Further Studies on the Nutritional Evaluation of Wheat, Triticale, and Rice Grains Using the Red Flour Beetle

G. SHARIFF, P. VOHRA, and C. O. QUALSET, Department of Avian Sciences and Department of Agronomy and Range Science, University of California, Davis 95616

Cereal Chem. 58(2):86–89

ABSTRACT

To assess the usefulness of *Tribolium* in nutritional research, *T. castaneum* larvae were used to evaluate the nutritional value of genetically different varieties of wheat, triticale, and rice samples. The growth of *T. castaneum* larvae was not correlated with crude protein, moisture, or ash contents of the tested samples of wheat and triticale. Triticales were significantly better for larval growth than were hard bread wheats and durum wheats but not soft bread wheats. Larval growth on rice samples was also not significantly correlated with crude protein or moisture contents but was negatively correlated (r = −0.65) with the amylose content of test samples. The carbohydrate complex of cereals appears to influence their nutritional value for *T. castaneum* larvae.

Plant breeders continually modify the genetic composition of cereals to improve their productivity and disease resistance. Nutritionists are interested in nutritional evaluation of new varieties, but sample size and experiment cost have been a constraint limiting the scope of feeding trials with conventional laboratory animals such as rats, guinea pigs, and poultry. An alternate inexpensive and reproducible biological assay method is desirable. Because the red flour beetle (*Tribolium castaneum*), an important pest of cereals, competes with humans for its diet, *T. castaneum* has been suggested for use in evaluating the nutritional value of cereals and cereal products (DeMuelenere and Quicke 1960, Medrano et al 1979, Srivastave et al 1973, Vohra et al 1978). This assay requires less than 10 g of a test sample. It is not only an inexpensive method but is also much faster than conventional methods. A large number of samples can be assayed at the same time by the *T. castaneum* larvae method.

Larval growth has been correlated with the nutritional value of proteins (Medrano et al 1979) and carbohydrates (Vohra et al 1979a, 1979b). In the present study, therefore, a broad range of genetic materials of wheat (both bread and durum), triticale, and rice were evaluated for their nutritional value for *T. castaneum* larvae to assess the usefulness of this assay procedure.

MATERIALS AND METHODS

Samples of spring bread wheat (*Triticum aestivum* L.), durum wheat (*T. turgidum* L.), and triticale (X Triticosecale Wittmack), selected from International Performance nurseries, were grown at Davis, CA, in 1978. Samples were divided into four groups, the first three from the International Durum Yield Nursery (IDYN), the International Spring Wheat Yield Nursery (ISWYN), and the International Triticale Yield Nursery (ITYN), all organized by the International Maize and Wheat Improvement Center in Mexico. The fourth group was from the International Winter Wheat Performance Nursery (IWWPN) organized by the U.S. Department of Agriculture and the University of Nebraska. These trials were grown as adjacent experiments at the University of California Agronomy Research Farm at Davis. The experiments were handled using the management practices commonly used for irrigated fall-planted wheat in the Central Valley of California.

Rice samples were obtained from the USDA Western Regional Research Laboratory, Albany, CA. A waxy rice starch (Mira Quik) was obtained from A. E. Staley Manufacturing Company, Decatur, IL. Uniform particle size was obtained by finely grinding all the test samples to pass through a 100-mesh sieve. Bran was not removed from wheat flours. The samples were analyzed for their moisture, ash, and Kjeldahl nitrogen contents according to AOAC methods (1975). Crude protein content was estimated by multiplying Kjeldahl nitrogen by 5.83 or 5.95 for wheat and rice, respectively. Larvae of *T. castaneum* were collected at six days of age. Three replicates, each containing 10 larvae, were fed each of the test diets and were incubated as described earlier (Vohra et al 1978). The final larval weights were determined at the 14th day of age.

The diets for evaluation of wheats and triticales contained 90% flour from the test cereal and 10% dried brewer's yeast; the control diet contained 90% unbleached white or wheat flour and 10% yeast. The diets for rice evaluation contained 87.5% rice flour or starch and 12.5% of a mixture containing 55.6% brewer's yeast and 44.4% isolated soybean protein that supplied 8% crude protein in the diet. Corn starch was substituted for rice flour in the control diet.

RESULTS AND DISCUSSION

The moisture, crude protein, and ash contents of various wheats and triticales obtained from the IDYN, ISWYN, ITYN, and IWWPN are given in Tables I–IV, respectively, as are weight gains of *T. castaneum* larvae on the diets based on these samples.

On all wheat samples from IDYN, larval growth was significantly less than on the control (Table I) and less, but not significantly so, than on the triticale. The wheats differed significantly among themselves in supporting the growth of larvae. The samples Jupateco, Anza, Mexicali 75, and Creso gave significantly better larval growth than did the rest. The poorest larval growth was on the Mexi-Fg variety.

Two varieties of wheats (Tesopaco and H-Ra^2-F^2) were as good in supporting the growth of larvae as were the triticale or the control from the ISWYN (Table II). The poorest larval growth was obtained on the varieties Nacozari 76, Cuckoo 'S', Siete Cerros 66, and Nacozari 'S'. The varieties differed significantly among themselves from this nursery also.

The wheat varieties from the ITYN were significantly poorer than the triticales in supporting larval growth (Table III). No significant differences among the wheat varieties were observed from this nursery. However, the triticale varieties Mapache, May I-Arm, and Cinnamon were significantly better than the Beagle variety.

The wheat varieties Atlas 66, Naphal/ Atlas 66, Ticonderoga, Zg 4293-73, and Lerma Rojo 64 from IWWPN were as good as the control in supporting larval growth (Table IV). The rest of the varieties differed significantly among themselves.

For all these varieties, larval growth was poorly correlated with moisture, crude protein, or ash contents of the samples, as is evident from the low values for the correlation coefficients in Tables I–IV. For varieties from ISWYN and ITYN, the ash contents correlated slightly better with larval growth than the other two indices did, but the correlation was still insignificant.

The data suggest that larval response depends upon the genetic makeup of the varieties and was not significantly influenced by the differences in the environmental conditions under which they were grown. The wheat varieties Anza (a hard wheat), Mexicali 75 (a durum wheat), and Mapache (a triticale) from different nurseries

009-0352/81/0208604/$03.00/0

TABLE I
Effect of Wheat Varieties and a Triticale from International Durum Yield Nursery on Growth of *Tribolium castaneum* Larvae

Cereal Variety[a]	Percent Composition: Moisture (X_1)	Crude Protein[b] (X_2)	Ash (X_3)	Weight Gain per Larva (mg) (Y)
Control, white flour	8.9	14.4	1.9	3.12
Triticale, Bacum	7.6	13.7	1.9	2.92
Wheats				
Jupateco (H)	8.3	14.3	1.4	2.89
Anza (H)	8.0	12.6	1.6	2.88
Mexicali 75 (D)	8.5	13.7	1.5	2.82
Creso (FB 55) (D)	8.4	12.2	1.6	2.75
Mexi-Chap[c] (D)	8.4	13.3	1.9	2.56
Cocorit 71 (D)	8.2	14.2	2.0	2.47
Mexi-Fg[d] (D)	8.4	14.0	1.8	2.22
Statistical Analysis				
SE	0.033	0.038	0.028	0.051
Mean square	0.523	1.161	0.086	0.234
Mean square of error	0.002	0.003	0.002	0.008
LSD (0.05)	0.09	0.05	0.08	0.15

Regression analysis
$Y = 2.46 + 0.03\ X_1 \quad r = 0.04$
$Y = 2.84 - 0.007\ X_2 \quad r = -0.02$
$Y = 3.37 - 0.37\ X_3 \quad r = -0.28$

[a] H = Hard bread wheat, D = durum wheat.
[b] Moisture free basis.
[c] Mexicale 'S' × Chapala-21563. Cross No. CD1894-3Y-OY-OM.
[d] Mexicale 'S' × Flamingo 'S'. Cross No. CD1895-12Y-1Y-OM.

TABLE II
Effect of Wheat Varieties and a Triticale from International Spring Wheat Yield Nursery on the Growth of *Tribolium castaneum* Larvae

Cereal Variety[a]	Percent Composition: Moisture (X_1)	Crude Protein[b] (X_2)	Ash (X_3)	Weight Gain per Larva (mg) (Y)
Control, wheat flour	8.9	14.2	1.9	3.12
Triticale, Mapache	8.2	13.2	1.8	3.09
Wheats				
Tesopaco 'S' (S)	8.4	13.3	1.6	3.03
H-Ra^2-F$_2$ (S)	8.2	14.7	1.8	3.02
Anza (H)	8.9	13.2	1.4	2.95
Tanori 71 (H)	8.7	15.5	1.5	2.94
Condor 'S' (H)	8.1	14.2	1.6	2.92
Mexicali 75 (D)	8.6	13.6	1.8	2.89
Ramon 50 (H)	7.7	14.6	1.6	2.89
Sonalika (H)	8.6	11.9	1.6	2.85
Pavon 76 (H)	8.9	11.9	1.5	2.84
M. J. Inta (H)	8.4	15.4	1.7	2.84
Inia 66 (H)	8.8	15.5	1.6	2.82
Nacozari 'S' (H)	8.9	12.8	1.8	2.79
Siete Cerros 66 (H)	8.6	12.6	1.7	2.76
Cuckoo 'S' (H)	8.1	13.3	1.3	2.73
Nacozari 76 (H)	8.9	13.6	1.6	2.69
Statistical Analysis				
SE	0.041	0.069	0.039	0.08
Mean square	0.52	1.161	0.086	0.044
Mean square of error	0.002	0.003	0.007	0.009
LSD (0.05)	0.097	0.109	0.169	0.156

Regression analysis
$Y = 3.33 - 0.05\ X_1 \quad r = -0.15$
$Y = 2.58 + 0.02\ X_2 \quad r = 0.21$
$Y = 2.35 + 0.32\ X_3 \quad r = 0.43$

[a] S = Soft wheat, D = durum wheat, H = hard wheat.
[b] Moisture free basis.

TABLE III
Effect of Wheat Varieties and Triticales from International Triticale Yield Nursery on the Growth of *Tribolium castaneum* Larvae

Cereal Variety[a]	Percent Composition: Moisture (X_1)	Crude Protein[b] (X_2)	Ash (X_3)	Weight Gain per Larva (mg) (Y)
Control, wheat flour	8.9	14.4	1.9	3.12
Wheats				
Siete Cerros (H)	8.2	13.7	1.6	2.82
Mexicali 75 (D)	8.6	14.1	1.9	2.82
Nacozari (H)	9.2	14.6	1.5	2.76
Triticales				
Mapache	8.7	13.3	1.7	3.20
May I-Arm[c]	8.6	12.6	1.9	3.15
Cinnamon	8.5	13.8	1.9	3.15
6TA-204	8.1	15.2	2.2	3.04
Beagle	8.5	13.8	2.0	2.99
Statistical Analysis				
SE	0.038	0.037	0.045	0.05
Mean square	0.241	1.258	0.100	1.107
Mean square of error	0.003	0.004	0.003	0.008
LSD (0.05)	0.115	0.13	0.115	0.15

Regression analysis
$Y = 3.48 + 0.06\ X_1 \quad r = -0.11$
$Y = 4.19 - 0.08\ X_2 \quad r = 0.38$
$Y = 2.38 + 0.34\ X_3 \quad r = 0.43$

[a] H = Hard wheat, D = durum wheat.
[b] Moisture free basis.
[c] May I-Arm × 2.48-5N-2M-3Y-2M-OY.

TABLE IV
Effect of Wheat Varieties from International Winter Wheat Performance Nursery on the Growth of *Tribolium castaneum* Larvae

Cereal Variety[a]	Percent Composition: Moisture (X_1)	Crude Protein (X_2)	Ash (X_3)	Weight Gain per Larva (mg) (Y)
Control, white flour	8.9	14.4	1.9	3.12
Wheats				
Atlas 66 (S)	8.3	14.0	2.1	3.06
Naphal/Atlas 66 (S)	8.1	17.5	1.8	3.06
Ticonderoga (S)	7.5	13.4	1.8	3.05
Zg 4293-73 (S)	7.9	14.5	1.9	3.01
Lerma Rojo 64 (S)	8.5	16.3	1.6	2.97
NE 73640 (HW)	8.6	15.1	1.7	2.95
Bezostaya (H)	7.5	15.9	1.8	2.93
Anza (HS)	8.4	13.2	1.6	2.92
CI 13449/Centurk (S)	8.1	14.8	1.8	2.91
Lindon (H)	8.6	14.7	1.8	2.89
Zg 4240-73 (S)	7.7	14.8	2.1	2.85
WW 33 (H)	8.6	12.8	1.7	2.83
KS 73112 (H)	7.5	14.2	1.8	2.79
Samsor (H)	8.3	14.8	2.0	2.77
Slavyanka (H)	7.7	15.4	1.6	2.74
Statistical Analysis				
SE	0.05	0.06	0.04	0.05
Mean square	0.34	2.94	0.05	0.04
Mean square of error	0.005	0.008	0.003	0.008
LSD (0.05)	0.14	0.18	0.11	0.15

Regression analysis
$Y = 2.40 + 0.07\ X_1 \quad r = 0.26$
$Y = 2.76 + 0.01\ X_2 \quad r = 0.12$
$Y = 2.69 + 0.13\ X_3 \quad r = 0.19$

[a] S = Spring wheat, HS = hard spring wheat, HW = hard winter wheat.
[b] Moisture free basis.

TABLE V
Larval Weights as Affected by Different Types of Wheats and Triticales

Cereal Type[a]	Mean Crude Protein[b] (%) (X)	Weight Gain per Larva[c] (mg) (Y)	Regression Analysis For $Y = M + NX$[d] (M)	(N)	Correlation Coefficient
Triticale (7)	13.63	3.09 c	3.76	−0.05	−0.4
Soft bread wheat (9)	14.81	2.97 bc	3.04	−0.003	−0.06
Hard bread wheat (24)	14.03	2.80 ab	2.69	+0.01	0.17
Durum wheat (7)	13.59	2.60	4.27	−0.12	−0.34

[a] Number of samples is given in parentheses.
[b] Moisture free basis.
[c] Statistical significance in this column is denoted by different letters ($P \leqslant 0.01$).
[d] Regression analysis where M is intercept and N is the slope.

TABLE VI
Effect of Rice Varieties and a Rice Starch on the Growth of *Tribolium Castaneum* Larvae

Cereal Variety	Percent Composition: Moisture (X_1)	Crude Protein[a] (X_2)	Amylose (X_3)	Weight Gain per Larva (mg) (Y)
Control, corn starch	9.4	3.1	low	2.34
Rice starch (Mira Quik)	10.1	6.3	low	2.73
Rice flours				
Calrose 76	13.1	5.0	19.9	3.00
Riviana RM 100	11.8	7.9	15.0	2.87
CP-231	12.0	6.8	16.6	2.83
Toro 1974	12.4	5.9	19.9	2.77
Riviana RL 100	11.9	8.0	21.1	2.63
T (N)1	12.0	8.7	24.9	2.53
Early Prolific'74	12.4	6.5	15.5	2.50
LA 110	12.4	6.9	25.8	2.33
IR-8	11.9	7.4	25.7	2.20
Labilla'75	12.4	7.3	22.4	2.17
Statistical Analysis				
SE	...	...	...	0.09
Mean square	...	...	...	0.21
Mean square of error	...	...	...	0.03
LSD (0.05)	...	...	...	0.28
Regression analysis				
$Y = 2.01 + 0.05 X_1$	$r = 0.18$			
$Y = 2.65 - 1.14 X_2$	$r = -0.06$			
$Y = 3.53 - 0.05 X_3$	$r = -0.65$			

[a] Moisture free basis.

were grown under different environmental conditions, but the bioassay with *T. castaneum* larvae did not indicate any significant differences attributable to their origin (Tables I–III).

An overall analysis of growth performance of larvae on triticales, hard bread wheats, soft bread wheats, and durum wheats based on Tables I–IV is presented in Table V. These samples ranked in the following descending order of ability to support the growth of *T. castaneum* larvae: triticales, soft bread wheats, hard bread wheats, and durum wheats. The differences between durum wheats and soft bread wheats or triticales were highly significant ($P < 0.01$). The growth is not significantly correlated to the crude protein contents of these cereals.

The finding that triticales ranked higher than some of the wheats in the present study confirms our earlier finding (Vohra et al 1978). In contrast to our earlier observation, however, the larval growth was poorly correlated with the crude protein content of the samples. Larval growth is also influenced by the amylopectin-amylose ratio in the starch and by some other sugars (Vohra et al 1979b), some complex carbohydrates similar to guar gum and gum arabic (Vohra et al 1979a), and the presence of amylase inhibitors (Silano 1978). The importance of the carbohydrates and antienzymes is still under investigation, but the unpublished data confirm their role in influencing larval growth.

Because rice samples contained very little of the inhibitor activity, these were also assayed by the larval growth method. The moisture, crude protein, and amylose contents of the starch and the growth of larvae as influenced by diets containing these samples are given in Table VI. The growth of larvae was markedly influenced by the rice variety. The best and the poorest larval growth were on Calrose 76 and Labilla 75, respectively.

Larval growth was not significantly correlated with the moisture or crude protein contents of the varietal samples, as is evident from the regression analysis. It was significantly influenced, however, by the amylose content of the samples. A correlation coefficient of −0.65 was found for the expression $Y = 3.53 - 0.05 X_3$, in which Y is the weight of the larva in milligrams and X_3 is the percent amylose.

T. castaneum larvae have been successfully used for nutritional evaluation of both proteins and carbohydrates. Medrano et al (1979) evaluated the nutritional value of corn, wheat, and a processed soybean-corn preparation using *T. castaneum* larvae and rats. They observed that *T. castaneum* larvae, rat body weight gain, and rat protein efficiency ratio values were twice as good when Opaque-2 corn was fed in contrast to two other corn types with low lysine content. A 70:30 corn/soybean mixture prepared in two treatments with pie-cooked and raw soybean was also classified in the treatment by larval weight gain and rat protein efficiency ratio values. Vohra et al (1979b) reported that *T. castaneum* larvae and chicken grew better on corn starches and rice grain with a low amylose content. Growth of chicken and *T. castaneum* larvae was significantly poor on raw potato starch; however, a significantly higher weight gain of both species was observed when autoclaved potato starch was fed. Vohra et al (1979a) observed the growth-inhibiting effect of guar gum pectin and locust gum on chicken, Japanese quail, and *T. castaneum* larvae when 2% guar gum was incorporated in the diet. The data in Table IV further confirmed that our bioassay is useful in screening cereals for nutritional evaluation. The poor correlation with crude protein of cereals in this study is possibly due to the lack of independence of crude protein as a variable used in the regression equation (Shariff 1980).

The nutritionist is interested in cereals that give optimal growth of *T. castaneum* larva because any cereal that will not support the growth of these larvae will not have optimal nutritional value for other animals. But the nutritionist may possibly be in opposition to the geneticist, who wants a cereal variety that will not be infested with beetles during storage.

LITERATURE CITED

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1979. Methods of Analysis. The Association: Washington, DC.

DeMUELENERE, H. J. H., and QUICKE, G. V. 1960. The possibilities of using Tribolium castaneum as test organism for evaluating the relative nutritional quality of different samples of maize. S. Afr. J. Agric. Sci. 3:137.

MEDRANO, J. F., BRESSANI, R. L., GOMEZ-BRENES, R., and ELIAS, L. G. 1979. Evaluation of nutritional quality of food with the red

flour beetle (Tribolium castaneum). II. Evaluation of corn, wheat and a processed soybean:corn preparation. Nutr. Rep. Int. 20:11.
SILANO, V. 1978. Biochemical and nutritional significance of wheat albumin inhibitors of α-amylose. Cereal Chem. 55:722.
SHARIFF, G. 1980. Evaluation of the nutritional value of the carbohydrate complex of genetically different varieties of wheats and triticales using red flour beetle (Tribolium castaneum) larvae, quail and chickens. Ph.D. thesis, University of California, Davis.
SRIVASTAVA, B. K., GOKHALE, V. G., and SHARMA, M. M. 1973. Development of Tribolium castaneum (Herbst) (Colesopter = Tenebrionidae) on the flours of raw and autoclaved pulses and wheat. J. Stored Prod. Res. 9:143.
VOHRA, P., SHARIFF, G., and KRATZER, F. H. 1979a. Growth inhibitory effect of some gums and pectin for Tribolium castaneum larvae, chickens and Japanese quail. Nutr. Rep. Int. 19:463.
VOHRA, P., SHARIFF, G., ROBINSON, D. W., QUALSET, C. O., and GALL, G. A. E. 1978. Nutritional evaluation of triticale wheat and rye grain using red flour beetle (Tribolium castaneum) larvae and chickens. Nutr. Rep. Int. 18:289.
VOHRA, P., SHARIFF, G., ROBINSON, D. W., and QUALSET, C. O. 1979b. Nutritional evaluation of starches, rice flours and carbohydrates using Tribolium castenum larvae and chickens. Nutr. Rep. Int. 19:101.

[Received April 28, 1980. Accepted August 6, 1980]