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Protein and Lysine Content of Grain, Endosperm, and Bran of Wheats from the USDA World Wheat Collection

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ABSTRACT

The effects of relative amounts and the protein and lysine concentrations of kernel components on whole grain protein and lysine in wheat (*Triticum aestivum* L.) were studied. Wheats from the USDA World Wheat Collection that differed in whole grain protein and lysine content were compared. The correlation of grain protein with endosperm protein was r = 0.98, showing that whole grain protein percentages accurately reflect endosperm protein content in wheat. The correlation of grain and endosperm lysine percentages was lower. Endosperm percent protein had the largest effect on grain lysine content of any of the factors tested. The combined effect of percent of bran, bran percent protein, and bran lysine (% of protein) on whole grain lysine content was as great as the effect of endosperm lysine (% of protein). Wheats with high grain lysine content do not always have high endosperm lysine content. Differences were detected among the wheats studied for endosperm and bran protein and lysine content.

Additional index words: ***Triticum aestivum*** **L., Protein quality, Starchy endosperm, Amino acid.**

SIGNIFICANT genetic differences in whole grain protein and lysine concentrations exist among common wheats (*Triticum aestivum* L.) in the USDA World Wheat Collection (14, 15). Part of the variability in grain lysine concentration among wheats in the USDA World Wheat Collection was attributable to variation in grain protein concentration (14, 15). Lysine expressed as a percent of sample was positively correlated with percent protein, while lysine expressed as a percent of protein was negatively correlated with percent protein. By applying regression procedures to adjust lysine values to mean protein levels, valid lysine comparisons were made among wheats differing in protein content. After adjustment for percent protein, lysine (% of sample), and lysine (% of protein) provided the same relative measure of lysine (15).

Wheat bran (including the aleurone layer) and germ are higher in protein and lysine concentrations than the starchy endosperm (7, 12). Variation in the proportion of bran may account for differences in grain protein and lysine concentrations among wheat cultivars.

Most of the breeding and genetic research involving the protein and lysine concentrations of wheat has been done using whole grain samples. Many societies eat only the endosperm or white flour of wheat. The purpose of this study was to determine if lysine variability among wheats other than that attributable to variation in protein concentration is due to variation in the amount of endosperm or to variation in the lysine concentration of the endosperm. For brevity, the term "endosperm" refers to the starchy endosperm and the term "bran" refers to all kernel components of wheat grain except the starchy endosperm.

MATERIALS AND METHODS

Six hundred wheats representing the range in grain protein and lysine in the USDA World Wheat Collection (14) were investigated. These wheats were grown in an irrigated nursery at Yuma, Ariz. during the 1972-73 growing season in 1.8-m single row plots spaced 51 cm apart. Nitrogen in the amount of 112 kg/ha was applied. Field design was an augmented randomized, complete block (3) with six check cultivars replicated four times. World Collection wheats were not replicated.

Whole grain protein and lysine results from the study have been reported (15). Wheats selected for protein and lysine analyses of endosperm and bran were among either the high or the low 30 for grain percent protein, lysine (% of protein), lysine (% of protein) adjusted for percent protein, or for lysine (% of protein) adjusted for percent protein and test weight. Some of the cultivars were in more than one of these categories. Including check entries, 153 samples were selected and analyzed. The wheats studied were spring and winter cultivars of various market classes.

Endosperm samples obtained by conventional milling are not satisfactory for determining endosperm percentages or for precise endosperm protein and lysine comparisons among wheats. Wheats of different hardness mill differently, producing different yields of flour and bran.

Milling differences also affect protein concentration of endosperm because the outer portions of the endosperm are higher in protein concentration than the interior of the kernel (2, 10, 16). Milling differences probably also affect lysine percentages of endosperm since lysine is a constituent of protein.

A modified milling procedure was used to separate endosperm and bran (16). The wheat samples were not scoured prior to milling. After conventional milling, the endosperm remnants adhering to the bran were removed by washing with a 80:20 (vol/vol) ethanol:acetone solution, filtered, oven dried, and added to the mill flour to reconstitute the endosperm. In this procedure, the germ is part of the bran. Little loss of kernel components or component protein occurs in this procedure and it is more rapid than manual dissection. Twenty-gram samples of the selected cultivars were fractionated into their endosperm and bran components.

Endosperm, bran, and grain samples were brought to uniform moisture levels in a controlled humidity cabinet (8). Samples were then weighed on a dry weight basis for protein and lysine analyses. Results of all analyses are expressed on a dry weight basis. Macro-Kjeldahl procedure AACC method 46-12 (1) was followed for determination of nitrogen concentration of the samples. Protein content was computed as percent N × 5.7. Ion exchange chromatography was used to determine lysine concentration of the samples (9). Lysine (% of protein) values were determined by dividing lysine (% of sample) values by protein (% of sample).

Endosperm dry weight (dwt), endosperm percent of sample, and percent of kernel protein and lysine in the endosperm were computed with the following equations:

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1. Endosperm (dwt) = mill flour (dwt) + bran flour (dwt).
2. % endosperm of sample = {endosperm (dwt)/[endosperm (dwt) + bran (dwt)]} × 100.
3. % of kernel protein in endosperm = {endosperm protein (g)/[endosperm protein (g) + bran protein (g)]} × 100.
4. % of kernel lysine in endosperm = {endosperm lysine (g)/[endosperm lysine (g) + bran lysine (g)]} × 100.

Regression analyses were used to study the effect of endosperm and bran protein content on their respective lysine contents and the relative effects of endosperm and bran protein and lysine content on whole grain lysine content. Linear, quadratic, cubic, and multiple regression models were tested.

Endosperm, bran, and grain lysine values were adjusted to population mean protein levels using regression procedures. As an example, the equation used for adjusting endosperm lysine (% of protein) to the mean endosperm protein level was: $Yi\ adj = Yi - b\ (Xi - \overline{X})$. The b value is the regression coefficient; Yi, the measured lysine (% of protein) of the ith endosperm sample; Xi, the protein content of the ith sample; and $\overline{X}$, the population protein mean.

Grain lysine (% of protein) values were also adjusted for percent protein and percent endosperm of test weight. The adjustment equation, which included test weight, was derived from regression analysis of the entire nursery and was reported previously (15).

The check cultivars were subjected to analysis of variance procedures for the randomized, complete block design to obtain estimates of experimental error and the standard error of a treatment mean.

Standard partial regression coefficients, which gave an indication of the relative importance of the independent variables (13), were computed for some of the regression equations.

RESULTS

The mean protein, lysine (% of protein), and lysine (% of sample) percentages of the bran from the World Collection wheats were much higher than those of the endosperm and whole wheat samples (Table 1). Whole grain samples were higher in protein and lysine concentration than the endosperm samples because of the high protein and lysine content of the bran. The difference between whole grain and endosperm protein percentages was small.

Endosperm percent protein was highly correlated with whole grain percent protein (Table 2). The correlation of grain percent protein with percent endosperm of sample was negative, i.e., as percent endosperm of sample increased, the protein content of the whole grain sample decreased. Grain lysine (% of sample) and grain lysine (% of protein) were positively correlated with their respective endosperm and bran lysine percentages. Grain lysine (% of sample) was negatively correlated with percent endosperm. Within each fraction, lysine (% of sample) was positively correlated with percent protein, but lysine (% of protein) was negatively correlated with percent protein.

Table 3 provides a summary of the regression models tested. Within each group of samples, the linear models for the regression of lysine (% of sample) and lysine (% of protein) on percent protein provided the best fit. Eighty-one percent of the variability for endosperm lysine (% of sample) that existed among cultivars could be attributed to variation of endosperm protein, while only 31% of the variation for endosperm lysine (% of protein) could be attributed to endosperm protein variation.

Table 1. Means, range values, and standard deviations for whole grain, endosperm, and bran protein and lysine values of wheats grown in the World Wheat Collection Special Study nursery at Yuma, Ariz. in 1973.†

Variable	Mean	Range	SD
% protein			
Whole grain	16.4	11.2 to 21.0	2.29
Endosperm	16.1	10.8 to 21.0	2.43
Bran	19.0	13.1 to 25.1	2.40
Lysine (% of sample)			
Whole grain	0.47	0.37 to 0.60	0.059
Endosperm	0.39	0.29 to 0.50	0.050
Bran	0.83	0.46 to 1.14	0.107
Lysine (% of protein)			
Whole grain	2.90	2.52 to 3.37	0.214
Endosperm	2.45	2.14 to 3.08	0.166
Bran	4.40	3.23 to 4.97	0.286

† Bran includes the germ. Results are for 129 World Collection Wheats plus six checks replicated four times.

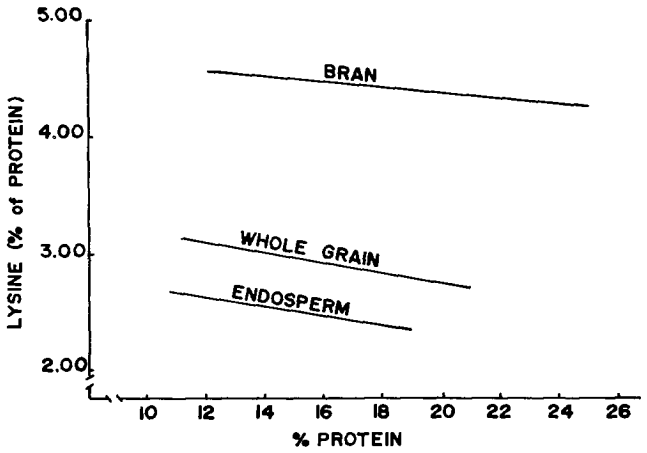

Fig. 1. Linear relationship of % protein and lysine (% of protein) for whole grain, endosperm, and bran of wheats from the 1973 World Wheat Collection Special Study nursery.

The coefficient of determination for the regression of grain lysine (% of sample) on grain protein and percent endosperm is slightly larger than the coefficient of determination for its linear regression on grain protein alone. Percent endosperm has a small but significant effect on grain lysine (% of sample) after taking into account variability due to variation in protein. Although the correlation of percent endosperm and grain lysine (% of protein) was not significant, percent endosperm did have a significant effect on grain lysine (% of protein) when included in a multiple regression model with grain protein.

Linear regressions of lysine (% of protein) on percent protein of whole grain, endosperm, and bran samples of the World Collection wheats are shown in Fig. 1. The length of regression lines reflects the range in protein values for each group of samples.

Standard partial regression coefficients for the regression of grain percent protein on endosperm and bran percent protein and percent endosperm are contained in Table 4. Percent endosperm had no significant effect on grain protein concentration. Compared with endosperm protein concentration the effect of bran percent protein on grain protein concentration is small. Standard partial regression coefficients for the regression of grain lysine (% of sample) on endosperm and bran protein and lysine (% of protein)

Table 2. Correlation coefficients for whole grain, endosperm, and bran protein and lysine percentages for 135 wheats grown in the World Wheat Collection Special Study nursery at Yuma, Ariz. in 1973.†

	Whole kernel		Endosperm			Bran			
	LS	LP	P	LS	LP	P	LS	LP	% End
Whole kernel									
% protein	0.85**	-0.49**	0.98**	0.89**	-0.54**	0.75**	0.55**	-0.34**	-0.35**
Lysine (% of sample)		0.04	0.82**	0.91**	-0.15**	0.72**	0.59**	-0.22**	-0.41**
Lysine (% of protein)			-0.48**	-0.17*	0.78**	-0.23**	-0.07	0.28**	-0.03
Endosperm									
% protein				0.90**	-0.55**	0.67**	0.49**	-0.32**	
Lysine (% of sample)					-0.14	0.64**	0.48**	-0.30**	
Lysine (% of protein)						-0.31**	-0.23**	0.14	
Bran									
% protein							0.87**	-0.21**	
Lysine (% of sample)								0.29**	

*,** Indicates significance at the 0.05 and 0.01 levels of probability, respectively. † Results are for 129 World Collection wheats plus six checks replicated four times. Abbreviations: P = % protein, LS = lysine (% of sample); LP = lysine (% of protein); % End = percent endosperm.

Table 3. Means, regression coefficients, 't' values for the regression coefficients, and intercept values for the regression of lysine (% of sample) and lysine (% of protein) for whole grain, endosperm, and bran samples for the wheats fractionated from the World Wheat Collection Special Study nursery grown at Yuma, Ariz. in 1973.†

Dependent variable	Independent variable	Independent variable mean	Regression coefficient	't' value	Intercept	Dependent variable mean	Coefficient of determination
ELS	EP	16.09	0.0186	25.35**	0.09	0.39	0.81
ELP	EP	16.09	-0.0380	-8.21**	3.06	2.45	0.31
BLS	BP	18.96	0.0386	21.68**	0.10	0.83	0.76
BLP	BP	18.96	-0.0256	-2.71**	4.89	4.41	0.05
GLS	GP	16.39	0.0218	19.74**	0.11	0.47	0.72
GLS	GP	16.39	0.0207	17.92**	0.47	0.47	0.73
	% End	81.93	-0.0042	-2.83**			
GLP	GP	16.39	-0.0455	-6.84**	3.64	2.90	0.24
GLP	GP	16.39	-0.0530	-7.67*	6.02	2.90	0.28
	% End	81.93	-0.0276	-3.09**			

*,** Indicates significance at the 0.05 and 0.01 levels of probability, respectively. † Abbreviations: G = whole grain; E = Endosperm; B = Bran; % End = % endosperm; P = % protein; LS = lysine (% of sample); LP = Lysine (% of protein).

and on percent of endosperm show that endosperm protein concentration has as much effect on grain lysine content as all other factors combined. The effect of endosperm lysine (% of protein) on grain lysine (% of sample) is greater than the effects of bran protein or bran lysine (% of protein). Of the factors tested, percent endosperm has the smallest effect on grain lysine (% of sample).

Coefficients for the correlation of adjusted grain, endosperm, and bran lysine (% of sample) values with their respective adjusted lysine (% of protein) values were all $r = 0.99$. Coefficients for the correlation of adjusted endosperm lysine (% of protein) with grain lysine (% of protein) adjusted for protein and test weight, protein and percent endosperm, and protein were $r = 0.64$, $r = 0.66$, and $r = 0.70$, respectively. The coefficient for the correlation of unadjusted grain lysine (% of protein) with unadjusted endosperm lysine (% of protein) was $r = 0.78$. Removal of the effect of protein level on lysine content by adjusting lysine values for protein decreased the correlation between grain and endosperm lysine percentages. Including percent endosperm or test weight in the grain lysine adjustment equations with protein resulted in an additional decrease in correlation of grain and endosperm lysine. Correlation of grain lysine (% of protein) adjusted for protein and test weight with grain lysine (% of protein) adjusted for protein and percent endosperm was high ($r = 0.94$).

Means, F ratios, coefficients of variation, and L.S.D. values for grain, endosperm, and bran protein, lysine, and adjusted lysine percentages for the check cultivars appear in Table 5. There were highly significant differences among the check cultivars for all variables tested.

Table 4. Standardized partial regression coefficients for whole grain protein and lysine content from the regression analysis of wheats grown in the 1973 Yuma World Wheat Collectiou Special Study nursery. Results are for 129 World Collection wheats plus six check cultivars replicated four times.

Dependent variables	Independent variables	Standardized partial regression coefficients	Coefficient of determination for regression model
Whole grain % protein	1. Endosperm % protein	0.87**	0.98
	2. Bran % protein	0.16**	
	3. % Endosperm	-0.01	
Whole grain lysine (% of sample)	1. Endosperm % protein	0.89**	0.87
	2. Endosperm lysine (% of protein)	0.40**	
	3. Bran % protein	0.25**	
	4. Bran lysine (% of protein)	0.13**	
	5. % Endosperm	-0.12	

*,** Indicates significance of the partial regression coefficients at the 0.05 and 0.01 levels of probability, respectively.

Protein and lysine percentages of grain, endosperm, and bran of World Collection wheats with highest and lowest endosperm protein percentages are listed in Table 6. Wheats with the highest and lowest grain lysine (% of protein) values adjusted for protein and percent endosperm are listed in Table 7. Wheats with the highest endosperm lysine (% of protein) values adjusted for protein are listed in Table 8.

Table 5. Means, coefficients of variation, F ratios, and L.S.D. values for whole grain, endosperm, and bran protein and lysine values for check cultivars in the 1973 World Wheat Collection Special Study nursery.†

Variables	Mean of check cultivars r = 4						C.V. %	F ratio for checks	F ratio for reps	L.S.D. 0.05
	Atlas 66	Triumph 64	Scout 66	Inia 66	Centurk	Nap Hal				
GP	19.0	17.4	14.5	16.4	13.9	18.5	5.8	18.4**	2.8	1.5
EP	19.2	17.5	14.4	16.6	13.5	17.8	6.0	19.1**	4.1*	1.5
BP	19.5	18.3	16.8	17.3	17.0	24.0	5.5	27.6**	3.9*	1.6
GLP	2.8	2.8	3.0	2.8	3.1	3.1	3.0	12.0**	2.6	0.1
GLP adj for P & % E	2.9	2.9	3.0	2.9	3.0	3.2	2.3	12.9**	1.5	0.1
GLP adj for P	2.9	2.9	2.9	2.8	3.0	3.2	2.4	14.1**	1.7	0.1
ELP	2.3	2.4	2.5	2.3	2.6	2.5	3.8	8.2**	5.9**	0.1
ELP adj for P	2.4	2.4	2.4	2.3	2.5	2.6	3.2	6.1**	4.3*	0.1
BLP	4.2	4.7	4.8	4.6	4.5	4.6	3.1	7.8**	10.7**	0.2
% of Kernal P in E	80.4	81.9	82.5	83.1	79.9	76.2	0.7	73.6**	0.9	0.9
% of Kernel L in E	69.3	69.3	71.2	71.2	69.9	63.7	1.6	24.6**	3.8	1.7

*,** Indicate significance at the 0.05 and 0.01 levels of probability respectively.

† Abbreviations: G = grain; E = endosperm; B = bran; P = % protein; LP = lysine (% of protein).

Selections with high endosperm protein percentages differ by eight percentage points from those with low endosperm protein percentages. Some of the endosperm protein values are slightly higher than whole kernel protein percentages but the differences are within the range of laboratory experimental error.

Significant differences for grain lysine (% of protein) adjusted for percent protein and percent endosperm and for endosperm lysine (% of protein) adjusted for percent protein were found. The range between the high five and low five wheats for adjusted grain lysine (% of protein) is 0.6%. The range between the high five and low five wheats for adjusted endosperm lysine (% of protein) is 0.5%. These differences are five times greater than the L.S.D. values for these variables computed from the analysis of variance of the check cultivars.

Table 6. Whole kernel, endosperm, and bran protein and lysine values of World Collection Wheats from the 1973 Yuma nursery that had the highest and lowest endosperm protein content of the wheats fractionated.†

CI/PI	Rank	Whole kernel		Endosperm		Bran	
		% protein	Adj lysine % of protein	% protein	Adj lysine % of protein	% protein	Lysine % of protein
9053 C‡	1	20.9	2.6	21.0	2.5	21.7	3.2
6225 C	2	19.8	3.0	20.9	2.6	20.5	4.6
192014 P	3	21.0	3.1	20.8	2.4	21.2	4.1
5022 C	4	20.1	2.8	20.8	2.4	19.8	4.4
285812 P	5	20.3	3.0	20.2	2.6	23.0	4.3
166292 P	125	13.4	2.8	12.3	2.3	18.1	4.8
142521 P	126	12.1	3.0	12.0	2.9	13.6	4.1
135044 P	127	12.3	2.9	11.9	2.4	15.2	4.6
135076 P	128	12.5	2.8	11.8	2.4	18.6	4.6
267449 P	129	12.4	3.1	11.6	2.6	16.5	4.7

† Whole kernel adjusted lysine, adjusted for grain % protein and % endosperm. Endosperm adjusted lysine adjusted for endosperm % protein.
‡ C = CI, P = PI.

DISCUSSION

The high correlation of grain and endosperm protein percentages can be attributed to the high percentage of the total protein of wheat kernels that is endosperm protein (Table 5). The high correlation of grain and endosperm protein indicates that wheat breeders can reliably use grain protein percentages as a selection criterion for endosperm protein content.

Coefficients for the correlation of bran protein with endosperm protein and with grain protein were lower than those for the correlation of grain protein with endosperm protein, indicating that wheats with high endosperm protein do not necessarily have high bran protein content.

Percent protein and lysine (% of protein) of endosperm and bran and percent endosperm all influence grain lysine content. Variation in endosperm protein concentration accounts for much of the variation in grain lysine concentration. Endosperm lysine (% of protein) and bran protein also contribute to variation among wheats for grain lysine content but are only of secondary importance in comparison to endosperm protein content. Bran lysine (% of protein) and percent endosperm are of minor importance in determining grain lysine content.

Because of the large effect protein has on lysine, the coefficients for the correlation of grain and endosperm lysine values were also high. Removal of lysine variability attributable to protein decreased the correlation of grain and endosperm lysine values because the grain samples of some wheats contained more lysine rich bran proteins than other wheats. Adjustment of grain lysine values for protein and percent of endosperm or test weight resulted in an additional decrease in the correlation of grain and endosperm values. This additional decrease results from the effect of percent of endosperm on grain protein and lysine content.

Before adjustment for protein, grain, endosperm, and bran lysine (% of sample) values were either not correlated or were negatively correlated to their respective lysine (% of protein) values. After adjustment, the coefficients for the correlation of lysine (% of sample) and lysine (% of protein) were r = 0.99, indicating that after adjustment, both lysine values provide the same relative measure of lysine for grain, endosperm, and bran samples. Grain lysine values adjusted for protein and percent of endosperm and grain lysine values adjusted for protein and test weight provide similar relative measures of the protein quality of whole grain samples.

'Atlas 66' was included as a check because of its known high grain protein content (5, 6, 11). 'Nap Hal' was included as a check because of its high grain protein and high grain lysine contents (4, 6). Results of endosperm and bran protein analyses of the check entries in the World Collection nursery indicate that Atlas 66 is high in grain protein content because of

Table 7. Whole kernel, endosperm, and bran protein and lysine values of World Collection Wheats from the 1973 Yuma nursery that had the highest and lowest grain lysine (% of protein) values adjusted for % protein and % endosperm of the wheats fractionated.†

		Whole kernel			Endosperm			Bran	
CI/PI	Rank	% protein	Lysine % of protein	Adj lysine % of protein	% protein	Lysine % of protein	Adj lysine % of protein	% protein	Lysine % of protein
10907 C‡	1	17.2	3.3	3.3	16.9	2.4	2.4	18.7	4.2
176217 P	2	18.2	3.2	3.3	17.1	2.5	2.5	24.4	4.5
162008 P	3	16.8	3.2	3.3	16.6	2.6	2.6	20.6	4.8
6616 C	4	16.7	3.2	3.2	16.4	2.7	2.7	19.7	4.7
245604 P	5	15.9	3.3	3.2	15.2	2.9	2.8	19.8	4.3
182563 P	125	16.4	2.6	2.6	16.3	2.3	2.3	18.6	4.5
151202 P	126	14.5	2.6	2.6	14.1	2.4	2.3	16.3	4.8
9393 C	127	17.5	2.6	2.6	17.4	2.2	2.3	21.0	4.4
125387 P	128	15.7	2.6	2.6	15.4	2.4	2.4	18.6	4.3
9050 C	129	13.7	2.2	2.5	13.6	2.5	2.4	13.8	3.8

† Whole kernel adjusted lysine (% of protein) adjusted for grain % protein and % endosperm. Endosperm adjusted lysine (% of protein) adjusted for endosperm % protein.
‡ C = CI, P = PI.

Table 8. Whole kernel, endosperm, and bran protein and lysine values of World Collection Wheats from the 1973 Yuma nursery that had the highest and lowest endosperm lysine (% of protein) values adjusted for endosperm % protein of the wheats fractionated.†

		Whole kernel			Endosperm			Bran	
CI/PI	Rank	% protein	Lysine % of protein	Adj lysine % of protein	% protein	Lysine % of protein	Adj lysine % of protein	% protein	Lysine % of protein
142521 P‡	1	12.1	3.2	3.0	12.0	3.1	2.9	13.6	4.1
245604 P	2	15.9	3.3	3.2	15.2	2.7	2.8	19.8	4.3
298587 P	3	14.6	3.3	3.0	14.5	2.7	2.8	16.4	3.9
254829 P	4	15.5	3.2	3.0	14.8	2.8	2.8	18.5	4.4
6616 C	5	16.7	3.2	3.2	16.4	2.7	2.7	19.7	4.7
166474 P	125	15.8	2.7	2.7	15.9	2.2	2.2	19.3	4.4
6523 C	126	17.4	2.6	2.7	17.1	2.2	2.2	18.5	4.3
7514 C	127	17.4	2.7	2.7	16.4	2.2	2.2	19.6	4.2
166877 P	128	13.6	2.9	2.8	12.7	2.3	2.2	16.6	4.7
245539 P	129	15.8	2.7	2.7	15.9	2.2	2.2	18.7	4.4

† Whole kernel adjusted lysine (% of protein) adjusted for grain % protein and % endosperm. Endosperm adjusted lysine (% of protein) adjusted for endosperm % protein.
‡ C = CI, P = PI.

its high endosperm protein content. The high grain protein content of Nap Hal results both from high endosperm protein content and high bran protein content. Nap Hal bran is five to seven percentage points higher in protein content than the bran of other check cultivars.

Bran protein contains nearly twice as much lysine as the endosperm proteins. Nap Hal has a significantly higher grain adjusted lysine percentage than the other check cultivars, mainly because of high protein concentration of its bran. Nap Hal also has higher endosperm adjusted lysine (% of protein) than the other check cultivars.

World Collection wheats differ significantly in endosperm protein content. The differences measured in this study are believed to be mainly genetic because within-nursery environmental variation was small. Some of the differences in endosperm protein concentration may be due to differences among the wheats for genotype × environment interaction effects. The wheats with high endosperm protein percentages were equal to Atlas 66 in endosperm protein content. Because the World Collection wheats are diverse in origin, some probably carry genes for high endosperm protein content different from those of Atlas 66.

Some of the wheats with high grain adjusted lysine percentages have endosperm adjusted lysine percentages as high as that of Nap Hal. Wheats with low grain adjusted lysine percentages all had low endosperm adjusted lysine percentages. The results indicate that grain adjusted lysine values are usable for selecting wheats that are likely to have high endosperm lysine content. However, some of the wheats with high grain adjusted lysine values had high grain lysine percentages because of high bran protein and lysine percentages. The best criterion for selection of wheats with high endosperm lysine content appears to be endosperm lysine adjusted for protein. Because of the work involved in separating bran and endosperm, initial selection could be made using grain adjusted lysine values.

Although the correlation of endosperm adjusted lysine with grain lysine adjusted for protein is slightly higher than its correlation with grain lysine adjusted for protein and test weight, we believe the latter adjusted lysine value to be the better selection criterion to use on whole grain samples. The use of grain lysine values adjusted only for protein could result in wheats with below average endosperm percentages being selected. Quantity as well as the quality of endosperm is important. If endosperm adjusted lysine percentages are used for selection of high lysine wheats, some attention should be given to percent of endosperm or seed size. Adjusting whole grain values for protein and percent of endosperm may be of little practical value because separation of bran and endosperm is required to obtain endosperm percentages.

World Collection wheats differ significantly for endosperm adjusted lysine content. Some of the wheats tested were as high as Atlas 66 in endosperm protein concentration and had higher endosperm adjusted lysine percentages than Nap Hal indicating that

it should be possible to improve both the protein and lysine content of the endosperm of wheat by breeding.

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