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LITERATURE CITED

Akeson, W. R., Stahmann, M. A., *J. Nutr.* **83**, 257 (1964).
Azari, P. R., Feeney, R. E., *J. Biol. Chem.* **232**, 293 (1958).
Barker, R. D. J., Derbyshire, E., Yarwood, A., Boulter, D., *Phytochemistry* **15**, 751 (1976).
Basaraba, J., Starkey, R. L., *Soil Sci.* **101**, 17 (1966).
Boonvisut, S., Whitaker, J. R., *J. Agric. Food Chem.* **24**, 1130 (1976).
Burns, R. E., *Agron. J.* **63**, 511 (1971).
Elodi, P., Szabolcsi, G., *Nature (London)* **184**, 56 (1959).
Feeny, P. P., *Phytochemistry* **8**, 2119 (1969).
Fields, R., *Biochem. J.* **124**, 581 (1971).
Fields, R., *Methods Enzymol.* **25B**, 464 (1972).
Fukushima, D., *Cereal Chem.* **45**, 203 (1968).
Galembeck, F., Ryan, D. S., Whitaker, J. R., Feeney, R. E., *J. Agric. Food Chem.* **25**, 238 (1977).
Gorini, L., Audrain, L., *Biochim. Biophys. Acta* **9**, 180 (1952).
Hall, T. C., private communication, 1977.
Hsu, H. W., Vavak, D. L., Satterlee, L. D., Miller, G. A., *J. Food. Sci.* **42**, 1269 (1977).
Kakade, M. L., Arnold, R. L., Liener, I. E., Waibel, P. E., *J. Nutr.* **99**, 34 (1969).
Kadade, M. L., Hoffa, D. E., Liener, I. E., *J. Nutr.* **103**, 1772 (1973).
Kakade, M. L., *J. Agric. Food Chem.* **22**, 550 (1974).
King, T. P., Spencer, M., *J. Biol. Chem.* **245**, 6134 (1970).
Kleczkowski, A., van Kammen, A., *Biochim. Biophys. Acta* **53**, 181 (1961).
Laemmeli, U. K., *Nature (London)* **227**, 680 (1970).
Liener, I. E., *J. Food Sci.* **41**, 1076 (1976).
Maga, J. A., Lorenz, K., Onayemi, O., *J. Food. Sci.* **38**, 173 (1973).
Marquardt, R. R., Ward, A. T., Campbell, L. D., Cansfield, P. E., *J. Nutr.* **107**, 1313 (1977).
Mihalyi, E., "Application of Proteolytic Enzymes to Protein Structure Studies", CRC Press, Cleveland, Ohio, 1972.
Nelson, T. S., Stephenson, E. L., Burgos, A., Floyd, J., York, J. O., *Poult. Sci.* **54**, 1620 (1975).
Nirenberg, M. W., Jakoby, W. B., *Proc. Natl. Acad. Sci. U.S.A.* **46**, 206 (1960).
Oakes, J., *J. Chem. Soc., Faraday Trans 1* **72**, 228 (1976).
Racusen, D., Foote, M., *Can. J. Bot.* **49**, 2107 (1971).
Ramachandra, G., Virupaksha, T. K., Shadaksharaswamy, M., *J. Agric. Food Chem.* **25**, 1101 (1977).
Romero, J., Sun, S. M., McLeester, R. C., Bliss, F. A., Hall, T. C., *Plant Physiol.* **56**, 776 (1975).
Saunders, R. M., Connor, M. A., Booth, A. N., Bickoff, E. M., Kohler, G. O., *J. Nutr.* **103**, 530 (1973).
Seidl, D., Jaffe, M., Jaffe, W. G., *J. Agric. Food Chem.* **17**, 1318 (1969).
Sheffner, A. L., *Newer Methods Nutr. Biochem.* **3**, 125, (1967).
Stockman, D. R., Hall, T. C., Ryan, D. S., *Plant Physiol.* **58**, 272 (1976).
Sun, S. M., Hall, T. C., *J. Agric. Food Chem.* **23**, 184 (1975).
Trayser, K. A., Colowick, S. P., *Arch. Biochem. Biophys.* **94**, 169 (1961).
Turner, R. H., Liener, I. E., *J. Agric. Food Chem.* **23**, 484 (1975).
Ward, A. T., Marquardt, R. R., Campbell, L. D., *J. Nutr.* **107**, 1325 (1977).

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Comparative Nutritive Value and Amino Acid Content of Triticale, Wheat, and Rye

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A study was conducted to compare the nutritive value, i.e., PER (protein efficiency ratio) and NPR (net protein retention), and amino acid content of triticale (a cross between wheat and rye) with that of wheat and rye. The protein quality index based on PER and NPR at a 10% protein level was found to be highest in rye, followed by triticale and wheat. A chemical score based on the essential amino acid content of egg protein and an FAO provisional pattern of milk protein indicates the level of amino acids which are limiting in rye, triticale, and wheat. The EAAI (essential amino acid index) and BV (biological value) were also calculated.

Triticale, a relatively new cereal, was developed by crossing two species of cereal grains, wheat and rye. The name was derived from the generic classification of these grains (*Triticum*, wheat and *Secale*, rye). Plant breeders have since developed some tetraploid and hexaploid triticales that combine the characteristics of both wheat and rye (Briggle, 1969). These new selections have shown improvement in plant fertility, vigor, and yield. They are drought resistant and yield about 50% more than wheat under poor moisture conditions.

The dietary value of triticale in comparison with other cereals like wheat, sorghum, barley, corn, and bran in different species has been reported by Bragg and Sharly (1970), Mertz et al. (1975), Stringham (1971), Lofgreen (1971), McCloy et al. (1971), and Palta and Arora (1973). Research data are very limited concerning the use of tetraploid or hexaploid triticales as food grain by rats. No biological test data based on PER, NPR, and amino acid content have been reported so far in parent, offspring, and newly developed dwarf variety wheats. The present paper describes results of such investigation on amber-colored dwarf mutant variety Kalyan Sona (normal protein wheat variety), HD4502 (a high protein wheat variety), rye, and triticale (tetraploid) developed at the Indian Agricultural Research Institute, New Delhi.

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MATERIALS AND METHODS

Crops Samples. Seeds of Kalyan Sona, HD4502, rye, and triticale were collected from a field experiment conducted by the Division of Genetics of the Indian

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Table I. Protein Efficiency Ratio (PER) Values of Wheat, Rye, Triticale, and Casein Samples[b]

	HD4502	Kalyan Sona	Rye	Triticale	Casein
Av initial wt, g	29.5 ± 1.6[a]	29.3 ± 2.04[a]	29.5 ± 1.8[a]	29.5 ± 1.6[a]	29.3 ± 1.6[a]
Av total wt gained, g	16.0 ± 1.76[a]	12.0 ± 1.09[a]	24.0 ± 4.07[a]	21.0 ± 2.88[a]	54.0 ± 21.2[a]
Av total feed consumed, g	131	130	165	150	190
Av protein intake at 10% level	13 ± 1.19[a]	13 ± 1.19[a]	16.5 ± 1.91[a]	15 ± 1.6[a]	19 ± 2.54[a]
PER	1.23 ± 0.01[a]	0.92 ± 0.006[a]	1.45 ± 0.015[a]	1.40 ± 0.012[a]	2.81 ± 0.054[a]
F value obsd	15.8**[c]		4.16*	1.18	3.24*

[a] Standard error. [b] Duration of experiment: 28 days (three male and three female rats in each group). [c] (*) significant at the 0.05 level; (**) significant at 0.01 level.

Agricultural Research Institute, New Delhi. In this experiment, nitrogen at the rate of 80 kg/ha was applied to the high nitrogen responsive dwarf variety wheat, rye, and triticale. P_2O_5 and K_2O were applied at the rate of 40 and 20 kg/ha, respectively.

Methods. Samples were dried in a hot-air oven at 105 °C for 6 h for the determination of moisture. The protein content of the samples was calculated by multiplying the Kjeldahl N by 5.7. The amino acid composition was studied using a Technicon automatic amino acid analyzer. Defatted samples containing 5 mg of protein were hydrolyzed by refluxing with 5 mL of 6 N HCl for 22 h. After removal of acid by evaporation under reduced pressure, the residue was dissolved in 2 mL of citrate buffer (pH 2.875). An aliquot (0.4 mL) was used for determination of amino acids according to the method of Moore and Stein (1954). Tryptophan was determined by the method of Spies and Chambers (1949).

Diets. The diets for all the biological experiments were prepared at a 10% protein level. The composition of 100 g of diet was as follows: test sample flour, calculated weight to give 10% protein; groundnut oil, 10 g (containing 1 mg or 100 IU of vitamin E); 4% mineral mixture (U.S.P. XVII 4) composition as per Sikka et al. (1975); 5 g of glucose and 5 g of a complete vitamin mixture (Manna and Hauge, 1953); and 2 drops of adoxline containing vitamin A (12000 IU/g) and vitamin D_2 (IP 2000 IU/g) was fed orally twice a week.

Protein Efficiency Ratio (PER). PER was determined by the method of Osborne et al. (1919). Weanling albino rats about 22-days old and weighing 30–40 g were divided into six groups. All groups within each experiment had the same average initial weight. Each group consisted of three males and three females.

The rats were placed in individual all-wire cages with a raised platform. Water was available to them at all times. Food intake was measured every day; spilled food was collected daily and used to correct the amount of food intake. The animals were weighed twice a week for 4 weeks or 28 days.

Net Protein Retention (NPR). NPR was determined by the method of Bender and Doell (1957). One-month-old albino rats, three males and three females in each group (six groups in all), having the same initial weight were used. All grain flours in the diet were at 10% protein level. A nonprotein diet was prepared by replacing grain flour with protein-free starch in the diet. Four groups were fed with four grains of flour, one was given a nonproteinous diet, and one group was given a standard casein diet. The experiment was continued for 10 days. The weight of each rat was recorded every third day. NPR was calculated as follows:

$$\text{NPR} = \frac{\text{Wt gain of TPG} + \text{wt loss of NPG}}{\text{Wt of protein consumed}}$$

where TPG = test protein group (wheat, rye, and triticale) and NPG = nonprotein group.

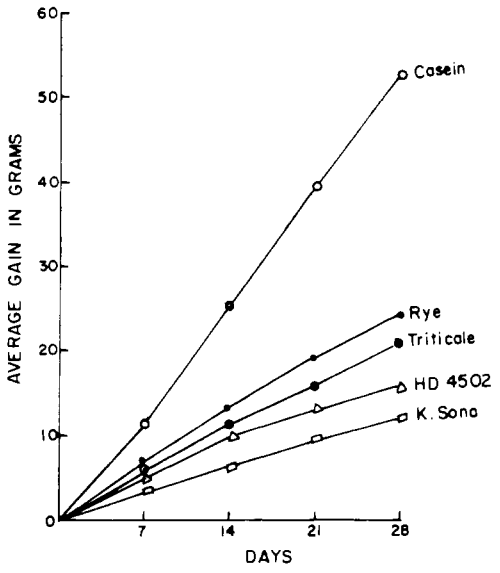

Figure 1. Growth curves showing average weekly gains of six rats fed whole wheat meal: HD4502 (Δ), K. Sona (□), triticale (⊙), and casein (○).

RESULTS AND DISCUSSION

Table I shows food intake, protein intake, weight gain, and PER. The PER values reveal that rye, closely followed by triticale, had better protein quality than high protein content wheat HD4502 (18%) and normal protein content wheat Kalyan Sona (14.6%). Growth rate in different periods was uniform in the weanling rats when weighed every fourth day or after a week. Since all the diets were at 10% protein level, the rats fed rye and triticale grew at faster rates than rats fed with high and normal protein wheat (Figure 1). The average weight gain rat^{-1} $week^{-1}$ was higher in the cases of rye and triticale than high or normal protein content wheat. Similar higher growth rate have been reported by Mertz et al. (1975), Palta and Arora (1973), and McCloy et al. (1971) with triticale over wheat, sorghum, and bran in rats and sheeps. The growth rate in the case of rye was significant at the 5% level over normal protein content wheat or triticale (Table I). Further high protein content wheat has also given significantly higher growth rate at the 5 and 1% levels. The growth rate in case of triticale was higher than normal protein content wheat although it was not significant at the 5 or 1% levels (Table I). The PER values obtained in case of normal protein content wheat and triticale confirm the PER values obtained by Mitra and Das (1971) and Sikka et al. (1975) for wheat flour made from mutant dwarf variety Sharbati Sonora and Mertz et al. (1975) in the case of triticale.

Net Protein Retention. The NPR values of rye, triticale, and high and normal protein content wheats are presented in Table II. The values listed in Table II are highest for rye, followed by triticale, high protein content wheat, and normal protein content wheat. The NPR

Table II. Net Protein Retention (NPR) of Wheat, Rye, Triticale, and Casein at 10% Protein Level

Protein source	Av protein intake in 10 days, g	Av wt gain, g	Av wt loss in nonprotein diet, g	NPR
HD4502	4.6*[b] ± 0.70[a]	6.8* ± 1.54[a]	4.4	2.43* ± 0.19[a]
Kalyan Sona	4.6 ± 0.69	5.3 ± 0.93	4.4	2.12 ± 0.15
Rye	5.3 ± 0.95	9.7 ± 3.13	4.4	2.63 ± 0.23
Triticale	5.0 ± 0.80	7.7 ± 1.97	4.4	2.44 ± 0.19
Casein	5.6 ± 1.04	17.0 ± 9.6	4.4	3.82 ± 0.48

[a] Standard error. [b] Asterisk indicates average value (mean value of six animals).

Table III. Amino Acid Composition of Wheat, Rye and Triticale (g/16 g of N)

Amino acid	HD4502	Kalyan Sona	Rye	Triticale
Aspartic acid	5.63	5.41	6.52	6.27
Threonine	2.89	2.79	3.01	2.99
Serine	4.31	4.26	3.59	3.88
Glutamic acid	31.55	30.02	26.66	29.42
Proline	9.08	8.22	10.19	8.59
Glycine	3.62	4.09	3.98	3.91
Alanine	3.55	3.53	3.78	3.85
Valine	4.50	4.14	4.60	4.71
Cystine	1.84	2.09	2.22	1.88
Methionine	1.52	1.56	1.60	1.55
Isoleucine	3.73	3.42	3.48	3.51
Leucine	6.58	6.40	6.00	6.35
Tyrosine	3.24	3.33	2.74	2.99
Phenylalanine	5.00	4.20	4.53	4.44
Lysine	2.62	2.87	3.33	2.56
Histidine	2.24	2.29	2.21	1.99
Arginine	4.90	5.05	5.13	5.41
Tryptophan	1.04	1.14	0.96	0.90
Ammonia	2.68	2.75	1.95	2.56
Protein, g/100 g of sample	18.00	14.60	16.30	18.00

values appear to magnify the difference in protein quality of rye, triticale, and high and normal protein content wheat to a greater extent than PER because the NPR measures protein efficiency based on both growth and maintenance. However, the relative order remains the same as in PER except that triticale and high protein wheat HD4502 come very close to each other. The results of both biological determinations (PER and NPR) in the case of rye, triticale, and wheat are supported by the results of earlier workers who have reported the possibility of rye grain being superior to wheat because of probable high lysine content (Kalmykov, 1968) or higher biological value of rye protein (Kofranyi and Mullar, 1961; Mc'Elroy, 1971).

Amino Acid, Chemical Score, BV, and EAAI. The amino acid composition of rye, triticale, and high and normal protein content wheat is presented in Tables III and IV. It is observed from Tables III and IV that rye, triticale, and high protein content wheat are deficient to a much lesser extent in the number of amino acids as compared to FAO pattern (1973). The first and second limiting amino acids in rye, triticale, and high and normal protein content wheat are lysine and threonine. This agrees very well with the results of earlier workers Kalmykov (1968) in rye and Sikka et al. (1975) in whole wheat flour.

A close correlation was observed between PER and the amino acid composition. The overall low PER obtained in the case of wheat (high and normal protein content) is due to the deficiency of lysine and threonine and also due to a lesser amount of other essential amino acids Sikka et al. (1975).

Table IV. Essential Amino Acid Composition of Wheat, Rye, Triticale, Egg, and FAO Pattern (Milk) g/16 g of N

Essential amino acid	FAO/WHO scoring pattern (1973)	Egg	HD4502	Kalyan Sona	Rye	Triticale
Isoleucine	4.0	5.76	3.73	3.42	3.48	3.51
Leucine	7.04	8.90	6.58	6.40	6.00	6.35
Lysine	5.44	6.65	2.62	2.87	3.33	2.56
Phenylalanine + tyrosine	6.08	10.32	8.24	7.53	7.27	7.43
Methionine + cystine	3.52	5.36	3.36	3.63	3.86	3.43
Threonine	4.00	5.14	2.89	2.79	3.01	2.99
Tryptophan	0.96	1.50	1.04	1.14	0.96	0.90
Valine	4.96	7.54	4.50	4.14	4.60	4.71
Arginine		6.15	4.90	5.05	5.13	5.41

Table V. E:N, E:P, and E:T Ratios, Chemical Score, EAAI, and BV of Wheat, Rye, and Triticale[a]

Feedstuff	E:N	E:P	E:T	EAAI	Chemical score, %, egg	BV	Chemical score, %, FAO/WHO (1973)
HD4502	0.558	0.360	0.358	63.74	39.3	52	48.1
Kalyan Sona	0.582	0.349	0.368	63.54	43.1	55	52.7
Rye	0.579	0.354	0.366	64.59	50.0	60	61.2
Triticale	0.592	0.354	0.371	62.55	38.4	52	47.0
Egg				100.00	100.00	100	
FAO/WHO (1973)							100.0

[a] EAAI (essential amino acid index) is based upon the ratios of the amounts of essential amino acids in a protein relative to their amounts in whole egg protein (Oser, 1951). Chemical score is the percentage of the most deficient essential amino acid in the protein as compared to the requirement pattern (Mitchell and Block, 1946). E:N, ratio of essential amino acid to nonessential amino acid; E:P, ratio of essential amino acid to 100 g of protein; E:T, ratio of essential amino acid to total amino acids.

E:N (essential amino acids to nonessential amino acids), E:P (essential amino acids to protein), and E:T (essential amino acids to total amino acids) ratios, chemical score, EAAI, and BV in rye, triticale, and wheat are presented in Table V. The results show that E:N and E:T ratios are highest in triticale, followed by wheat, Kalyan Sona, and rye. The results obtained for chemical score, EAAI, and BV in the cases of wheat and rye agree very closely with those of Sharbati Sonora and rye reported by Eggum (1970) and Duggal and Eggum (1977). As observed from Table V, PER is well correlated with chemical score in the case of rye and wheat, but this is not true in the case of triticale. Superiority in terms of PER, NPR, and growth of triticale over wheat in this study could not be due to essential amino acids, but it could be due to some other unknown factors, such as digestibility.

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LITERATURE CITED

Bender, A. E., Doell, B. H., *Brit. J. Nutr.* **11**, 140 (1957).
Bragg, D. B., Sharly, T. F., *Poult. Sci.* **49**, 1022 (1970).
Briggle, L. W., *Crop. Sci.* **9**, 197 (1969).
Duggal, S. K., Eggum, B. O., Fifth International Symposium on Amino Acids, Budapest, 1977.
Eggum, B. O., International Atomic Energy Agency, IAEA-SM-132/40, 1970, p 289.
FAO/WHO, "Energy and Protein Requirements", Report of a Joint FAO/WHO Nutrition Report, Series No. 52, FAO, Rome, 1973.
Kalmykov, P. E., *Nutr. Abstr. Rev.* **38**, 1162 (1968).
Kofranyi, E., Muller Weeker, H., *Nutr. Abstr. Rev.* **31**, 524 (1961).
Lofgreen, G. P., *J. Anim. Sci.* **32**, 538 (1971).
Manna, L., Hauge, S. M., *J. Biol. Chem.* **202**, 91 (1953).
McCloy, A. W., Sherrod, L. B., Albin, R. C., Hansen, K. R., *J. Anim. Sci.* **32**, 534 (1971).
Mc'Elroy, L. W., *J. Anim. Sci.* **32**, 538 (1971).
Mertz, E. T., Jambunathan, R., Villegas, E., Bauer, R., Kies, C., McGinnis, J., Shenk, J. S., Symposia on High Quality Protein Maize, Purdue University, Lafayette, Ind., 1975, p 306.
Mitchel, H. H., Block, R. J., *J. Biol. Chem.* **163**, 599 (1946).
Mitra, G. N., Das, N. B., *J. Agric. Food Chem.* **19**, 927 (1971).
Moore, S., Stein, W. H., *J. Biol. Chem.* **211**, 892 (1954).
Osborne, T. B., Mendel, L. B., Ferry, E. L., *J. Biol. Chem.* **37**, 223 (1919).
Oser, B. L., *J. Am. Diet. Assoc.* **27**, 396 (1951).
Palta, S., Arora, S. P., *Ind. J. Anim. Sci.* **43**, 388 (1973).
Sikka, K. C., Johari, R. P., Duggal, S. K., Ahuja, V. P., Austin, A., *J. Agric. Food Chem.* **23**, 24 (1975).
Spies, J. R., Chambers, D. C., *Anal. Chem.* **21**, 1240 (1949).
Stringham, E. W., *J. Anim. Sci.* **32**, 538 (1971).

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Volatile Aroma Components of Cooked Artichoke

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The volatile oil of artichokes (*Cynara scolymus*), obtained by atmospheric steam distillation continuous extraction, was analyzed by the direct combination of capillary gas chromatography and mass spectrometry. A total of 32 compounds were characterized. The major components were β-selinene and caryophyllene. Odor threshold determinations indicated that the components most important to the aroma included oct-1-en-3-one, hex-1-en-3-one, decanal, non-*trans*-2-enal, phenylacetaldehyde, and eugenol.

California is the main growing area for artichokes (*Cynara scolymus*) in the United States. An improved knowledge of the aroma constituents of artichokes could give a better basis for breeding for improved flavor in the production of artichokes. There have been a number of studies on the nonvolatile constituents of artichokes particularly in regard to bitter off-flavor components such as the sequiterpene lactones (Samek et al., 1971; Schneider and Thiele, 1974). However, there does not seem to have been any previous reports on the volatile aroma constituents of artichoke. The present work was begun with the purpose of characterizing the major important volatile aroma constituents.

EXPERIMENTAL SECTION

Materials. Whole fresh California artichokes (*Cynara scolymus*) were obtained from local retail markets.

Authentic samples of organic compounds were obtained from reliable commercial sources or synthesized by established methods. They were purified by gas–liquid chromatography (GLC) separation before use.

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Isolation of Volatile Oil. Fresh artichokes (3 kg) were cut into quarters and placed in a 12-L round-bottom flask. They were covered with odor-free water (6 L) and a Likens-Nickerson steam distillation continuous extraction head attached to the top of the flask. Freshly distilled diethyl ether (150 mL) containing a trace of Ionox 330 antioxidant was placed in a flask attached to the solvent arm of the head. The extraction was carried out at atmospheric pressure for 3 h. After drying over anhydrous sodium sulfate, the ether was removed by distillation through low hold-up Vigreux distillation columns to give the artichoke volatile oil.

For separation into hydrocarbon and oxygenated fractions, the artichoke volatile oil (50 μL) was placed on a column (12 × 100 mm) of silica gel (Mallinckrodt SilicAR CC-7). The hydrocarbon fraction was eluted with pentane (200 mL). The oxygenated fraction was then eluted with freshly distilled diethyl ether (200 mL). Solvent from both fractions was removed by distillation using low hold-up distillation columns.

Capillary GLC–Mass Spectral Analysis. This was carried out in a similar way to that previously described by the authors (Buttery et al., 1975). In the present work, two major types of capillary columns were used: a 150 m long × 0.75 mm i.d. Pyrex glass capillary column coated