	95	5.50
Rex	10065	44.4	61.6	66.5	.48	10.3	9.1	3.50	2.91	.61	31.3	152	255	56	578	68	63	946	95	5.67
Goldcoin (Fortyfold)	4156	39.9	61.0	68.7	.47	10.1	9.0	2.11	1.74	.64	24.4	31	218	55	470	46	63	963	101	5.54
Athena	11693	45.2	60.1	67.7	.44	9.8	8.5	2.42	1.76	.72	27.8	36	256	55	498	55	71	963	99	5.08
Golden	10063	45.1	60.2	67.4	.46	9.6	8.5	2.22	1.84	.72	26.7	29	239	55	469	48	59	931	95	5.50
White club:																				
Hybrid 128	4512	45.4	61.4	68.4	.49	10.2	9.1	3.02	2.39	.89	23.7	30	194	56	517	56	61	945	93	5.94
Hymar	11605	49.0	61.4	70.4	.47	9.9	8.7	3.39	2.78	1.06	22.7	45	211	55	522	59	59	941	90	5.62
Albit	8275	45.3	60.6	68.0	.43	9.8	8.8	3.15	2.55	.79	26.6	37	212	55	535	58	58	974	91	5.80
Jenkin	5177	43.1	60.9	70.5	.46	9.7	8.7	3.90	3.03	1.03	28.0	27	182	54	513	53	53	973	96	5.92
Elgin	11755	52.6	61.1	70.3	.45	9.0	7.9	2.25	1.66	.60	27.5	29	200	55	490	50	64	944	96	5.76

[1] The grain of each variety used in these studies was grown at several locations each year and thoroughly mixed or composited by variety, as noted for table 1. It was grown at the following places: 1936, Pullman, Pomeroy, and Walla Walla, Wash., and Pendleton, Oreg.; 1937, Pullman, Wash., and Pendleton, Oreg.; 1938, Pullman, Pomeroy, Walla Walla, and Lind, Wash., Tetonia, Idaho, and Clarkston, Utah; 1939, Pullman, Pomeroy, and Walla Walla, Wash., Moro, Oreg., and Moscow and Sandpoint, Idaho.

[2] See footnote 2, table 1.

[3] Dockage free.

[4] Moisture-free basis.

[5] 13.5-percent moisture basis.

[6] Carotenoid content expressed as carotene parts per million; naphtha-alcohol extract.

[7] W/T, ratio of width to thickness.

[8] Grown in 1937, 1938, and 1939 only. The data given are the averages for Turkey (1442) for the full 4-year period, plus the algebraic differences between the averages for Turkey (1442) and Ridit for the 3 years in which Ridit was grown.

[9] No determinations were made for carotenoid content of grain, absorption, and for loaf volume, grain and texture, and crumb color of bread in 1938. The data given are the averages for Turkey (1442) for the full 4-year period plus the algebraic differences between the averages for Turkey (1442) and Turkey (6175) for the 3 years in which Turkey (6175) was grown.

622670°—45——2

TABLE 4.—*Yield and quality characteristics of varieties of winter wheat grown in nonirrigated field plots; averages 1936–39, inclusive* [1]

Type and variety	O. I. No.[2]	Yield per acre	Test weight [3]	Flour yield [4]	Ash content of flour [5]	Protein content of [5]— Wheat	Protein content of [5]— Flour	Carotenoid content of [6]— Wheat	Carotenoid content of [6]— Unbleached flour	Carotenoid content of [6]— Bleached flour	Particle-size index	Dough-ball time	Gassing power	Absorption	Bread: Loaf volume	Bread: Grain and texture	Bread: Crumb color	Cake: Loaf volume	Cake: Grain and texture	Cooky factor
Hard red winter:		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P. p. m.*	*P. p. m.*	*Pct.*	*Min.*	*Mm.*	*Pct.*	*Cc.*	*Score*	*Score*	*Cc.*	*Score*	*W/T* [7]
Turkey (Kharkof)	1442	45.3	62.9	68.1	0.40	10.6	9.5	2.44	1.99	0.72	14.7	94	277	63	562	79	75	891	79	4.75
Ridit	6703	44.5	62.9	68.6	.43	10.4	9.5	2.44	2.00	.81	14.5	99	313	63	549	70	73	902	78	4.79
Soft red winter:																				
Triplet	5408	48.6	63.1	66.4	.36	9.7	8.5	2.52	1.95	.60	24.7	51	204	56	528	71	73	955	96	5.22
White:																				
Rex	10065	46.7	61.8	66.4	.45	10.4	9.3	3.17	2.49	.83	29.7	167	232	55	571	68	68	943	94	5.58
Golden	10063	45.6	60.8	66.8	.41	10.3	8.7	2.19	1.63	.67	24.3	35	216	55	484	53	64	944	94	5.67
White club:																				
Hybrid 128	4512	47.0	61.9	68.0	.42	10.6	9.4	2.95	2.21	.73	21.6	32	172	56	515	55	63	922	91	5.86
Albit	8275	45.8	61.3	67.2	.41	10.1	9.0	3.07	2.27	.74	24.7	37	200	55	548	68	69	940	94	5.98
Hymar [8]	11605	48.8	61.8	68.4	.45	9.9	8.8	3.28	2.58	1.03	23.3	51	199	56	535	61	68	916	89	6.08

[1] The grain used in these studies was grown at several locations and composited by variety as noted for table 1. It was grown at the following places: 1936, Pullman, Wash., Pendleton and Union, Oreg., and Moscow, Idaho; 1937, Pullman, Wash., and Pendleton, Oreg.; 1938, Pullman, Wash., Pendleton and Union, Oreg., and Moscow and Sandpoint, Idaho; 1939, Pullman, Wash., Pendleton and Union, Oreg., and Moscow, Idaho.

[2] See footnote 2, table 1.

[3] Dockage free.

[4] Moisture-free basis.

[5] 13.5-percent moisture basis.

[6] Carotenoid content expressed as carotene parts per million; naphtha-alcohol extract.

[7] W/T, ratio of width to thickness.

[8] Grown in 1937, 1938, and 1939 only. The data given are the averages for Hybrid 128 for the full 4-year period, plus the algebraic differences between the averages for Hybrid 128 and Hymar for the 3 years in which Hymar was grown.

TABLE 5.—*Yield and quality characteristics of spring wheat varieties grown in irrigated and nonirrigated field plots; averages 1936–39, inclusive* [1]

IRRIGATED

Type and variety	C. I. No.[2]	Yield per acre	Test weight[3]	Flour yield[4]	Ash content of flour[5]	Protein content of[5]—		Carotenoid content of[6]—			Particle-size index	Dough-ball time	Gassing power	Absorption[5]	Bread			Cake		Cooky factor
						Wheat	Flour	Wheat	Unbleached flour	Bleached flour					Loaf volume	Grain and texture	Crumb color	Loaf volume	Grain and texture	
Hard red spring:		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P. p. m.*	*P. p. m.*	*Pct.*	*Min.*	*Mm.*	*Pct.*	*Cc.*	*Score*	*Score*	*Cc.*	*Score*	*W/T*[7]
Marquis	4158	63.4	62.3	71.6	0.48	11.5	10.6	2.46	1.65	0.76	16.5	184	259	61	653	83	80	915	89	4.85
White:																				
Baart	1697	65.9	62.6	69.9	.51	11.1	9.7	2.45	1.59	.57	28.7	45	290	55	579	64	67	942	103	4.76
White Federation	4981	64.8	60.6	71.5	.50	10.1	9.2	2.60	1.88	.74	18.7	81	340	62	610	75	75	868	71	4.55
Onas	6221	73.4	59.2	69.8	.55	9.0	7.7	3.28	2.29	.79	30.6	45	297	56	554	51	55	913	93	5.40
Federation	4734	71.3	59.5	71.7	.50	8.9	7.5	3.86	2.61	1.05	27.6	39	280	55	549	56	59	938	95	5.50
Dicklow[8]	8855	72.6	58.5	69.9	.43	8.7	7.2	1.71	1.33	.28	31.6	25	229	55	561	63	76	900	94	6.07
Lemhi[8]	11415	76.9	58.8	69.6	.46	8.5	7.2	2.16	1.38	.38	28.8	28	212	54	556	73	74	906	94	5.63

NONIRRIGATED

Type and variety	C. I. No.	Yield per acre	Test weight	Flour yield	Ash content of flour	Protein: Wheat	Protein: Flour	Carotenoid: Wheat	Carotenoid: Unbleached flour	Carotenoid: Bleached flour	Particle-size index	Dough-ball time	Gassing power	Absorption	Bread: Loaf volume	Bread: Grain and texture	Bread: Crumb color	Cake: Loaf volume	Cake: Grain and texture	Cooky factor
Hard red spring:																				
Marquis	4158	34.1	61.7	71.0	0.47	11.4	10.6	2.46	1.72	0.78	13.1	225	235	60	687	87	82	904	73	5.08
White:																				
Baart	1697	35.6	62.6	70.6	.48	11.1	9.9	2.31	1.65	.63	27.6	53	322	55	653	80	80	969	99	5.15
White Federation	4981	34.8	61.6	70.8	.47	10.8	9.9	2.62	1.79	.74	15.1	208	334	62	672	87	78	864	72	4.56
Federation	4734	36.9	59.7	70.4	.46	9.7	8.5	3.58	2.69	.95	26.1	72	249	54	634	75	65	953	91	5.91
Onas	6221	39.9	60.0	70.2	.54	9.4	8.2	3.19	2.30	.78	30.3	137	259	54	638	76	67	969	97	5.41

[1] The irrigated grain used in these studies was grown at Aberdeen, Idaho, only in 1936, and at Aberdeen, Idaho, and Bozeman, Mont., in 1937, 1938, and 1939. It was not composited before milling, and the data for the latter years are averages of the results of the two stations.

The nonirrigated grain was grown as follows: 1936, at Pullman, Wash., Pendleton and Union, Oreg., and Moscow, Idaho; 1937, Pullman, Moscow, Pendleton, and Union; 1938, Pullman and Lind, Wash., and Pendleton, Oreg.; 1939, Pullman and Lind, Wash., and Pendleton, Oreg. In 1938 the grain from each station was milled and the flour baked separately. The data are averages of the results. In all other years the grain was composited by variety before milling, as noted for table 1.

[2] See footnote 2, table 1.

[3] Dockage free.

[4] Moisture-free basis.

[5] 13.5-percent moisture basis.

[6] Carotenoid content expressed as carotene parts per million; naphtha-alcohol extract.

[7] W/T, ratio of width to thickness.

[8] Not grown in 1938 and 1939. The data given are the averages for Federation for the full 4-year period plus the algebraic differences between the averages for Federation and for Dicklow or Lemhi, as the case may be, for 1936 and 1937.

TABLE 6.—*Yield and quality characteristics of varieties of spring wheat seeded in the fall in nonirrigated field plots at Davis, Calif.; averages 1936–38, inclusive*

Type and variety	C. I. No.[1]	Yield per acre	Test weight [2]	Flour yield [3]	Ash content of flour [4]	Protein content of [4]—		Carotenoid content of [5]—			Particle-size index	Dough-ball time	Gassing power	Absorption	Bread			Cake		Cooky factor
						Wheat	Flour	Wheat	Unbleached flour	Bleached flour					Loaf volume	Grain and texture	Crumb color	Loaf volume	Grain and texture	
White:		*Bu.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*P.p.m.*	*P. p. m.*	*P. p. m.*	*Pct.*	*Min.*	*Mm.*	*Pct.*	*Cc.*	*Score*	*Score*	*Cc.*	*Score*	*W/T*[6]
Ramona	8241	42.5	61.6	73.4	0.45	10.4	9.8	1.91	1.36	0.65	16.3	172	282	58	546	57	77	866	90	4.64
Bunyip	5125	39.8	61.9	74.5	.44	10.1	9.1	2.05	1.63	.62	17.9	79	235	57	576	73	78	898	90	4.76
Baart	1697	36.9	61.3	72.8	.56	9.8	8.7	2.22	1.77	.72	26.3	62	252	55	589	75	77	921	103	5.15
White Federation	4981	44.7	60.5	72.0	.54	9.2	8.2	2.46	1.80	.60	13.3	120	311	58	527	68	68	848	78	4.33
Federation	4734	37.8	57.5	72.4	.52	8.8	7.7	3.15	2.77	.79	28.3	56	232	55	546	65	53	904	98	5.43
White club (subclass):																				
Poso	8891	47.3	63.0	71.1	.46	10.3	9.2	2.26	2.02	.73	27.6	35	219	55	526	53	57	937	100	5.09

[1] See footnote 2, table 1.
[2] Dockage free.
[3] Moisture-free basis.
[4] 13.5-percent moisture basis.
[5] Carotenoid content expressed as carotene parts per million; naphtha-alcohol extract.
[6] W/T, ratio of width to thickness.

Because of space limitations, averages only are reported, and in order to avoid confusing the reader, those for the 4-year period only are given, except at Davis, Calif., which are for the 3-year period. A careful comparison of the 4- and 5-year averages, where both were available, revealed no important differences. Also, the comparative results for the different varieties for individual years were surprisingly alike.

A few varieties were grown for less than the 4-year period, or for various reasons data are not available. In such cases, interpolated values are given in the tables. They were derived by comparing the average for the available years with the average for the same period of a similar variety for which data are available for the full 4-year period. The data given in the tables are the averages for the 4-year period of the variety used for comparison plus the algebraic differences between the averages of the two varieties for the shorter period. The variety used as a basis for comparison is indicated in footnotes to the tables in each case. For the kind of data here considered, this method of interpolation is thought to be more reliable than others commonly used, as it involves no assumption other than that the variety being considered and the one with which it is compared respond alike to differences in season. As noted above, this appears to be a valid assumption for most of the data, even for dissimilar varieties. In the tables the varieties are arranged first as to market class and within each class from top to bottom according to decreasing protein content of the grain. The source of the grain in each case is indicated in footnotes to the tables.

Agreement Between Field and Nursery and Irrigated and Nonirrigated Tests

A comparison of varieties and of methods of evaluating them can be made to best advantage after considering the same varieties grown in different sets of plots and in different environments. As noted above, the 8 varieties of winter wheat in field plots were included also in the uniform nurseries. A comparison of 4-year averages of the yield and quality characteristics for the varieties grown under these 2 environments is shown in figure 1. Likewise, 15 varieties of spring wheat were grown both in the uniform irrigated and nonirrigated nurseries. Five of these also were grown in irrigated and nonirrigated plots, making possible a comparison of 4 sets of data for each of the latter varieties. The 4-year average results for the 15 varieties grown in irrigated and nonirrigated nurseries are compared in figure 2, and for the 5 varieties in irrigated and nonirrigated uniform nurseries and in field plots, in figure 3. These graphs are based on the data in tables 1 to 5.

The results from the different tests agree remarkably well considering the differences in the environments. In comparing the different sets of data, it should be remembered that the sources of variation are more numerous than may at first be apparent, especially with respect to the irrigated and nonirrigated grain. For example, such differences in quality characteristics as are evident in these figures are due not merely to irrigation and to the fact that the grain was or was not grown in nursery or field plots but in some cases at least to differences in location, soil type, and land management.

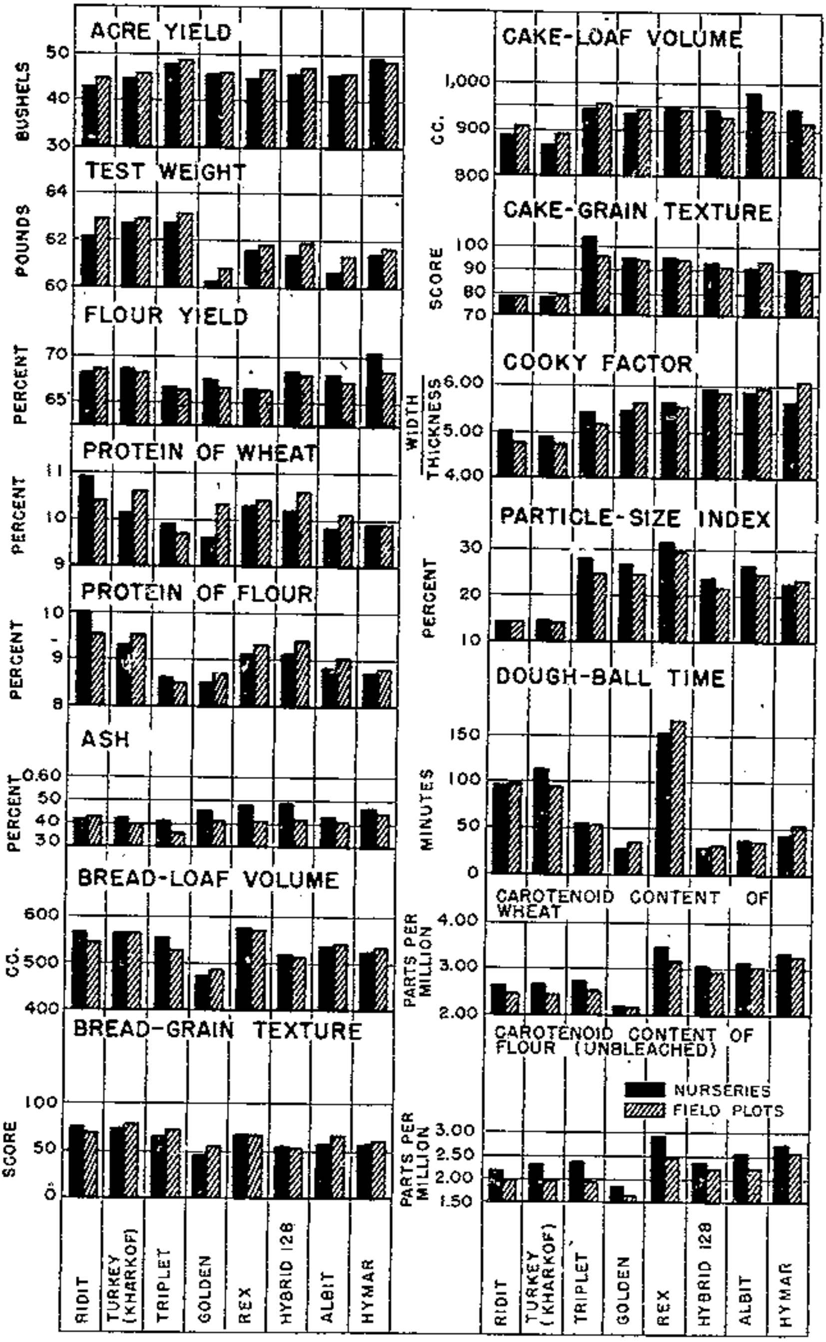


FIGURE 1.—A comparison of quality characteristics of eight varieties of winter wheat grown in field and nursery plots.

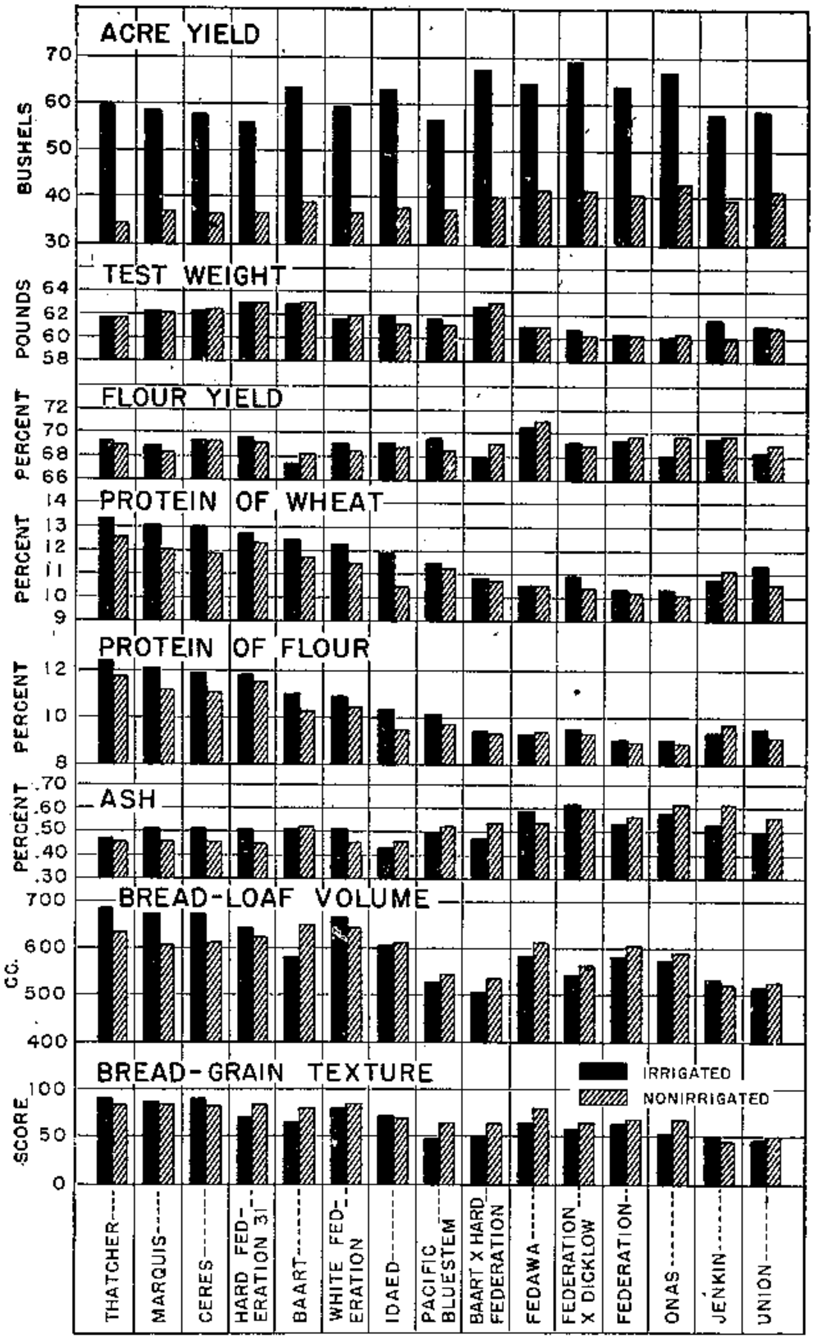
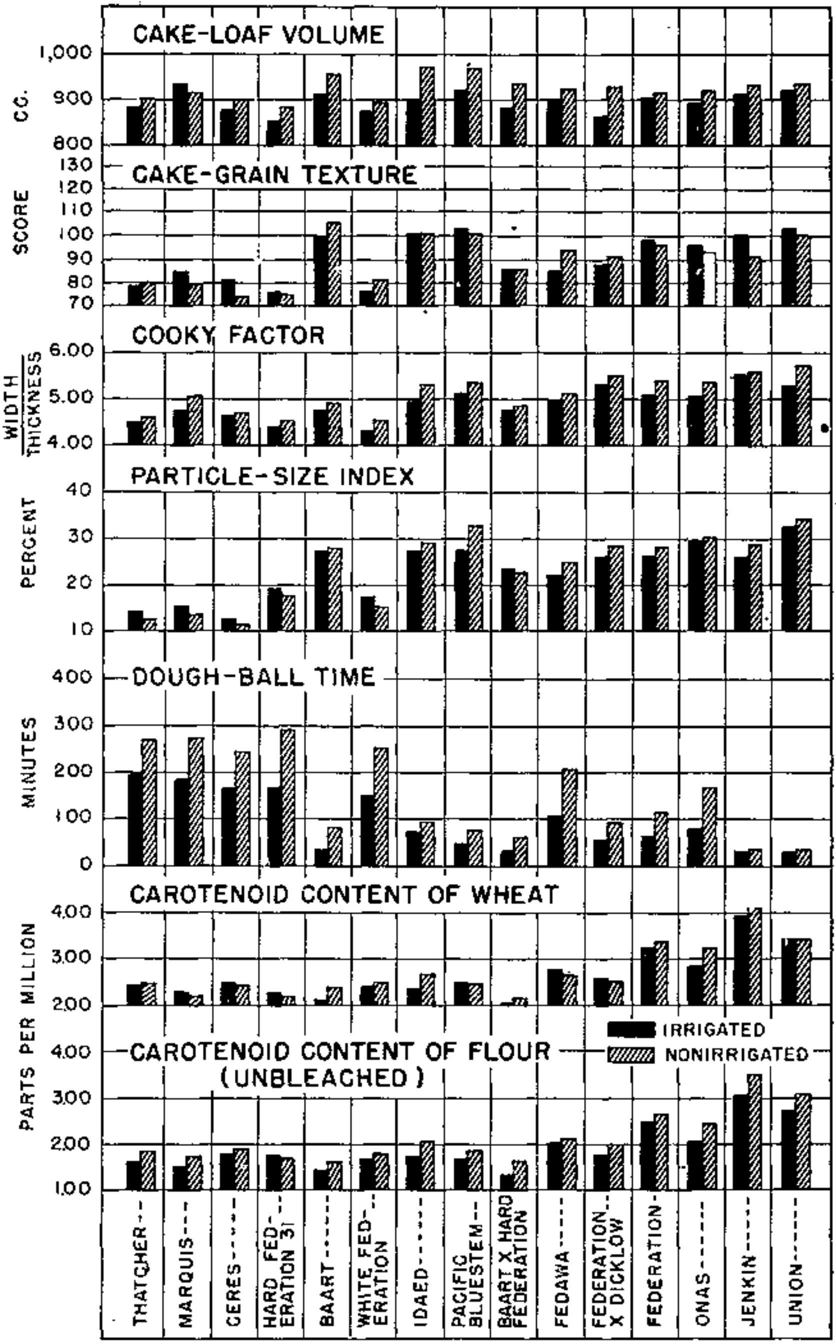


FIGURE 2.—A comparison of quality characteristics of 15 varieties of



spring wheat grown in irrigated and nonirrigated nursery plots.

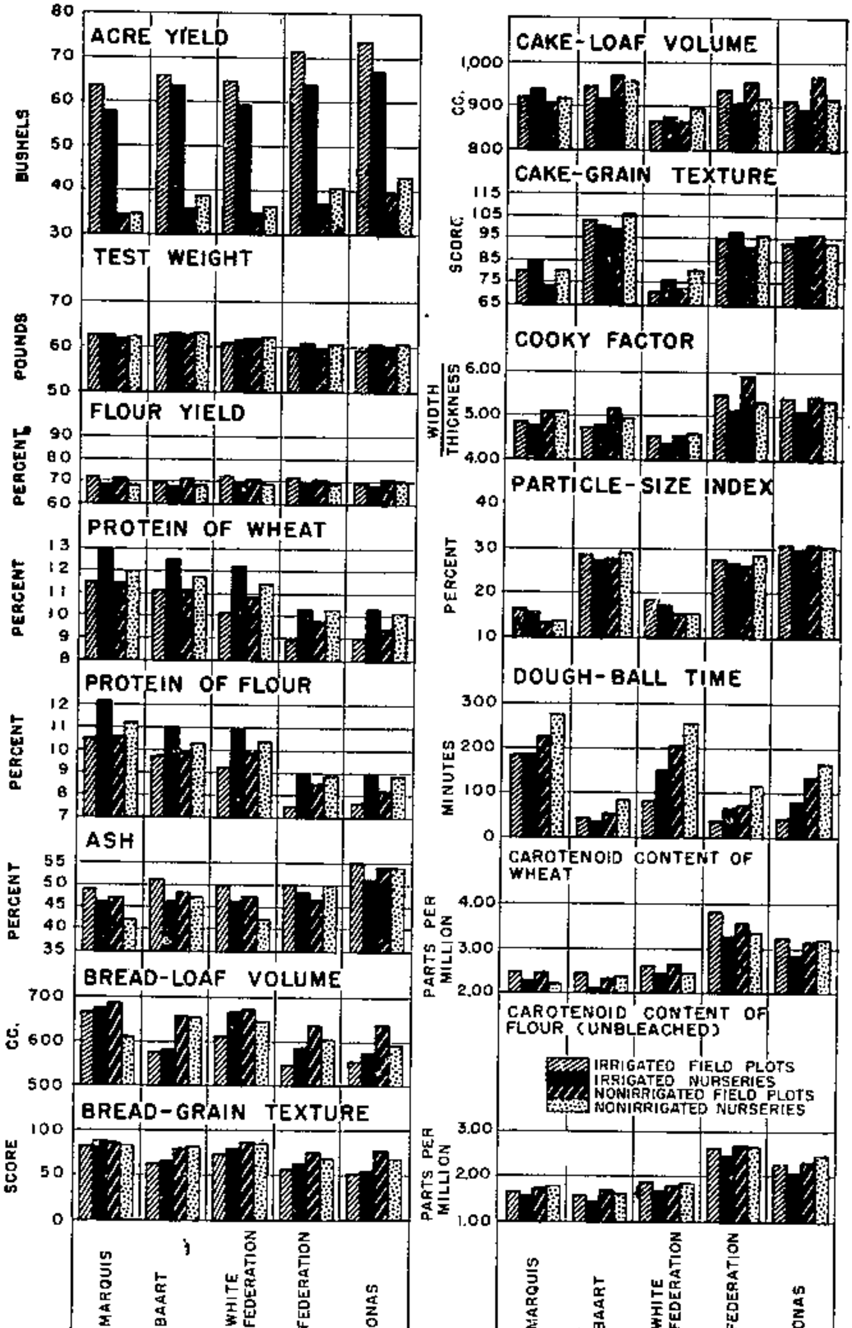


FIGURE 3.—A comparison of quality characteristics of five varieties of spring wheat grown on irrigated and nonirrigated field and nursery plots.

In view of the sources of variation, it seems doubtful whether any of the differences between the quality characteristics of field- and nursery-grown varieties of winter wheat for which data are presented in figure 1 are of any practical significance. The discrepancies with respect to the protein content of wheat and flour appear to be greater than those for other characteristics and are greater than it would seem reasonable to attribute to random laboratory errors; but they are not reflected, as would ordinarily be expected, in bread-loaf volume differences. It seems reasonable, therefore, to attribute them to the sum total of sampling errors, including field and laboratory determinations.

Somewhat greater and more numerous discrepancies are apparent for the spring wheat varieties for which data are given in figures 2 and 3, and some rather wide differences in protein content are evident. It is interesting to note that, contrary to usual expectations, the irrigated grain and its flour averaged slightly higher in protein content than that from the nonirrigated plots.

The bread-baking data (loaf volumes and grain-and-texture scores) also indicate that there is a differing response of varieties to the conditions represented by the two sets of data. Thus, irrigated grain of the hard spring varieties (Thatcher, Marquis, Ceres, Hard Federation 31, and White Federation) produced somewhat better loaves than the nonirrigated grain, whereas the reverse was true for most of the soft varieties. This difference may be explained in part but not entirely by differences in protein content, which, in turn, are in part due to differences in yield. The bread quality of Baart seems to have been adversely affected by irrigation. This will be discussed in greater detail later. Altogether it appears that the differences in bread quality, as between spring varieties grown in the irrigated and nonirrigated nursery plots, can be partly but not entirely explained by differences in protein content and this in turn partly, but not entirely, by differences in yield.

There can be little doubt that dough-ball time is affected by the environmental conditions here represented and that varieties respond very differently in this respect. Dough-ball time for the hard spring wheats averages 75 to 100 minutes longer for the nonirrigated than for the irrigated plots, whereas the difference for the soft varieties tends to be less and for some is clearly within the limits of random errors.

There is some evidence of differential response with respect to test weight, carotenoid content of the grain and unbleached flour, and ash content of flour, but the differences, if any, are small and unimportant so far as the present study is concerned.

The data presented in figure 3 are of special interest, since they represent four different sets of plots: Irrigated and nonirrigated field plots and irrigated and nonirrigated nurseries. The data for the nursery-grown varieties represented in figure 3 are the same as those for the nursery-grown varieties represented in figure 2, but are reproduced in figure 3 to permit a comparison of all four sets of plots. As previously noted, the environmental conditions of the wheat grown in the four types of plots were very different. This is indicated by the rather marked differences in yield and in certain other characteristics, especially the protein content of grain and flour and the dough-ball time.

622670°—45——3

With few exceptions, however, these differences appear to have affected all five varieties substantially alike. The wheat and flour protein of Marquis and Baart are relatively higher for the irrigated field plots than for other varieties, but the differences, especially for Baart, have not been reflected in loaf volume of the bread. The average loaf volume of Marquis in the nonirrigated nurseries is low in relation to other varieties. It was less than that of Baart in 3 of the 4 years (data not shown). The marked differential response between the varieties with respect to dough-ball time indicated in figure 2 is rather generally lacking in the data presented in figure 3, probably because of the fewer varieties represented. In general, the results from the plots for which data are submitted in figure 3 substantiate the results presented in figure 2 in indicating that most varietal characteristics are relatively much the same, regardless of how the varieties are grown.

The very general agreement between the various sets of data for most of the determinations is, of course, fortunate from the viewpoint of varietal characterization and evaluation. It means that varieties can be reliably evaluated from either field-plot or nursery-grown samples and, for the most part, regardless of whether grown on irrigated or nonirrigated land. It also means that a comparison of averages in the present study is a valid procedure, except for those cases in which there is clear-cut evidence of differential response. It would seem to indicate, also, that differences between varieties recorded in these studies may be expected to prevail generally for most of the conditions where the varieties are likely to be grown.

Comparison of Varieties of Winter Wheat

The varieties of winter wheat grown in the western United States represent 3 commercial classes: Hard red winter, soft red winter, white, and the subclass white club. Of the 18 varieties studied, all but one (Rex M2) are grown commercially in the area and all but three (Rex M2, Athena, and Elgin) are grown rather extensively.

Hard red winter wheat, as grown in the area, is used mostly for bread. The bread-, cooky-, and cake-baking data presented in tables 3 and 4 indicate, as would be expected, that this is the proper use for this kind of wheat. None of the six varieties produced satisfactory cakes or cookies, and all have a low particle-size index (indicating large flour particles), which, as will be indicated later, appears to be a very reliable indication of poor pastry qualities. In this respect the hard and the soft winter wheats are very distinct, since the highest particle-size index for the hard wheats in the nursery plots, for example, is 16.3 for Rio, as compared with 22.7 for Hymar, the lowest for the soft wheats.

The hard wheats as a group averaged high in test weight, although no higher than the semihard variety, Triplet; also slightly higher in protein content of grain and flour, gassing power, and long with respect to dough-ball time. The protein differential as between grain and flour is less for the hard wheats; that is, more of the protein is retained in the flour of the hard than in the soft wheats.

Of the varieties of hard red winter wheats, the two strains of Turkey (C. I. 6175 and 1442) and Rio produced the best loaves of bread on the average. Ridit appears to be substantially equal to Turkey.

The relatively low loaf volume of Relief can be explained by a lower average protein content of grain and flour, but neither of these lower protein contents explains the low bread-loaf volume of Oro. Since all varieties were comparably grown, it must be assumed that the low protein of Relief and the low loaf volumes of Relief and Oro are inherent in the varieties themselves and are expressed when grown under the conditions of these experiments. It is of interest to note, however, that Oro grown in the Great Plains compares favorably in bread-loaf volume with other hard winter varieties. Relief, it should be noted, is consistently high in carotenoid content of the wheat and of unbleached flour, and generally produces bread with a distinct yellow color (not shown in the tables). Rio and Oro appear to be relatively low in carotenoid content of grain and unbleached flour.

All the soft winter wheats produced satisfactory cakes and cookies, and some of them seem to be about as good for bread as the hard wheats at the same level of protein. For example, Rex in the field plots (table 4) and Rex M1 and Rex M2 in the nursery plots (table 3) had the highest average loaf volumes of any variety, including the hard wheats. The bread grain-and-texture scores were relatively low, however, suggesting that the high volumes were obtained at the expense of internal loaf quality. Even so, it seems likely that these varieties are not greatly inferior to the hard wheats for bread. Triplet also produced bread nearly equal to the hard wheats in loaf volume, although somewhat inferior in grain-and-texture scores; and Albit with a slightly lower flour protein content appears to be about equal to Relief. The remaining varieties produced poor bread, which it appears can be attributed in part though not entirely to a low protein content. Golden and Goldcoin, for example, produced loaves with the lowest average volume and grain-and-texture scores of any variety, although they were not the lowest in protein content. The differences in quality characteristics for these last two varieties are very consistent from year to year.

Although all varieties of soft wheat produced satisfactory cakes, some appear to be somewhat better in this respect than others. Triplet, as judged by the grain-and-texture scores, produced the best cakes of any variety, both in the plot and nursery trials and consistently so in the latter. Hymar, Hybrid 128, and Albit were generally poor in cake quality, although in the 1939 field-plot tests they were rated with the best. The remaining varieties appear to be equal in cake quality within the limits of experimental error.

The best cookies on the average were made from Jenkin, which was included in the nursery plots only, and from Albit and Hybrid 128 in both field and nursery plots. These three varieties appear to be distinctly better than most others for this purpose, although the difference, as compared with Rex and Hymar especially, is probably not significant.

Although the differences in particle-size index do not appear to be consistent among the hard wheats, they are very marked among the soft; the index for Hymar, for example, is 22.7, as compared with 34.3 for Rex M1. Rex and its near relatives, Rex M1 and Rex M2, are exceptions in several respects; although very soft they are characterized by a long dough-ball time, a relatively high protein content, and bread-loaf volume similar to the hard wheats. Possibly the high particle-size index of Rex is associated with or is the cause of the "fluffy" nature of the flour and the difficulty encountered in bolting that is often complained of by millers.

The semihard variety Triplet, as previously noted, averages with the hard wheats in test weight, being considerably superior in this respect to the true soft wheats, with the exception of Rex M1, which is nearly as good. Golden and Athena, especially, tend to be low.

The flour yields of Triplet, Golden, and Rex, both in field-plot and nursery tests, appear to be distinctly low, whereas those of Hymar, Jenkin, and Elgin (grown in nursery tests only) appear to be distinctly high.

The ash content of the flour is unusually and characteristically low for Triplet, both in field and nursery plots. This in part can be attributed to the lower flour yield already noted. Other varieties, including Rex, however, which were also low in flour yield, are not low in ash, and some of those, including Elgin, which were high in flour yield, are not conspicuously high in ash. The consistency of some of these differences suggests they are definite varietal characteristics, but since all lots of grain were milled on an experimental mill the differences should not be emphasized until verified by commercial experience.

Differences in carotenoid content of the wheat and unbleached flour are especially marked. Jenkin averages the highest in carotenoid content with Rex M2, Rex, Hymar, and Rex M1 not far below. Those having the least carotenoid pigment are Golden, Goldcoin, and Elgin. Bleaching reduced these pigments to a satisfactory level, although a tendency is evident for the high carotenoid pigment of the grain and unbleached flour of certain varieties to carry over into the bleached flour. There are rather marked and characteristic differences in gassing power of the soft wheats, but their significance, if any, is unknown.

Comparison of Varieties of Spring Wheat

All but 1 of the varieties of spring wheat included in this study fall into 2 market groups: Hard red spring and white, including white club. These are represented by 3, 17, and 3 varieties, respectively. The hard red springs, of course, are characterized by hard grain, as also are some of the common white varieties, principally Hard Federation 31, White Federation, and some of the newer hybrids. Baart is usually classed as semihard or hard, though the grain has many of the characteristics of a soft wheat.

Most of these varieties were grown both in irrigated and nonirrigated nursery plots and five of them in irrigated and nonirrigated field plots. As pointed out above, all appeared to respond alike to environmental conditions, except that the dough-ball time of all varieties except Jenkin, Lemhi, and Union was reduced by irrigation and also that the bread-loaf volume of irrigated Baart was considerably lower than that of nonirrigated Baart. This latter difference may be of some importance from a breeding point of view, although it probably should not be emphasized until more clearly established. Since, with these exceptions, quality characteristics were much alike for the different tests, the discussion of varietal characteristics will be based largely on averages of all tests.

The hard red spring wheats like the hard winters are regarded primarily as bread wheats. The data obtained in these studies are in accord with this usage. It appears, however, that the generally superior bread produced from them (tables 1, 2, and 5), as compared with most other varieties, is due mostly to their higher protein content, which in turn appears to be largely a result of relatively low yields. The white varieties with hard or semihard grain, Hard Federation 31, White Federation, and Baart, averaged somewhat higher than the soft wheats in protein content and also produced better bread. Baart was fully equal to the hard red spring wheats when grown without irrigation, but for some unknown reason it has been consistently poor when grown under irrigation. Very poor bread was produced by all the soft varieties, but the protein content also was very low—well below that usually considered necessary for good bread. Of the well-known or standard varieties, the poorest bread was made from Jenkin and Union, although they were not the lowest in flour protein. Idaed and Fedawa, on the other hand, produced somewhat better bread than their relatively low protein content would suggest. It appears, therefore, that while most of the differences in bread quality can be explained by differences in protein content, this probably is not true for the four last-mentioned varieties.

In general, poor cakes and cookies were made from the hard wheats and good or at least satisfactory cakes and cookies from the soft wheats. This is in agreement with the particle-size indexes, the commercial usage of these varieties, and also with the results reported above for winter wheat. Baart produced good cakes, but the cookies from this variety on the average were no better than those from Marquis.

Of the soft and semihard varieties, Baart, Pacific Bluestem, Idaed, and Union were the best for cakes, and rather consistently so. Attention is called to the fact that good cakes were made from Baart, which in the nonirrigated plots and nurseries also produced excellent bread. The cake grain and texture for Fedawa fluctuated considerably from year to year, both in the irrigated and nonirrigated tests, and averaged about the same as other soft wheats except that whereas most of them were somewhat better from irrigated land, Fedawa from the nonirrigated plots was best. Additional studies will be necessary to determine whether there is any real difference in these respects. Neither of the new varieties Baart × Hard Federation or Federation × Dicklow was outstanding. Lemhi, which was grown in irrigated nurseries in all years and in irrigated plots for 3 years only, appears to be equal to Dicklow, one of its parents.

Of the well-known varieties, Jenkin appeared to be superior for cookies to all others included in both the irrigated and nonirrigated nurseries but not consistently better than Dicklow, which was grown under irrigation only. Lemhi averaged slightly inferior to Dicklow, although the difference is neither great nor consistent.

Baart was substantially equal to the highest or had the highest average test weight of all varieties and with few exceptions was equal to the highest in this respect in all plots and in every year. The hard wheats tended to have higher test weights than the soft or semihard varieties, though the differences are neither so great nor so consistent as might be expected. Of the varieties grown in all plots, Federation and Onas averaged lowest and, excepting Dicklow and Lemhi, which were grown in irrigated plots and nurseries only, and Pilcraw and Hard Federation × Dicklow (C. I. 11427), grown in the irrigated nurseries only, tended to be the lowest of all varieties. Lemhi was rather consistently higher than Dicklow in test weight.

Fedawa averaged highest in flour yield of all varieties in both irrigated and nonirrigated nurseries and was consistently high in all years. Pilcraw and Jenkin × Ridit, grown only in the irrigated nurseries, were among the highest three in flour yield. Other differences appear to be well within the limits of experimental error.

Some of the differences in ash content are greater than can readily be explained by random errors. Fedawa, Federation × Dicklow, Onas, and Jenkin averaged highest. High flour yield is a possible explanation for the high ash of Fedawa but does not explain the others. Idaed, on the other hand, was consistently low in ash and averaged lowest of all varieties both in irrigated and nonirrigated nurseries; the flour yield was low but no lower than for some others. It seems probable that there are inherited differences in spring as well as in winter wheats with respect to flour ash, but further studies will be necessary to determine whether they are real or due to experimental errors incidental to techniques necessarily used with small lots of grain.

Jenkin and Union were high in carotenoid pigments both in the grain and in the unbleached flour, with Federation, Onas, and Pilcraw not far below. Baart, especially, was low, as also were Lemhi, Dicklow, and Baart × Hard Federation (C. I. 11615). All varieties bleached to a satisfactory level.

There were marked differences between varieties in dough-ball time, as was true for the winter wheats. Varietal response to the diverse environmental conditions was, however, quite different, as noted above. Dough-ball time for most varieties was much longer for the nonirrigated than for the irrigated grain, except for the two varieties Jenkin and Union. The hard spring wheats tended to have longer dough-ball time than the soft wheats, though Fedawa and Onas, both soft wheats, averaged high.

The gassing power of spring wheat was affected very little by environment. There were consistent differences between varieties, as was found for the winter wheats, but in contrast with the latter there appears to be no consistent relation between gassing power and hardness of grain. The significance of the differences, if any, is not known.

Varieties in California

Although six varieties included in these studies grown uniformly for each of 3 years at Davis, Calif., were true spring wheats, they were grown from late fall seeding, as is the common practice in California. Three of them—Baart, White Federation, and Federation—grown throughout the region were included, but the other three—Ramona, Bunyip, and Poso—were grown in the California tests only. The data are presented in table 6.

The general characteristics of the grain and flour were much the same as for the spring varieties. Yields and test weight were high and protein content low. Bread quality therefore was poor, though on a par with wheat grown elsewhere with comparable protein content.

Baart, though not the highest in protein content, produced the highest average loaf volumes and grain-and-texture scores, and was the highest every year except for Bunyip in 1938. White Federation and Poso were the poorest. The differences with respect to relative bread quality were rather consistent from year to year, but the period of testing was too short to permit final conclusions.

Baart and Poso produced the best cakes, though they probably were not significantly different from Federation. Reasonably good cookies were made from Federation and passable cookies from Baart and Poso. Cookies made from the other varieties were poor. The particle-size determinations are in accord with these evaluations especially with respect to the indicated value for cakes.

Bunyip and Ramona averaged high in flour yield, though probably they were not significantly different from the others, with the possible exception of Poso, which was consistently low. Ash content was generally high, especially for Baart and White Federation. Because of the experimental milling techniques used in these studies the differences in their yield and quality characteristics should not be regarded too seriously.

Carotenoid pigments were high in Federation, low in Ramona and Bunyip, and intermediate in Baart and Poso. Considering the similarity of varietal responses in these wheats and other tests noted, these differences must be regarded as indicative of inherited characteristics.

A relatively long dough-ball time appears to be characteristic of White Federation and Ramona and a short time for Poso. Gassing power was much the same for all varieties, though White Federation averaged higher than any other variety and was higher than most varieties every year; Poso tended to be low.

Commercial Utilization and Experimental Characterization of Varieties

A consideration of the commercial uses made of the various varieties in relation to their characteristics as revealed in these studies is of interest. Unfortunately, reliable information as to such use of specific varieties is not generally available except for a very few. Crawford (*4*) has recently assembled the available information as to many of the characteristics considered likely to limit their utility and has made certain recommendations as to the probable value of certain varieties for specified uses. These recommendations are based in part on the general experience of commercial milling chemists of the Pacific Northwest, in part on the data here included, and in part on data previously reported in mimeographed form by the writers of this bulletin. His conclusions, therefore, are not entirely independent of those given above. Also it should be repeated that, whereas the data in this publication are for varieties grown under strictly comparable conditions, this is not true of those that reach the terminal markets. Since environment is known to have a very marked effect on wheat quality, especially with respect to protein content and test weight, perfect or even good agreement between experimental data and commercial experience should not be expected if these differences are not taken into account.

The hard red winter wheats of the region are used mostly for bread, and the soft wheats generally but not exclusively for cakes, crackers, cookies, and other pastries. If sufficiently high in protein, or more likely if blended with high-protein hard wheats, the soft wheats may be used for family-trade flour, which means they may be used for bread also. The experimental data are in agreement with this usage.

As to the commercial utility of different varieties of the hard red winter wheats, there appears to be little information available. Turkey is highly regarded. Rio is often marketed as Turkey and apparently is considered its equal. Ridit is regarded as satisfactory, but according to Crawford (*4*) not so good as Turkey, and the limited data for Oro indicate it is not equal to Turkey. The slightly lower protein content, deficient loaf volume, and yellow color of bread from Relief, as shown in the experimental trials, appear to have been recognized by the trade.

None of the soft winter wheats are rated by Crawford as good for bread. All are grown in the more humid parts of the area and are generally lower in protein than the hard winter wheats, which are grown in the drier areas. The experimental data indicate that at equal protein levels Triplet is about equal to the hard winter wheats for bread, as also is Rex. For pastry purposes the commercial cereal chemists rate Rex as somewhat inferior to Goldcoin. The experimental data indicate that Rex makes poorer cakes than Goldcoin but indicate no significant differences in cooky quality.

Albit is rated by commercial chemists as superior to Hybrid 128 for cake and cookies, but no consistent differences were noted in the experimental tests. The particle-size index, however, is higher for Albit, which is in accord with the commercial rating. Hymar is also rated above Hybrid 128 for cake, according to commercial chemists but not in the experimental trials.

Of the spring wheat varieties included in the present study, Marquis, Baart, White Federation, and Pacific Bluestem are regarded primarily as bread wheats; Baart is highly regarded as a cake flour also, but according to Crawford (*4*) is only fair for cookies. Pacific Bluestem is generally rated for bread as inferior to Baart. These various ratings are in accord with the experimental data. White Federation is often regarded as a poor milling wheat in California, where it is principally grown. The objection to it seems to apply to the milling rather than to the characteristics of the flour. No milling difficulties in White Federation were observed in this study. Some mills, it has been reported, do not object to its milling properties but do not like it for bake-shop use. Crawford (*4*) reports that limited data indicate it to be unsatisfactory for these purposes. The grain of this variety is very hard and would probably be found objectionable by some millers who normally mill soft wheat, even though not by others.

Dicklow has long been highly regarded for making pastry flour, and Lemhi is being accepted as a satisfactory replacement for Dicklow. This acceptation is in accord with the experimental data. The yellow flour of Federation and Jenkins, as indicated by the high carotenoid content, has long been known to the trade. Whether the apparently superior characteristics of Jenkin for cookies is recognized in commercial channels is not known. So little is now grown commercially that it probably loses its identity before it gets to the bakeries.

If the differences in protein content caused by differences in environment and probable experimental errors are accounted for, the experimental data indicate that the commercial uses of the various classes and varieties essentially are in accordance with the findings of the study. This, of course, is encouraging support for the belief that the methods that have been used are at least reasonably satisfactory and that reliable characterization and evaluation of new varieties by similar methods may be expected.

Interrelations of Quality Characteristics

A knowledge of the interrelations of quality character in wheat is helpful in a study of characteristics and in evaluating varieties. Correlation coefficients have been calculated for all the interrelations it is desired to consider in detail, and scatter diagrams with regression lines (figs. 4, 5, and 6) are presented for a few of the more interesting and important ones. These calculations, based on the 5-year averages, include only the nursery data, since the number of varieties in field plots was too small. Even for the nurseries the numbers involved are very small.

In this bulletin only the coefficients "within years" are presented. Others, i. e., "within varieties" and "residual" were calculated for the spring wheat nursery, and all with one unimportant exception were found to be less than the corresponding "within years" coefficients; generally they were much lower and frequently indicated no significant correlation. This result would be expected in the light of the similarity of most of the various determinations for different years, as previously pointed out.

For these coefficients separate calculations were made each year for 25 pairs of characteristics each for the irrigated and nonirrigated spring wheat and for the winter wheat nurseries. There were thus 75 sets of coefficients altogether, each set including coefficients for each of 4 or 5 years according to the data available. The coefficients of each set were then tested by means of the z test, to determine whether they differed significantly from each other. At the 5-percent level there was a significant difference between the coefficients for different years in only 3 of the 75 sets compared. Since this is no more than would be expected as a result of random fluctuations, all of each set were regarded as belonging to the same population, and new correlation coefficients were calculated from the averages of the 4 or the 5 years, as the case might be. These coefficients are given in table 7. Scatter diagrams with regression lines and regression equations are presented in figures 4 to 6 for what are believed to be the more important relations.

These coefficients and the regression equations must be interpreted cautiously, and especially so when considered individually. Each set includes varieties from widely different market classes and hence the data cannot be regarded as strictly homogeneous. With certain exceptions, to be mentioned later, however, they appear to be sufficiently homogeneous for the purpose of the present study. The numbers in each set entering into the calculations are small and the use of composites made up of different numbers of samples for the different years might be expected to interfere slightly with conventional statistical tests. Whatever may be said of these methods, it is apparent that the correlation coefficients and regression lines provide a convenient way of summarizing and reducing the data to the point where they can be visualized and discussed. For this purpose and to indicate some of the broader relations, there appears to be no satisfactory substitute.

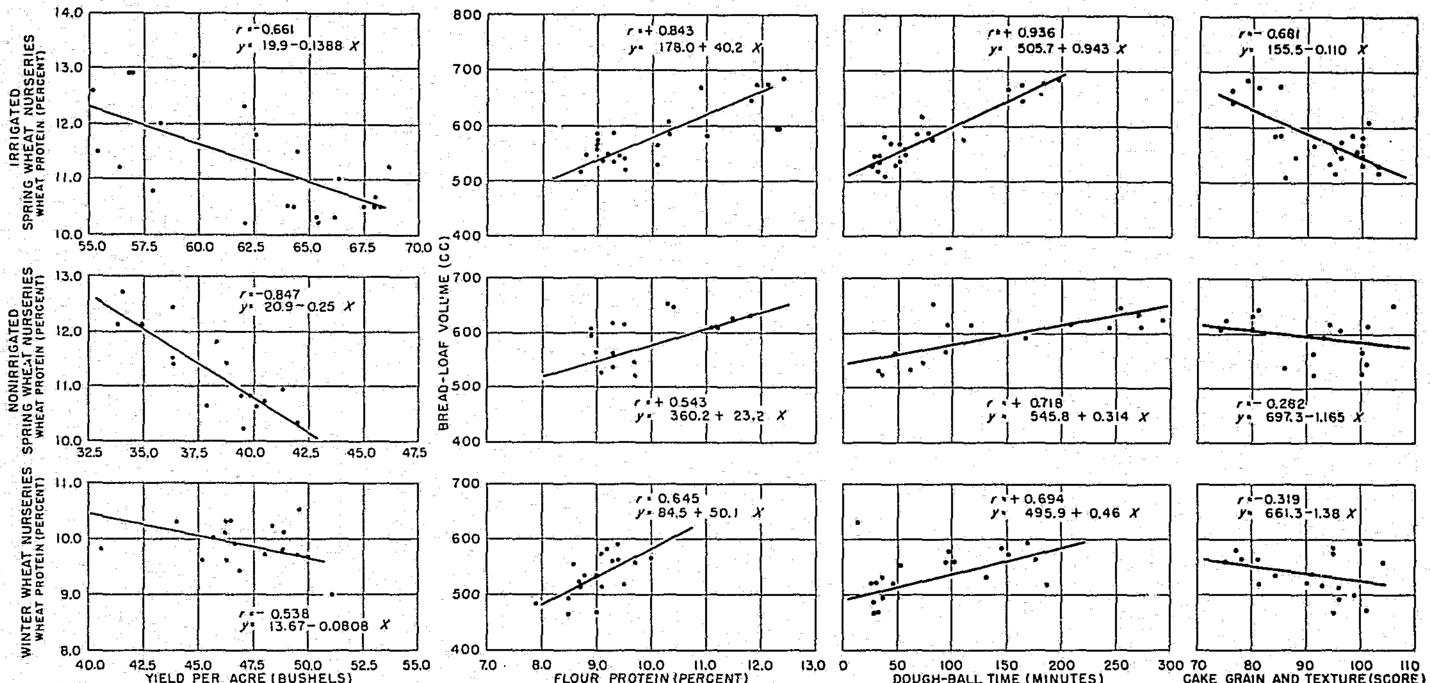


FIGURE 4.—Scatter diagrams and regression lines for wheat protein and yield per acre and for bread-loaf volume and flour protein, dough-ball time, and cake grain and texture; each for the irrigated spring wheat nursery, the nonirrigated spring wheat nursery, and the winter wheat nursery, for the 5-year period 1935–39.

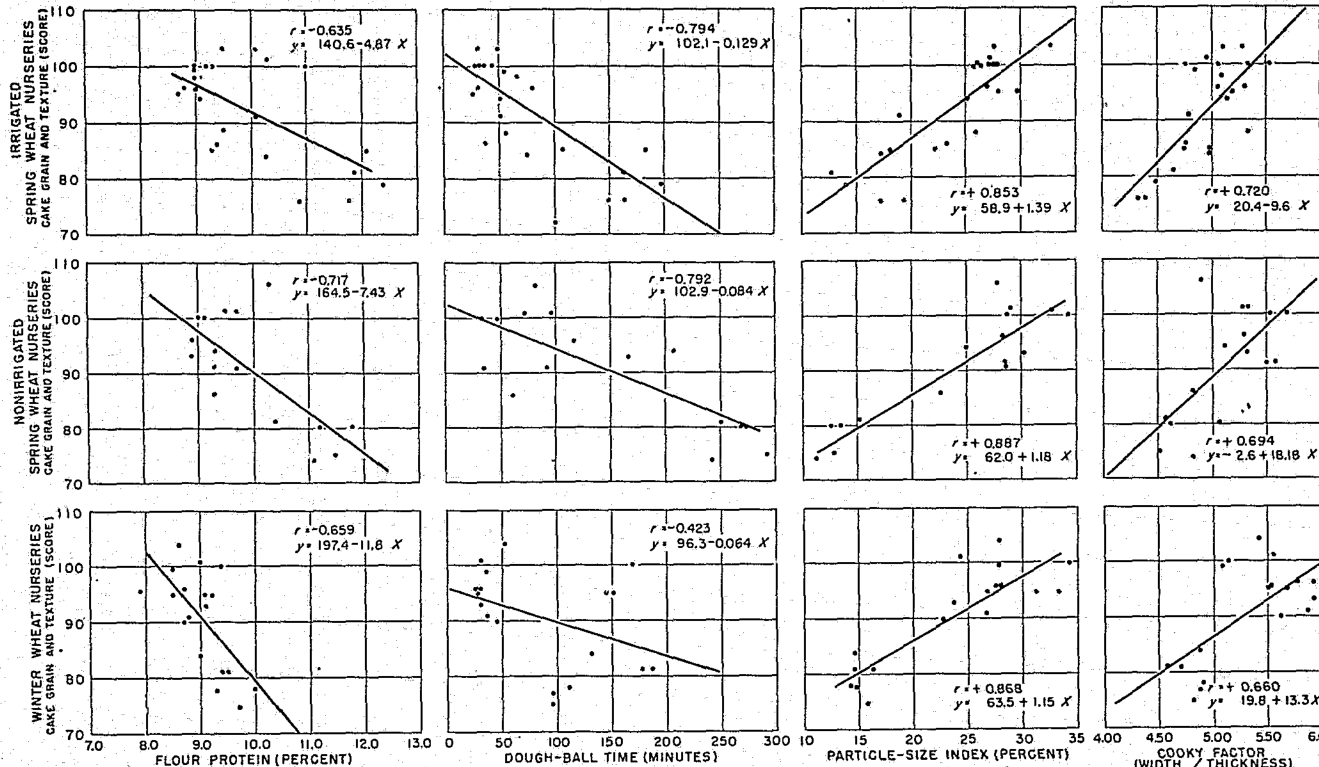


FIGURE 5.—Scatter diagrams and regression lines for cake grain and texture and for flour protein, dough-ball time, particle-size index, and cooky factor; each for the irrigated spring wheat nursery, the nonirrigated spring wheat nursery, and the winter wheat nursery, for the 5-year period 1935–39.

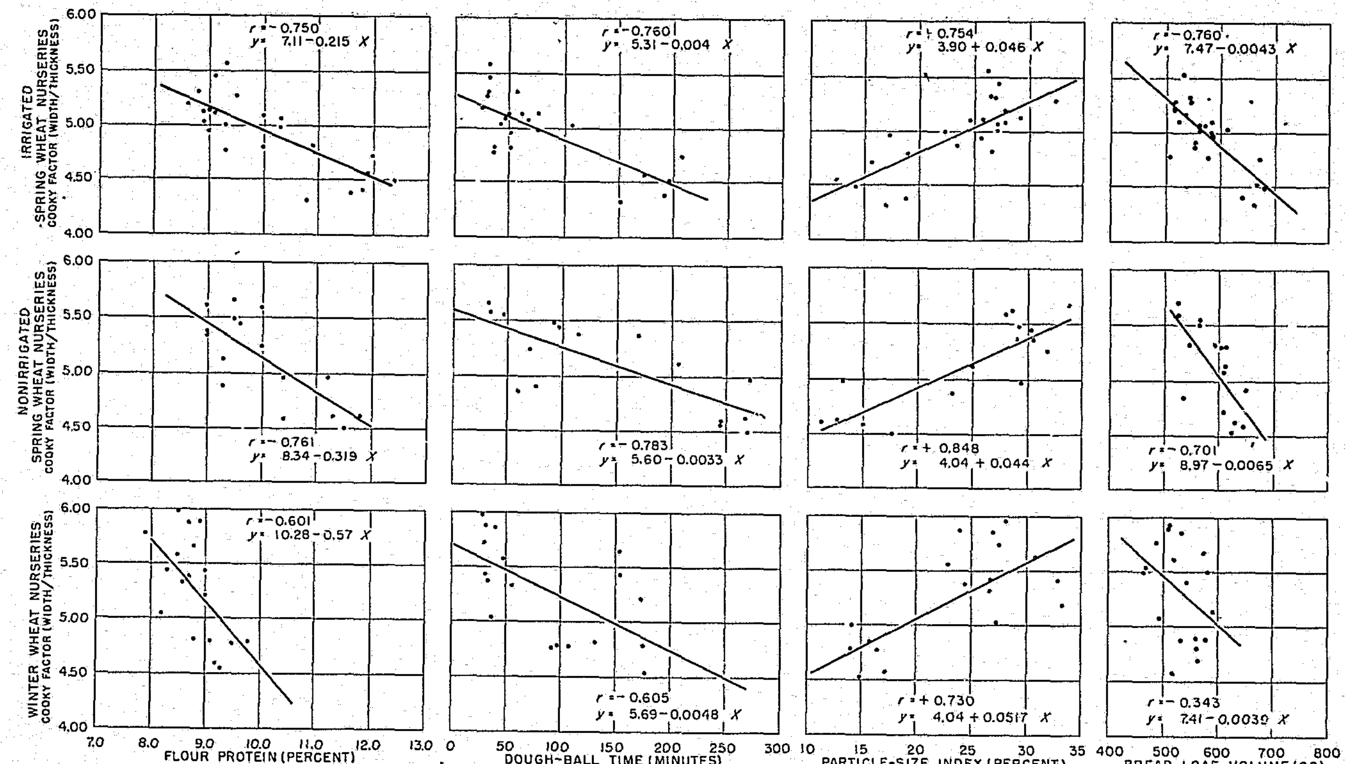


FIGURE 6.—Scatter diagrams and regression lines for cooky factor and flour protein, dough-ball time, particle-size index, and bread-loaf volume: each for the irrigated spring wheat nursery, the nonirrigated spring wheat nursery, and the winter wheat nursery, for the 5-year period 1935–39.

TABLE 7.—*Correlation coefficients*[1] *for various quality characteristics for varieties of spring and winter wheat (based on averages for 4 or 5 years)*

Quality character and nursery	Yield per acre	Protein content of flour	Loaf volume of bread	Dough-ball time	Particle-size index	Cake grain and texture	Cooky factor	Gassing power	Carotenoid content of grain	Test weight
Protein content of grain:	*Bu.*	*Pct.*	*Cc.*	*Min.*	*Pct.*	*Score*	*W/T*[2]	*Mm.*	*P. p. m.*	*Lb.*
Irrigated spring wheat nursery	−0.661	+0.986	+0.805	+0.777	−0.709	−0.562	−0.723	------	------	------
Nonirrigated spring wheat nursery	−.847	+.967	+.454	+.589	−.732	−.620	−.721	------	------	------
Winter wheat nursery	−.538	+.955	+.698	+.683	−.373	−.439	−.572	------	------	------
Protein content of flour:										
Irrigated spring wheat nursery	------	------	+.843	+.849	−.780	−.635	−.750	------	------	------
Nonirrigated spring wheat nursery	------	------	+.543	+.719	−.812	−.717	−.761	------	------	------
Winter wheat nursery	------	------	+.645	+.604	−.542	−.659	−.601	------	------	------
Loaf volume:										
Irrigated spring wheat nursery	------	------	------	+.936	−.787	−.681	−.760	+0.443	------	------
Nonirrigated spring wheat nursery	------	------	------	+.718	−.565	−.282	−.701	+.583	------	------
Winter wheat nursery	------	------	------	+.694	−.010	−.319	−.343	+.501	------	------
Dough-ball time:										
Irrigated spring wheat nursery	------	------	------	------	−.824	−.794	−.760	------	------	------
Nonirrigated spring wheat nursery	------	------	------	------	−.850	−.792	−.783	------	------	------
Winter wheat nursery	------	------	------	------	−.202	−.423	−.605	------	------	------
Particle-size index:										
Irrigated spring wheat nursery	------	------	------	------	------	+.853	+.754	------	------	------
Nonirrigated spring wheat nursery	------	------	------	------	------	+.887	+.848	------	------	------
Winter wheat nursery	------	------	------	------	------	+.868	+.730	------	------	------
Cake grain and texture:										
Irrigated spring wheat nursery	------	------	------	------	------	------	+.720	------	------	------
Nonirrigated spring wheat nursery	------	------	------	------	------	------	+.694	------	------	------
Winter wheat nursery	------	------	------	------	------	------	+.660	------	------	------
Carotenoid content of unbleached flour:										
Irrigated spring wheat nursery	------	------	------	------	------	------	------	------	+0.972	------
Nonirrigated spring wheat nursery	------	------	------	------	------	------	------	------	+.978	------
Winter wheat nursery	------	------	------	------	------	------	------	------	+.967	------
Flour yield:										
Irrigated spring wheat nursery	------	------	------	------	------	------	------	------	------	−0.009
Nonirrigated spring wheat nursery	------	------	------	------	------	------	------	------	------	−.027
Winter wheat nursery	------	------	------	------	------	------	------	------	------	−.168

[1] The first figure for each pair of characteristics is for the irrigated spring wheat nursery (N=23), the second for the nonirrigated spring wheat nursery (N=16), and the third for the winter wheat nursery (N=18). All coefficients except for a few varieties involving bread-loaf volume, cake grain and texture, gassing power, and carotenoid pigments are based on averages for 4 years; all others for 5 years. Coefficients above 0.41 for the irrigated spring wheats, above 0.50 for the nonirrigated spring wheats, and above 0.47 for the winter wheats differ significantly from zero at the 5-percent level. Corresponding coefficients above 0.53, 0.62, and 0.59 are significant at the 1-percent level.

[2] W/T, ratio of width to thickness.

Of the 75 coefficients in table 7, only 12 are below the level of significance at the 5-percent level. These include the coefficients for test weight and flour yield in all 3 nurseries. As previously pointed out, high test weight is generally characteristic of the region under discussion, and in the present study all lots of grain with very low test weights were excluded. As a result, the range is much less than that which in other circumstances might be expected and the correlation coefficients are low, no doubt largely for this reason. All coefficients for the irrigated spring wheats, except that for flour yield and test weight, are significant at the 5-percent level. For the nonirrigated spring wheats those for flour yield and test weight, loaf volume of bread and grain and texture of cake, and for protein content of grain and loaf volume of bread are below the level of significance.

Eight of the 25 coefficients involving winter wheat are below the level of statistical significance. These are for protein content of grain, correlated with particle-size index and with cake grain and texture; loaf volume of bread, correlated with particle-size index, with cake grain and texture, and with cooky factor; dough-ball time, correlated with particle-size index and with cake grain and texture; and flour yield, correlated with test weight. Also, the statistically significant coefficients for winter wheats tend to be smaller than the corresponding coefficients for spring wheats. The tendency toward higher coefficients for spring as compared with winter wheats may be the result of the generally greater range in values for the characteristics that are correlated, due in turn to including in the spring wheat nurseries a number of varieties not well adapted to the region.

PROTEIN CONTENT AND YIELD OF GRAIN

Protein content of grain and yield of grain are negatively correlated, the coefficients in all three nurseries being statistically significant. The lowest coefficient is for winter wheat, only about 29 percent of the variation being accounted for in this case, as compared with about 72 percent for the nonirrigated spring wheat. This probably is due to the greater range in protein content and yield of the spring wheat varieties for the reasons mentioned above.

It is apparent that not all the differences in protein content can be attributed to grain yield. This appears to be especially true for the winter wheat and to a lesser degree for the nonirrigated and irrigated spring wheat. In general, it appears that the hard wheats, both spring and winter, tend to have a protein content slightly higher than would be expected from the regression equations and the soft wheats generally less, although there are exceptions. Also, early-maturing varieties with light vegetative growth tend to have a higher protein content.

Whether these explanations are entirely valid must await more exact and comprehensive studies. The data are of interest chiefly in suggesting that, although varieties differ in their protein content, this difference may be partly but not entirely explained by differences in yield. An understanding of this relation seems necessary to a logical interpretation of varietal quality insofar as it is related to protein content, and particularly so as a basis for a logical breeding program designed to improve varietal quality.

PROTEIN CONTENT OF GRAIN AND OF FLOUR

The coefficients for protein content of grain and of flour are high, as would be expected, considering that a part is being correlated with the whole.

It is perhaps more important to learn whether the differential between wheat and flour protein is the same for all varieties. Calculations showed that the average percentage of protein in the flour of all varieties, both hard and soft, was 1.33 percent lower than the grain protein for the irrigated spring wheat, 1.16 lower for the nonirrigated spring wheat, and 1.06 percent lower for the winter wheat varieties. Comparing the hard and the soft varieties, it was found that in each nursery a smaller proportion of the protein of the grain is retained in the flour of the soft wheats than in the flour of the hard wheats. For example, the average difference between the protein content of the grain and the flour of the hard wheats in the irrigated spring wheat nursery was 1.16 percent, as compared with a difference of 1.40 percent for the soft wheats; that is, the loss of protein during milling was greater in the soft wheats.

CAROTENOID CONTENT OF GRAIN AND OF FLOUR

The coefficients for carotenoid content of grain and flour are extremely high for the same reason that protein content of grain and flour are highly correlated. The relationship is so close that determinations of both grain and flour may not be necessary as a guide to selection in breeding. In all cases the carotenoid content of the flour was materially less than that of the grain. The loss was not precisely the same for all varieties, but the differences in most cases were small and probably of no practical importance. The flour of Rex M1 is considerably lower in carotenoid content than that of Rex M2 or Rex, partly because of the lower carotenoid content of the wheat, but also apparently because more is removed in milling. These differences, although larger than can be readily explained by errors in determination, are more interesting than important, since, as pointed out elsewhere, bleaching removes the excess pigment to a satisfactory degree in all the varieties studied. It should be remembered also, as pointed out by Fifield and others (*8*), that carotenoid content is considerably influenced by the conditions under which the crop is grown, and this influence is probably different for different varieties.

RELATIONS INVOLVING BREAD-LOAF VOLUME

Since loaf volume is usually the best single measure of bread quality, it is of interest to note the relations between loaf volume on the one hand and protein content of the flour, dough-ball time, particle-size index, and gassing power on the other.

The correlation coefficients for loaf volume and flour protein (table 7) (0.843, 0.543, and 0.645) for the irrigated spring wheats, the nonirrigated spring wheats, and the winter wheats, respectively, all differ significantly from zero, but it is apparent that only a part and in some cases only a small part of the variation in loaf volumes (about 29.5 percent in the nonirrigated spring wheats) can be explained by differences in protein content. The corresponding coefficients for loaf volume and dough-ball time (0.936, 0.718, and 0.694) are of the same general order, but in each case are slightly or somewhat higher. The variations in loaf volumes accounted for by dough-ball time are 87.6, 51.6, and 48.2 percent, as compared with 71.1, 29.5, and 41.6 percent by flour protein, or gains of 16.5, 22.1, and 6.6 percent for irrigated spring wheat, nonirrigated spring wheat, and winter wheat, respectively.

The relation between dough-ball time and loaf volume for Oro in winter wheat and Baart in nonirrigated spring wheat appears to be different from that of other varieties. Oro has a long dough-ball time, but in these studies has been characterized by comparatively low loaf volumes. Baart, on the other hand, has a relatively short dough-ball time but in the nonirrigated nurseries has the highest average loaf volume of any variety. Omitting these varieties raises the coefficient for winter wheats (from 0.694 to 0.811) and for nonirrigated spring wheats (from 0.718 to 0.864).

Since dough-ball time and flour protein are themselves correlated, it is of interest to determine whether their relations to loaf volume are independent or due wholly or in part to the relation of each to the other. This question is answered by the partial coefficients of table 8. The partials for loaf volume and flour protein with dough-ball time constant were found to be 0.684, 0.010, and 0.358 for the three sets of varieties, the first mentioned being the only one statistically significant. Similarly, the coefficients for loaf volume and dough-ball time with flour protein constant are 0.879, 0.560, and 0.476. The first two are statistically significant at the 5-percent level and the third just below the level of significance. Omitting Baart in the nonirrigated spring wheat and Oro in the winter had no material effects on the coefficients for loaf volume and flour protein, either with or without dough-ball time constant. Omitting them, however, does result in a considerable increase in the partial coefficients for loaf volume and dough-ball time. With flour protein constant, for example, they were increased from 0.560 to 0.818 for the spring wheats and from 0.476 to 0.897 for the winter wheats. The relation between loaf volume and flour protein and between loaf volume and dough-ball time, therefore, are apparently determined to some extent by the relation between flour protein and dough-ball time.

The coefficients for loaf volume and gassing power barely reached the level of statistical significance in all three sets of plots, and hence gassing power appears to have little to offer by way of evaluating varieties.

TABLE 8.—*Partial coefficients for selected variables of spring and winter wheat* [1]

Kind of wheat and constant	Bread-loaf volume and—					Cake grain and texture and—				Cooky factor [2] and—		
	Flour protein	Dough-ball time	Particle-size index	Cooky factor	Cake grain and texture [2]	Flour protein	Dough-ball time	Particle-size index	Cooky factor	Flour protein	Dough-ball time	Particle-size index
Irrigated spring wheat:	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*
Zero order [3]	+0.843	+0.936	−0.787	−0.760	−0.681	−0.635	−0.794	+0.853	+0.720	−0.750	−0.760	+0.754
Flour protein constant	----	+.879	−.338	−.363	−.351	----	−.627	+.746	+.477	----	−.353	+.409
Dough-ball time constant	+.684	----	−.110	−.241	+.291	−.144	----	+.584	+.306	−.305	----	+.348
Particle-size index constant	+.573	+.824	----	−.462	−.031	+.108	−.323	----	+.310	−.392	−.372	----
Dough-ball time and flour protein constant	----	----	+.359	−.120	+.538	----	----	+.618	+.352	----	----	+.276
Nonirrigated spring wheat:												
Zero order [3]	+.543	+.718	−.565	−.701	−.282	−.717	−.792	+.887	+.694	−.761	−.783	+.848
Flour protein constant	----	+.560	−.239	−.527	+.182	----	−.543	+.752	+.330	----	−.524	+.607
Dough-ball time constant	−.010	----	+.119	−.341	+.671	−.287	----	+.667	+.227	−.457	----	+.555
Particle-size index constant	+.152	+.545	----	−.494	+.576	+.108	−.157	----	+.131	−.233	−.225	----
Dough-ball time and flour protein constant	----	----	+.130	−.312	+.698	----	----	+.636	+.060	----	----	+.351
Winter wheat:												
Zero order [3]	+.645	+.694	−.010	−.343	−.319	−.659	−.423	+.868	+.660	−.601	−.605	+.730
Flour protein constant	----	+.476	+.466	+.089	+.185	----	+.004	+.829	+.430	----	−.380	+.602
Dough-ball time constant	+.358	----	+.208	+.212	−.039	−.558	----	+.876	+.559	−.371	----	+.780
Particle-size index constant	+.737	+.710	----	−.456	−.625	−.530	−.469	----	+.194	−.357	−.684	----
Dough-ball time and flour protein constant	----	----	+.458	+.331	+.208	----	----	+.837	+.466	----	----	+.717

[1] The levels of significance for the partial coefficients at the 5-percent level are 0.42 for the irrigated spring wheats, 0.51 for the nonirrigated spring wheats, and 0.48 for the winter wheats. At the 1-percent level they are 0.54, 0.64, and 0.61, respectively.

[2] These partial coefficients can be calculated directly from the zero order coefficients given in this and the preceding table; not all the others can be so calculated since they are based on 4 years' data, whereas some of the zero order coefficients are for 5 years.

[3] The zero order coefficients are the same as those in table 7. They are repeated here for the convenience of the reader.

Loaf volumes were found to be negatively correlated (table 8) with particle-size index, the coefficients (−0.787, −0.565, and −0.010) being statistically significant for the spring wheat but not for the winter wheat. Their prediction value appears to be less than for the corresponding coefficients for loaf volume and dough-ball time and loaf volume and flour protein. When protein content or dough-ball time were held constant, all were below the level of significance, although holding both constant at the same time resulted in coefficients two of which attained the level of significance and all of which were positive as to sign.

Since the characteristics most highly correlated with bread-loaf volume are dough-ball time and protein content of flour, it is of interest to determine whether variations in loaf volume can be more completely accounted for by combining dough-ball time and flour-protein content by means of the multiple-correlation technique. The coefficients (R) of table 9 are 0.967, 0.718, and 0.740, respectively, for the three sets of plots. They account for 93.5, 51.7, and 54.8 percent of the variation in loaf volume, or a gain over the zero order coefficients with dough-ball time alone of 5.9, 0.1, and 6.6 percent, and over flour protein alone of 22.4, 22.1, and 13.2 percent.

TABLE 9.—*Multiple coefficients for selected variables of spring and winter wheat*

Kind of wheat	Bread-loaf volume—dough-ball time and flour protein	Cake grain and texture and—: Flour protein and particle-size index	Particle-size index and dough-ball time	Particle-size index and cooky factor	Flour protein and dough-ball time	Cooky factor and flour protein	Flour protein, particle-size index, and dough-ball time	Cooky factor and—: Particle-size index and flour protein	Particle-size index and dough-ball time	Flour protein and dough-ball time	Particle-size index, flour protein, and dough-ball time
	R	R	R	R	R	R	R	R	R	R	R
Irrigated spring wheat	+0.967	+0.858	+0.870	+0.869	+0.799	+0.738	+0.878	+0.707	+0.793	+0.785	+0.761
Nonirrigated spring wheat	+.718	+.889	+.890	+.859	+.811	+.753	+.893	+.856	+.856	+.833	+.863
Winter wheat	+.740	+.907	+.899	+.874	+.659	+.721	+.911	+.770	+.867	+.673	+.868

Taken at their face value, these data suggest that dough-ball time is a better index of loaf volume than is flour protein and that both taken together provide a somewhat better index than either one alone. Tending to offset this is the thoroughly established and well-known relation between loaf volumes and protein content of the flour and the lack of such well-established relations for loaf volumes and dough-ball time; also the greater expense and time necessary to make the dough-ball determination and the fact that protein determinations are made for other purposes and are usually part of the laboratory routine, whereas dough-ball time determinations are not.

Especially to be considered is the fact, noted above, that the general relation for dough-ball time and loaf volume apparently does not hold for all varieties, noticeably the spring wheat Baart and the winter wheat Oro. Other investigators have reported similar exceptions. It would appear that so long as exceptions such as these cannot be satisfactorily explained, dough-ball time cannot be regarded as a dependable index of bread-quality characteristics, no matter what the relation may be in general. Neither should it be disregarded. Dough-ball time might be very useful to a plant breeder for identifying good and poor bread-quality segregates from a cross between certain parents of known bread-quality and dough-ball time characteristics. Without this latter knowledge its value would seem to be questionable.

The relations considered in this study, it should be noted, are for varieties of wheat grown under strictly comparable conditions. In the studies with spring wheat, irrigation tended to reduce the dough-ball time for most but not all varieties, without a corresponding reduction in loaf volume. This indicates that the relations shown in these studies would not hold if varieties were not grown under strictly comparable conditions.

BREAD-LOAF VOLUME, COOKY FACTOR, AND CAKE GRAIN AND TEXTURE

It is often assumed that varieties of wheat suitable for bread are not satisfactory for pastry purposes and vice versa. This assumption is borne out by the fact that the coefficients for loaf volume of bread and cake grain-and-texture score and cooky factor, shown in table 7, were negative as to sign. Three of the six coefficients, however, are below the level of significance, the highest (that for bread-loaf volume and cooky factor for the irrigated spring wheats) being only −0.760. Of the six partial coefficients, holding flour protein constant (table 8), only one reached the level of statistical significance, and the same is true when dough-ball time is held constant. Only two of them attain the level of statistical significance when both flour protein and dough-ball time are held constant at the same time, and these two are variable as to sign. It would appear, therefore, that such relations as exist between bread-loaf volume and cake grain and texture and between bread-loaf volume and cooky factor can be satisfactorily explained by differences in protein content and dough-ball time.

These results are in accord with those already noted, that several varieties appear to be satisfactory either for bread or pastry purposes, depending upon the protein content of the flour. Thus Baart produced excellent bread and good cakes. Triplet in general was the best or among the best for cakes and cookies and produced good bread. Good cakes and cookies were made from the very soft variety Rex and also bread nearly equal to that from the hard wheats.

RELATIONS INVOLVING COOKY FACTOR

The characteristic most highly correlated with cooky factor is particle-size index, the coefficients (table 7) being 0.754, 0.848, and 0.730 for the three sets of varieties. Holding flour protein constant resulted in coefficients of 0.409, 0.607, and 0.602, and holding dough-ball time constant in coefficients of 0.348, 0.555, and 0.780. Holding both flour protein and dough-ball time constant at the same time gave coefficients of 0.276, 0.351, and 0.717. Five of the nine partials are statistically significant. Contrariwise, the six coefficients for cooky factor and flour protein and for cooky factor and dough-ball time, with particle-size index constant, are with one exception below the level of significance.

All the data are in agreement in indicating that cooky factor is more closely related to particle-size index than to either of the other two variables, but nevertheless it is not entirely independent of the others.

Including flour protein with particle-size index resulted in multiple coefficients (table 9) of 0.797, 0.856, and 0.770, and including dough-ball time with particle-size index in coefficients of 0.793, 0.856, and 0.867. Including the three independent variables gave coefficients of 0.761, 0.863, and 0.868. These latter account for 57.9, 74.5, and 75.3 percent of the variability in cooky factors, as compared with 56.9, 71.9, and 53.3 for particle-size index alone. These represent gains of 1.0, 2.6, and 22.0 percent.

RELATIONS INVOLVING CAKE GRAIN-AND-TEXTURE SCORES

Cake grain-and-texture scores also are more highly correlated with particle-size indexes than with other determinations. The coefficients (table 7) are 0.853, 0.887, and 0.868 for the three sets of varieties. Those with dough-ball time for the spring wheats are fairly high (−0.794, −0.792) and statistically significant, although not for the winter wheats (−0.423); and those with flour protein are statistically significant for all three sets of varieties, although not sufficiently high (−0.635, −0.717, and −0.659) to offer much promise for prediction purposes.

The partial coefficients for cake grain and texture and particle-size index, holding flour protein constant, are 0.746, 0.752, and 0.829 (table 8), and the corresponding coefficients, holding dough-ball time constant, were 0.584, 0.667, and 0.876. Holding both flour protein and dough-ball time constant at the same time gave coefficients of 0.618, 0.636, and 0.837. All these partials are statistically significant. Five of the six coefficients, with particle-size index constant, are below the level of significance and the sixth barely reaches the level of significance.

The multiple coefficients for cake grain and texture, flour protein, and particle-size index were found to be 0.858, 0.889, and 0.907. Replacing flour protein with dough-ball time gave coefficients of 0.870, 0.890, and 0.899, and including the three independent variables with cake grain and texture resulted in coefficients (R) of 0.878, 0.893, and 0.911. The percentages of the variability accounted for by the latter are 77.3, 79.7, and 83.0, as compared with 72.8, 78.7, and 75.3 percent for particle-size index alone. These figures represent gains of 4.5, 1.0, and 7.7 percent for irrigated spring wheat, nonirrigated spring wheat, and winter wheat, respectively.

The data for cake grain and texture, like those for cooky factor, show that particle-size index is more closely related to pastry qualities than are flour protein and dough-ball time; that particle-size index is to a considerable degree independent of dough-ball time and flour protein; and that only a slight gain in prediction values may be expected by making use of dough-ball time and flour protein in addition to particle-size index by means of the multiple-correlation technique.

Particle-size index appears to be more closely related to cake grain and texture than it is to cooky factor, as shown not only by the higher zero order coefficients but also by the higher partial coefficients obtained when other variables are held constant. This is in agreement with the fact discussed in the next paragraph, that cooky factor is not a very reliable index of cake quality.

CAKE GRAIN AND TEXTURE AND COOKY FACTOR

Cookies are more easily made than cakes and can be evaluated by objective measurements, whereas cake quality is to some extent a matter of opinion. The coefficients between cooky factor and cake grain-and-texture scores are therefore of interest. All of these coefficients, as shown in table 7, are statistically significant and range from 0.660 for the winter wheat to 0.720 for the irrigated spring wheat. Only slightly more than 50 percent of the variability in cake-and-texture scores is accounted for in the case of the irrigated spring wheat. This indicates that the factors responsible for good cookies are responsible only in part for good cakes; also, that while cookies may be used in a general way to indicate cake quality, they are by no means a reliable index. A striking example of this latter is the variety Baart, which generally makes excellent cakes but only fair-to-poor cookies.

An interesting result is obtained when cake grain-and-texture scores and cooky factor are correlated with particle-size index, flour protein, or dough-ball time held constant, singly or together. Of the twelve partial coefficients so obtained (table 8), only two reach the level of significance. All, however, are positive in sign. The failure of so many of these partials to reach the level of significance indicates that the reason most varieties that make good cakes also make good cookies is that they are similar as to particle-size index, dough-ball time, and flour protein. The fact that some of them are significant and that all are alike as to sign suggests that there are pastry characteristics yet to be accounted for.

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