# Protein, Lysine, and Grain Yields of Triticale and Wheat as Influenced by Genotype and Location

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Three triticale varieties (T-1324, 6TA-204, and Rosner) yielded an average of 29% less grain per acre than three wheat varieties (Siete Cerros 66, INIA 66, and Oviachic 65). Compared to wheat, triticale had 14% higher whole-grain protein content (16.3 *vs.* 14.3%), 39% higher lysine content in the grain (0.428 *vs.* 0.307%), and 23% higher lysine content in the protein (2.63 *vs.* 2.14%). Yields of protein per acre were generally lower for triticale than wheat (540 *vs.* 675 lb/acre), but lysine yields were comparable (14.2 *vs.* 14.5 lb/acre). Differences among four widely separated California locations were small, but acre-yields of grain, protein, and lysine showed significant variety × location interaction. Oviachic 65 wheat and 6TA-204 triticale were very stable, whereas INIA 66 wheat and T-1324 triticale were unstable in protein, lysine, and grain production.

Seeds, cereal seeds in particular, have historically served as the major source of protein for the people of the world. About one-half of the world's human food consumption is currently in the form of cereals. Although more than one-third of protein consumption in the United States comes from animal sources, between 5 and 6 lb of plant protein must be fed to animals in order to produce 1 lb of animal protein, and much of this protein comes from cereals. Robinson (1972) pointed out that cereals satisfy 70–90% of the energy demands of animals.

Triticale is a new cereal grain developed from hybridization of wheat and rye. Little is known of the nutritional properties of this new species and variable results have been obtained in feeding trials (humans: Kies and Fox, 1970a.b; avian species: Bragg and Sharky, 1970; Sell and Johnson, 1969; Vohra, 1972; swine: Cornejo *et al.*, 1972; Harrold *et al.*, 1971; Stothers and Shebeski, 1965; Shimada *et al.*, 1971; cattle: Lofgreen *et al.*, 1970; McCloy *et al.*, 1971). Triticale has been equivalent, and sometimes superior, to wheat in studies where the feed was not contaminated with ergot. Preliminary results of Elliott (cited in Zillinsky and Borlaug, 1971) indicate that animals fed some triticale strains show high weight gain per unit of protein consumed. The protein efficiency ratios of some triticale strains were comparable to casein. Until recently it was believed that triticale was unsuitable for breadmaking; however, Lorenz *et al.* (1972) found that only minor modifications in the dough mixing process were needed to produce satisfactory loaves of bread with triticale flour. The protein content of whole-grain triticale is often higher than that of wheat (McDonald, 1968; Qualset *et al.*, 1969; Villegas *et al.*, 1968), but in the flour extracted from triticale grain the protein content is comparable to or lower than the protein content of bread wheat flours (Lorenz *et al.*, 1972). The amino acid composition of triticale was intermediate to those of wheat and rye in studies by Yong and Unrau (1966) and Chen and Bushuk (1969); however, in these studies and in those by Villegas *et al.* (1968), lysine content was higher than observed in standard bread wheats.

As wheat and triticale become more widely used as feed grains and for improved human nutrition, attention needs to be given to yields as well as to contents of protein and amino acids, just as grain yield now receives major attention. We have undertaken a study of wheat and triticale varieties at widely separated locations in California to compare composition and yields of protein and lysine of these two crops. Such information is needed by plant breeders to provide a basis for selection and by nutritionists to understand the variation in nutritional quality of cereals as caused by environmental and genetic relationships.

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## METHODS

**Varieties.** The wheat varieties used were two common wheats, INIA 66 and Siete Cerros 66 (*Triticum aestivum* L.), and one durum, Oviachic 65 (*Triticum durum* Desf.). INIA 66 is a hard red spring wheat with moderately high grain protein content and good milling and baking quality. Siete Cerros 66 is a white spring wheat, generally with low grain protein content and unacceptable milling and baking quality. Oviachic 65 is an amber durum spring wheat with unacceptable semolina quality. The wheat varieties are short-statured developments from the Mexican wheat breeding program and the International Maize and Wheat Improvement Center (CIMMYT), Mexico City.

The three triticale varieties (*Triticale hexaploide* Lart.) used were: 6TA-204, from the Jenkins Foundation for Research, Salinas, California; Rosner, from the University of Manitoba, Winnipeg; and T-1324, from CIMMYT. All triticale varieties are tall. Rosner and 6TA-204 mature much later than T-1324 or the wheat varieties. The varieties differ in breeding history and represent some of the variation now present in triticale.

**Field Experiments.** The field experiments were conducted at four locations in California spanning a north-south distance of more than 600 miles: El Centro, 30-ft elevation, 32° 46′N latitude in the Imperial Valley; Five Points, 285-ft elevation, 36° 22′N latitude in the San Joaquin Valley; Davis, 60-ft elevation, 38° 32′N latitude in the Sacramento Valley; and Tulelake, 4035-ft elevation, 41° 58′N latitude. The plots were planted in December 1969 or January 1970, except for April 1970 at Tulelake. Standard field-plot techniques were used. Fertilization was employed as used for optimum production at each location. There were three or four replications in each experiment (Gustafson *et al.*, 1972); however, only two replicates were used for the studies reported here. Grain yields are reported at approximately 8% moisture.

**Protein and Lysine Determinations.** Grain samples from each of the two replicates were equilibrated at 9–11% moisture and ground through a Lab-Con-Co burr mill. The ground samples were dried overnight at 105°. Nitrogen was determined on all samples, using a macro-Kjeldahl procedure (AOAC, 1960) except that 2% boric acid was used in the receiving flasks and a mixed indicator of methylene blue and methyl red was used for titrations. Percentage protein, on a dry-weight basis, was calculated as N × 5.7. Lysine was determined by the method of Zscheile and Brannaman (1972), using a Varian Aerograph gas chromatograph (1520 Series) with a Model 20 recorder and Model 477 digital integrator. Lysine, on a dry-weight basis, was determined as percentage of the

**Table I. Analyses of Variance, Coefficients of Variation, and Standard Errors**

| Source of variation | df | Protein, % | Lys, % in seed | Lys, % in protein | Grain,[a] lb/acre | Protein,[a] lb/acre | Lys, lb/acre |
|---|---|---|---|---|---|---|---|
| Locations | 3 | 1.481 | 0.0041 | 0.0617 | 26,346[c] | 615.31[c] | 404.33[c] |
| Replicates in locations | 4 | 0.361 | 0.0010 | 0.0659 | 898 | 18.36 | 21.52 |
| Varieties | 5 | 12.886[c] | 0.0373[c] | 0.6154[c] | 10,638[c] | 165.95[c] | 68.66[c] |
| Variety × locations | 15 | 0.780 | 0.0007 | 0.0114 | 1,417[c] | 21.93[c] | 14.09[c] |
| Error | 20 | 0.371 | 0.0007 | 0.0120 | 252 | 6.23 | 3.51 |
| | | | Coefficient of variation, % | | | | |
| | | 4.0 | 7.2 | 4.6 | 11.5 | 13.0 | 13.0 |
| | | | Standard error of mean[b] | | | | |
| Locations | | 0.17 | 0.009 | 0.074 | 274 | 39.1 | 1.34 |
| Varieties | | 0.31 | 0.009 | 0.038 | 421 | 52.3 | 1.32 |
| Variety × locations | | 0.43 | 0.019 | 0.078 | 355 | 55.8 | 1.32 |
| Wheat *vs.* Triticale | | 0.25 | 0.008 | 0.031 | 344 | 42.8 | 1.09 |

[a] Mean squares × $10^{-3}$ are given. [b] Error mean squares used to calculate standard errors for locations, varieties, and varieties × locations were replicates in locations, varieties × locations, and error, respectively. [c] $p < 0.01$.

**Table II. Grain Yields, lb/acre**

| Location | Triticale | | | | Wheat | | | | Mean of all varieties |
|---|---|---|---|---|---|---|---|---|---|
| | T-1324 | 6TA-204 | Rosner | Mean | Siete Cerros 66 | INIA 66 | Oviachic 65 | Mean | |
| El Centro | 3580 | 3570 | 930 | 2690 | 3220 | 3460 | 3650 | 3440 | 3060 |
| Five Points | 2730 | 3080 | 980 | 2260 | 4840 | 5650 | 3420 | 4640 | 3450 |
| Davis | 4620 | 5040 | 1890 | 3850 | 4380 | 6150 | 5130 | 5220 | 4540 |
| Tulelake | 4680 | 7280 | 5100 | 5690 | 7630 | 6220 | 7340 | 7060 | 6380 |
| Mean | 3900 | 4740 | 2220 | 3620 | 5020 | 5370 | 4880 | 5090 | 4360 |

**Table III. Protein Content and Production per Acre**

| Location | Triticale | | | | Wheat | | | | Mean of all varieties |
|---|---|---|---|---|---|---|---|---|---|
| | T-1324 | 6TA-204 | Rosner | Mean | Siete Cerros 66 | INIA 66 | Oviachic 65 | Mean | |
| | | | | Protein, % | | | | | |
| El Centro | 15.4 | 16.2 | 16.6 | 16.1 | 13.4 | 15.4 | 13.9 | 14.2 | 15.2 |
| Five Points | 15.6 | 15.6 | 16.7 | 16.0 | 12.5 | 13.9 | 15.6 | 14.0 | 15.0 |
| Davis | 15.5 | 16.9 | 16.8 | 16.4 | 12.6 | 14.9 | 14.9 | 14.1 | 15.2 |
| Tulelake | 17.1 | 15.9 | 16.7 | 16.6 | 13.8 | 15.9 | 15.3 | 15.0 | 15.8 |
| Mean | 15.9 | 16.2 | 16.7 | 16.3 | 13.1 | 15.0 | 14.9 | 14.3 | 15.3 |
| | | | | Protein, lb/acre | | | | | |
| El Centro | 504 | 531 | 141 | 392 | 394 | 492 | 467 | 451 | 422 |
| Five Points | 392 | 441 | 150 | 328 | 558 | 720 | 489 | 589 | 458 |
| Davis | 660 | 782 | 293 | 578 | 509 | 844 | 707 | 687 | 632 |
| Tulelake | 737 | 1069 | 785 | 864 | 972 | 908 | 1037 | 972 | 918 |
| Mean | 573 | 706 | 342 | 540 | 608 | 741 | 675 | 675 | 608 |

grain and as percentage of protein. A single determination of nitrogen and lysine was made for each of the two samples from different replicates in the field experiments.

## RESULTS AND DISCUSSION

The analyses of variability for grain, protein, and lysine yields and for protein and lysine contents are given in Table I. Significant location effects were found for acre-yields of grain, protein, and lysine, but not for the percentage of protein and lysine in the grain or percentage of lysine in the protein. Variety effects were significant for all six measurements and the variety × location interaction was significant only for the acre-yield measurements. Standard errors are given in Table I for use in comparing means given in Tables II–IV.

**Grain Yield.** Detailed analyses of the productivity of wheat and triticale were presented by Gustafson *et al.* (1972), and only the major features of grain production are mentioned here (Table II). Tulelake was the most productive environment, showing a mean yield of 6380 lb/acre. Mean triticale yields did not exceed the wheat yields at any location. The performance of the best triticale (6TA-204) was 88% of the yield of the best wheat (INIA 66). Considering all varieties and locations, the mean triticale performance was only 71% of wheat. Triticale produced 81% as much as wheat at Tulelake, but only 49% as much at Five Points. Triticale is better adapted to the longer days and cooler conditions at the high-elevation station at Tulelake.

**Protein.** As indicated in Table I, the grain protein contents did not vary significantly among locations, ranging from 15.0% at Five Points to 15.8% at Tulelake (Table III). The higher protein content of triticale varieties occurred at all locations, with a mean difference of 2.0% protein. This difference was consistent with earlier results where different groups of wheat and triticale varieties

**Table IV. Lysine Content of Grain and Protein and Production per Acre**

| Location | Triticale | | | | Wheat | | | | Mean of all varieties |
|---|---|---|---|---|---|---|---|---|---|
| | T-1324 | 6TA-204 | Rosner | Mean | Siete Cerros 66 | INIA 66 | Oviachic 65 | Mean | |
| | | | | | Lysine, % of grain | | | | |
| El Centro | 0.414 | 0.417 | 0.433 | 0.421 | 0.296 | 0.304 | 0.295 | 0.298 | 0.360 |
| Five Points | 0.383 | 0.389 | 0.445 | 0.406 | 0.268 | 0.281 | 0.310 | 0.286 | 0.346 |
| Davis | 0.386 | 0.449 | 0.468 | 0.434 | 0.296 | 0.316 | 0.333 | 0.315 | 0.374 |
| Tulelake | 0.469 | 0.417 | 0.465 | 0.450 | 0.314 | 0.342 | 0.324 | 0.327 | 0.388 |
| Mean | 0.413 | 0.418 | 0.453 | 0.428 | 0.294 | 0.311 | 0.316 | 0.307 | 0.368 |
| | | | | | Lysine, % of protein | | | | |
| El Centro | 2.70 | 2.58 | 2.60 | 2.63 | 2.21 | 1.96 | 2.12 | 2.10 | 2.36 |
| Five Points | 2.45 | 2.50 | 2.66 | 2.54 | 2.14 | 2.03 | 1.99 | 2.05 | 2.30 |
| Davis | 2.48 | 2.66 | 2.78 | 2.64 | 2.34 | 2.12 | 2.23 | 2.23 | 2.44 |
| Tulelake | 2.74 | 2.62 | 2.78 | 2.71 | 2.27 | 2.16 | 2.11 | 2.18 | 2.44 |
| Mean | 2.59 | 2.59 | 2.70 | 2.63 | 2.24 | 2.07 | 2.11 | 2.14 | 2.38 |
| | | | | | Lysine, lb/acre | | | | |
| El Centro | 13.6 | 13.7 | 3.7 | 10.3 | 8.7 | 9.8 | 9.9 | 9.5 | 9.9 |
| Five Points | 9.7 | 11.0 | 4.0 | 8.2 | 12.0 | 14.6 | 9.8 | 12.1 | 10.2 |
| Davis | 16.4 | 20.8 | 8.2 | 15.1 | 12.0 | 17.8 | 15.7 | 15.2 | 15.2 |
| Tulelake | 20.1 | 28.2 | 21.8 | 23.4 | 22.2 | 19.6 | 21.9 | 21.2 | 22.3 |
| Mean | 14.9 | 18.4 | 9.4 | 14.2 | 13.7 | 15.4 | 14.3 | 14.5 | 14.4 |

were used (Qualset *et al.*, 1969). Rosner triticale had significantly higher protein content than T-1324 triticale and all of the wheat varieties. However, because of its late maturity and spike sterility, this variety does not perform well in California (Table II).

In contrast, protein yields, on a dry weight basis, of triticale were significantly lower than those of wheat at all locations (Table III). Further, the protein yields were not consistent for all varieties, as indicated by the significant location × variety interaction (Table I). INIA 66 produced the highest mean protein yield per acre, significantly higher than all varieties except 6TA-204 triticale, which produced 95% as much protein as INIA 66. The mean protein yields of triticales were 80% of the yields of wheats, emphasizing the importance of developing varieties with high grain yield potential to obtain high protein yields.

Triticale grain has a lower specific weight than wheat because of poorer endosperm development. It is likely that the higher protein content in comparison to wheat, on a whole-grain basis as observed here, is due to a lower ratio of endosperm to embryo and/or to a greater amount of aleurone and pericarp tissue relative to endosperm. Improvement in triticale endosperm development, *viz.* the elimination of wrinkled grain, might dissipate its advantage over wheat in protein content.

**Lysine.** Knipfel (1969) and Kies and Fox (1970b) pointed out that the amino acid lysine is the first limiting amino acid in the utilization of the potential food value of cereal grains. Improvement in lysine content is clearly needed and it is important to evaluate triticale as a possible lysine-rich cereal grain. Lysine contents, given as percentage of grain weight and as percentage of protein for the varieties studied here, are given in Table IV. Differences among locations were not significant, although the range of means over all varieties was 0.346 to 0.388% of grain weight and 2.30 to 2.44% of protein. All of the triticale varieties were significantly higher than the wheets: 0.428 and 0.307% of grain and 2.63 and 2.14% of protein for triticale and wheat means, respectively. Rosner triticale had significantly higher lysine content than the other triticales or the wheats. The difference between triticale and wheat for lysine content in the grain (39%) was greater than the difference between the two crops for lysine content in the protein (23%). The latter value no doubt results from differences in the kind of protein in the two crops, while the former may indicate a difference in the amount of protein as well as kind. The difference between wheat and triticale seems quite large and suggests that additional work on the nutritional aspects of triticale is needed, both for whole-grain and for milled food products. Since it was determined that a portion of the advantage for triticale was the higher lysine component of protein, it seems likely that this can be maintained while genetic improvements in endosperm development of triticale are being made.

**Table V. Percentage Contribution of Each Variety to Locations × Varieties Interaction Variation**

| Character | Triticale | | | Wheat | | |
|---|---|---|---|---|---|---|
| | T-1324 | 6TA-204 | Rosner | Siete Cerros 66 | INIA 66 | Oviachic 65 |
| Grain yield | 26.6[c] | 8.1 | 10.5 | 17.0[b] | 33.1[c] | 4.7 |
| Protein yield | 24.2[b] | 11.5 | 15.3 | 17.5[a] | 28.7[c] | 2.8 |
| Lysine yield | 17.8[b] | 15.1 | 25.8[c] | 12.4 | 28.3[c] | 0.6 |

[a] $0.05 < p < 0.10$. [b] $0.01 < p < 0.05$. [c] $p < 0.01$.

Lysine yields per acre, as for protein yields, depend to a large extent on the productivity of the variety. However, in contrast to the results for protein, the difference between triticale and wheat was not significant (14.2 and 14.5 lb/acre, respectively, Table IV). The large advantage of the triticale in lysine in grain compensated for the disadvantage in grain yields. The triticale 6TA-204 produced significantly more lysine per acre than the other wheat or triticale varieties. This result was particularly striking at Tulelake when it produced 6.0 lb/acre or 27% more lysine than Siete Cerros 66, the next highest variety.

**Environmental Stability.** It is widely recognized that there are large season-to-season and location-to-location differences in grain yield and protein content. These differences have strong economic and nutritional implications from the standpoint of production and quality of the product, especially with bread wheat for which protein content is correlated with loaf volume and other quality characteristics. In the present study large environmental (location) effects were noted for total production of grain, protein, and lysine. However, for the locations and year studied, protein and lysine contents were remarkably constant, as indicated by nonsignificant location and variety × location effects. Grain production showed strong interaction of varieties with locations and this was carried through to protein and lysine yields per acre.

It is desirable to identify genotypes that show a minimum interaction with environments. The variety × location interaction sums of squares in the analyses of variance (Table I) were subdivided using Wricke's (1962) method to determine the contribution of each variety (Table V). Since there were six varieties in the experiment, each is expected to contribute 16.7% to the total interaction. Positive deviations from this value indicate varietal instability and negative deviations indicate stability. Table V shows that, for grain, protein, and lysine yields, T-1324 triticale and INIA 66 wheat were unstable over environments. Rosner showed instability for lysine yield and Siete Cerros 66 was moderately unstable for grain and protein yields. Oviachic 65 was remarkably stable and 6TA-204 showed good stability. There was no qualitative difference in stability of triticale and wheat varieties and these results support the data of Kaltsikes (1971) in a study of Rosner triticale and four wheat varieties in Canada. Over all locations INIA 66 was the highest-yielding wheat variety and 6TA-204 was the highest-yielding triticale. It is somewhat surprising that these two varieties differ so greatly in stability. This difference is related to differences in growth characteristics of the varieties, but the particular factors have not yet been determined.

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# The System $NH_3$–$K_2O$–$H_3PO_4$–$H_4P_2O_7$–$H_2O$ at 25°

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Study of the system $NH_3$–$K_2O$–$H_3PO_4$–$H_4P_2O_7$–$H_2O$ at 25° disclosed the presence of three new ammonium potassium pyrophosphates—$(NH_4,K)_3HP_2O_7 \cdot H_2O$, $(NH_4,K)_2H_2P_2O_7 \cdot 0.5H_2O$, and $(NH_4,K)_2H_2P_2O_{7-8}$ in each of which the ratio N:K ranged continuously within definite limits. These mixed salts, whose optical properties, X-ray powder diffraction patterns, and infrared spectra are reported, are not members of isomorphous series with the pure ammonium or potassium end members. Results of measurements of solubility in the system show that the total plant-nutrient content (N + $P_2O_5$ + $K_2O$) of the saturated solution can be raised from 51.9 to 56.1% by adding potassium phosphate to an ammonium phosphate solution, and from 63.6 to 65.2% by adding ammonium phosphate to a potassium phosphate solution.

Commercial liquid polyphosphate fertilizers that contain all three major plant nutrients (N, $P_2O_5$, and $K_2O$) have relatively low concentrations, such as 7-21-7, 14-8-8, and 4-11-11. In these solutions the potassium is usually added as the chloride, a salt that is slightly more soluble than the nitrate and more than twice as soluble as the sulfate, but only half as soluble as the phosphate when the pH is between 5.5 and 7.0, the range in which most liquid fertilizers fall.

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In the continuing search for stable, high-analysis liquid fertilizers, measurements have been made of solubilities in the systems $NH_3$–$H_4P_2O_7$–$H_2O$ at 0° and 25° (Farr and Fleming, 1965), $NH_3$–$H_3PO_4$–$H_4P_2O_7$–$H_2O$ at 0° (Farr and Williard, 1971), and $K_2O$–$H_3PO_4$–$H_4P_2O_7$–$H_2O$ at 25° (Frazier *et al.*, 1972). Each of these systems, however, contained only two of the three major plant nutrients, and the system $NH_3$–$K_2O$–$H_3PO_4$–$H_4P_2O_7$–$H_2O$ at 25° was investigated to determine the concentrations of the three nutrient elements that could be obtained in a single solution. From previous studies it was concluded that this five-component system would contain no mixed orthopy-