Int. Agrophysics, 2001, 15, 279-285

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Fertilization and technological quality of wheat grain**

J. Sadowska[1], W. Błaszczak[1], T. Jeliński[1], J. Fornal[1], H. Borkowska[2], and B. Styk[2]*

[1]Division of Food Science, Institute of Animal Reproduction and Food Research, Polish Academy of Sciences, Tuwima 10, 10-747 Olsztyn, Poland
[2]Department of Cultivation and Plant Production, University of Agriculture, Akademicka 15, 20-950 Lublin, Poland

Received September 21, 2000; accepted February 6, 2001

A b s t r a c t. The influence of genetic and environmental effect on grain quality and physical properties for Polish varieties of winter wheat and spring wheat (*T. aestivum*) cultivated at three N-fertilization levels (50, 100 and 150 kg N ha^{-1}) was studied. The grain quality in varieties examined was ranged from bad/medium to medium/good according to COBORU system. The baking quality (LWP) ranged from 21 to 120 responding to medium and good quality of flour (except very good Omega). The general tendency of better baking quality of spring wheat than that of winter wheat was confirmed. The grain quality and physical properties of the cultivars examined were always strongly influenced by the variety and, above all, the form of the wheat, while the N-fertilization effects were not regular. Increasing the N-fertilization does not always regularly increase the bread-making quality of wheat grain.

K e y w o r d s: quality, N-fertilization, physical properties, wheat grain

INTRODUCTION

The genetic effect of wheat on grain quality is commonly accepted while influences of environmental (climate, soil, temperature) condition [4,7], watering [5], fertilization level [6,15] and timing [13], and crop rotation [12] are still widely discussed. Among those factors, the level of nitrogen fertilisation is very important which strongly affects the yield as well as the physical properties of the wheat grain.

The size and shape of kernels (expressed by weight of 1000 kernels and kernel size distribution in bulk grain) and the percentage of vitreous kernels are traditionally used in the preliminary evaluation of grain quality. Technological hardness, which is a very important quality factor underestimated in Poland, plays an important role in the classification of wheat with regard to their technological suitability. The fracture resistance of kernels can also be used in the general description of wheat hardness because the force required to deform the grain, the manner in which a fracture occurs, the particle size and sifting behaviour depend upon kernel hardness [1]. On the other hand, wheat grain of different sizes and mechanical resistance requires different processing conditions.

The aim of the present work was to find out the relations between the fertilization level and some physical properties and the technological quality of wheat grain.

MATERIAL AND METHODS

Material

Four varieties of winter wheat (Alba, Begra, Nike, Rosa) and four varieties of spring wheat (Alkora, Jota, Omega, Sigma) - wheat (*T. aestivum*) cultivated at three N-fertilization levels in the same location at the Experimental Station near Lublin in 1995/1996 were investigated. The wheat grain was mechanically harvested at full maturity and cleaned. The wheat samples were stored in a store room at a temperature below 10°C and in a respective humidity. The fertilization level of 50, 100 and 150 kg N ha^{-1} are sometimes replaced in the text and tables by Roman numerals, i.e., I, II, III, respectively. The kernels examined were conditioned until the technological moisture, i.e., 15 ± 0.1% had been reached.

Methods

The falling number was determined according to Polish Standard No. BN-81/8060-02.

*Corresponding author's e-mail: jaga@pan.olsztyn.pl
**This work was supported by the Polish Committee for Scientific Research under grant No. 5 P06G 00312.

© 2001 Institute of Agrophysics, Polish Academy of Sciences

The milling yield was done using mill type SD equipped with five grinding cylinders (ZPP Bydgoszcz, Poland).

The protein content (N×5.7) in whole wheat kernels was determined with Kjeldahl's standard method. Determinations were made in triplicate.

The sedimentation index was determined according to AACC Method No. 56-61A.

The wet gluten content was determined according to Polish Standard No. PN-A/7043 (equivalent to ISO Standard No. 5531).

The percentage of vitreous kernels was determined with Farinotom according to Polish Standard No. PN - 53/R - 74008.

The weight of 1000 kernels was determined according to Polish Standard No. PN-68/R-74017.

The compression resistance of wheat kernels was measured according to Sadowska *et al*. [18].

The mixing properties of dough were studied with a Brabender-like konsistometer SK-5 (ZPP Bydgoszcz, Poland) equipped with a 80 ml stainless steel mixing bowl using the standard ICC No. 115 procedure.

Experimental yeast breads from wheat flour were baked using the direct method and scored according to Jakubczyk and Haber [10].

The textural properties of the crumbs were measured during double compression using the Instron compression device 1011 [17].

Size and shape of kernel

Digital image analysis (DIA) was used for the determination of the size and shape of the wheat kernels. A manually ordered 100-kernel sample was positioned, crease-downwards, on a back-lit glass plate and a CCD camera (Elemis K-15 with objective type Ernitec 1:1.4 6-12 mm) and a Matrox Meteor (Matrox, USA) vision processor-board were used to obtain the wheat grain images. A digital analysis of images (768 × 576 pixels at 256 grey level) was made with Micro Image ver. 3.0 (Media Cybernetics, USA) software. Calibration was made using a few ‘2 grosze’ coins of a repeatable constant diameter. The contour of each kernel was detected automatically using the programme standard option Intensity Range Selection/Automatic Dark Object. Area, major and minor axes, aspect, maximum and minimum radius, perimeter, roundness expressed by formula $\text{perimeter}^2/(4 \times \text{area})$ and the length and width of the objects were measured. Major and minor axes report the length of the main and minor axes, respectively, of the ellipse equivalent to the object. The aspect is the ratio of those axes. Maximum and minimum radii report the maximum and minimum distance, respectively, between each object's centroid pixel position and its perimeter. The data collected was exported and stored in Microsoft Excel (Microsoft, USA) software.

The evaluation of wheat grain quality I was done according to Klockiewicz-Kamińska and Brzeziński [11]. The system for the evaluation of the quality of Polish wheat varieties developed and used in Research Centre for Cultivar Testing in Słupia Wielka is based on the determination of the following quality parameters: falling number, protein content, sedimentation index (or Zeleny index, if needed) in grain, the milling yield and the colour of the flour, water absorption and dough weakening determined with a Brabender farinograph, energy of dough tension (determined with extensometer) and a standardised volume of a loaf of bread baked in standard conditions. The results of the determinations scored are the basis for the final classification of both variety and grain technological quality.

The evaluation of wheat grain quality II was done by estimating the baking value of flours according to Jakubczyk and Haber [10].

The statistical analysis of results was carried out with Statistica ver. 5 (StatSoft, USA) software.

RESULTS AND DISCUSSION

For a detailed evaluation of the technological quality of wheat grain, both quality parameters and physical properties characterising wheat hardness and vitreosity and kernel size were determined (Tables 1-3). The varietal differences in weight of 1000 kernels and the size and shape of single kernels (characterised by digital image analysis) were observed. It is worth noting, that kernels were always larger (irrespective of variety and fertilization level) in winter wheat than in spring wheat (Table 1). In general, wheat grains demonstrated typical vitreosity (from 75.2 to 90.0% of vitreous kernels), except Rosa and Alba grains, which were characterised by medium vitreosity, i.e., 31.0-64.4% and 65.2-74.0%, respectively (Table 1). Two weaker cultivars (Alba and Rosa) of medium vitreosity and one extremely strong (Sigma) of the highest vitreosity were found in mechanically tested wheat (Table 1). Mechanical resistance expressed by fracture and corrected force (fracture force value corrected for different thickness of kernels) have been partly matched with technological hardness of the same samples determined with SKCS apparatus by Grundas *et al*. [8], who classified the varieties examined as hard wheat, except cv. Rosa which was scored as medium wheat.

Determined values of quality indices were presented in Table 2. The obtained values of protein and wet gluten content, sedimentation index and falling number were always higher for spring wheat than those for winter wheat (Table 2). Rothkaehl [16] discussing the quality of Polish winter wheat and spring wheat cultivated in 1995 in 8 regions, noted that the protein content ranged from 8.4 to 15.7 and from 9.2 to 17.0% dm., the wet gluten content ranged from 14.7 to 36.2% and from 17.5 to 38.7%, the sedimentation indices were 14-56 and 23-61 ml, and the

T a b l e 1. Physical properties of spring wheat and winter wheat grains

Variety	Weight of 1000 kernels	Geometrical features of kernel projection				Vitreosity (%)	Resistance for compression	
		Area (mm^2)	Width (mm)	Roundness (-)	Aspect (-)		Fracture force (N)	Corrected force (N mm^{-1})
				Spring wheat				
Alkora I	27.3	15.16	2.78	1.384	2.539	78.8	107.7	32.2
Alkora II	25.8	15.30	2.80	1.392	2.510	77.5	122.8	39.1
Alkora III	25.7	15.26	278	1400	2.557	80.0	142.8	43.7
Jota I	25.1	14.35	2.60	1.348	2.410	83.6	121.8	39.6
Jota II	23.6	14.28	2.76	1.343	2.407	78.8	99.9	33.1
Jota III	23.7	14.37	2.78	1.341	2.393	88.0	94.0	30.3
Omega I	27.8	15.16	2.98	1.286	2.193	76.8	152.8	46.3
Omega II	25.1	14.79	2.94	1.282	2.192	80.4	100.9	31.6
Omega III	26.4	14.74	2.93	1.278	2.188	87.2	101.6	32.7
Sigma I	28.1	15.92	3.24	1.213	1.945	89.2	164.7	48.8
Sigma II	32.4	15.75	3.24	1.209	1.921	88.4	133.3	40.4
Sigma III	35.6	15.97	3.26	1.204	1.925	90.0	110.6	32.9
				Winter wheat				
Alba I	31.4	16.71	3.13	1.307	2.187	66.4	72.0	22.1
Alba II	30.2	16.33	3.06	1.326	2.239	74.0	65.8	19.9
Alba III	45.7	16.01	3.02	1.331	2.253	65.2	79.4	24.0
Begra I	44.8	17.72	3.37	1.239	1.996	65.2	156.3	45.1
Begra II	42.8	18.43	3.41	1.256	2.035	82.8	132.5	38.8
Begra III	43.1	17.86	3.32	1.266	2.078	86.0	127.7	37.9
Nike I	42.2	19.22	3.35	1.318	2.201	75.2	104.6	31.6
Nike II	45.1	18.96	3.34	1.318	2.211	78.8	102.0	30.7
Nike III	43.7	19.66	3.40	1.311	2.188	89.2	139.6	41.4
Rosa I	42.9	17.98	3.30	1.273	2.113	31.0	118.5	35.1
Rosa II	41.7	18.35	3.34	1.271	2.107	64.4	106.3	32.1
Rosa III	41.7	18.47	3.30	1.291	2.177	54.0	102.4	30.4

falling numbers were 138 - 362 and 78-383 s, respectively. These results also confirmed the general tendency of the better baking quality of spring wheat than that for the winter wheat. The water absorption and weakening values (Table 2) indicated the diversified rheological characteristics of experimental dough, from very weak Alba (winter wheat, 11 < FQN < 25) to hard from Sigma (spring wheat, 120 < FQN < 130). The final result of quality evaluation was presented in Table 2. The grain quality ranged from bad/medium to medium/good according to the COBORU classification system. The baking quality (LWP) calculated according to Jakubczyk and Haber [10] ranged from 21 to 120 responding the medium and good quality of the flour (except cv. Omega, which was scored as very good). The texture of the experimental loaves was similar, except that the bread from the Sigma flour whose crumbs were characterised by a high degree of hardness and stickiness (Table 3).

The wheat variety and N-fertilization level were accepted as dependent variables and independent variables were arranged into following groups: 1 - features of kernel geometry (defined in Methods), 2 - physical properties (mentioned in Table 1), 3 - parameters of grain quality (Table 2), and 4 - bread texture (Table 3) for statistical analysis. Even so, the simple statistical method, as for example ANOVA, showed a statistically significant (at $p \leq 0.05$) effect of wheat form and variety on all the parameters analysed. The MANOVA multivariate variance analysis always confirmed the statistically significant effect (at $p \leq 0.05$) of the wheat variety while the fertilization level affected significantly only the physical properties and quality parameters of the grains (Table 4). The differences observed in the parameters examined were not always regularly related to an increased fertilization level. Then, for a detailed estimation of the fertilization influence, discriminatory analysis was used. Discriminatory analysis calculations were conducted separately for spring wheat and winter wheat because of the explicitly significant differences in grains dependent on the wheat form. The significant influence of the variety was again confirmed for both the spring wheat and winter wheat groups. The discrimination power of the variety in independent variable groups was, however, diversified - Wilks' coefficients ranged from

T a b l e 2. Grain quality of spring wheat and winter wheat cultivars

Variety	Protein content (% d.m.)	Wet gluten content (%)	Sedimen-tation index (ml)	Falling number (s)	Milling yield (%)	Water absorption (%)	Weaking (Brab. U.)	Bread volume (g/100 g)	Quality evaluation	
					Spring wheat					
Alkora I	15.7	31.1	39	331	70.3	65.0	60	420	5.9	M/G
Alkora II	14.9	31.7	39	361	70.5	62.0	50	426	6.1	M/G
Alkora III	15.3	31.2	38	372	69.7	62.0	50	425	5.7	M/G
Jota I	15.8	30.9	38	300	67.0	61.2	50	418	5.7	M/G
Jota II	15.6	33.6	37	270	68.2	62.6	70	431	5.3	M
Jota III	15.6	32.8	38	262	68.1	61.4	80	433	5.0	M
Omega I	15.5	29.9	46	363	69.2	60.2	40	452	6.1	M/G
Omega II	15.8	31.5	50	326	68.9	61.4	50	443	6.0	M/G
Omega III	15.7	30.5	46	241	71.5	62.2	10	349	6.0	M/G
Sigma I	13.4	25.9	66	276	74.3	55.0	0	362	4.1	B/M
Sigma II	13.6	26.7	60	270	72.6	55.4	0	380	5.1	M
Sigma III	14.4	27.0	62	297	72.5	56.0	10	366	5.0	M
					Winter wheat					
Alba I	12.3	19.9	29	264	75.0	50.2	160	382	39	B/M
Alba II	11.9	24.2	34	264	73.3	51.8	110	428	37	B/M
Alba III	13.0	27.8	37	250	73.3	52.0	120	433	41	B/M
Begra I	11.6	17.8	34	261	77.1	53.8	60	365	43	B/M
Begra II	12.4	23.2	48	255	76.8	53.4	30	418	53	M
Begra III	12.6	25.9	52	264	75.5	53.0	30	427	53	M
Nike I	11.7	22.5	36	264	75.0	53.4	90	426	40	B/M
Nike II	13.1	26.1	44	250	74.2	55.8	60	463	51	M
Nike III	14.9	30.8	46	227	73.4	53.2	70	425	50	M
Rosa I	11.4	21.5	49	294	74.8	52.0	70	417	59	M/G
Rosa II	12.8	26.2	58	270	73.1	53.0	20	413	60	M/G
Rosa III	14.5	27.0	60	287	72.0	52.8	50	401	64	M/G

0.0000 to 0.0760 for predicted arrangements of independent variables (Tables 5 and 6). Influence of N-fertilization levels on the parameters examined in the wheat form groups was not found univocal again. The classification of the fertilization group according to physical properties, quality parameters and bread texture of the spring wheat was impossible and two fertilization groups (50 kg N ha^{-1}) and (100 and 150 kg N ha^{-1}) were discriminated in kernel geometry features (Table 5). The classification of fertilization groups in winter wheat was accurate for the physical properties and quality parameters while kernel geometry and bread texture groups remained indivisible (Table 6). Subsequently, the discrimination analysis results also confirmed the irregular changes of the parameters examined at the used N-fertilization levels.

The discriminatory analysis of all quality parameters for all the examined cultivars allowed two groups to be discriminated (winter and spring wheat) and two cultivars Alba (winter wheat) and Sigma (spring wheat) which did not fit into the basic group (Wilks' λ = 0.0053, percentage of correct classification = 100). A similar analysis for the indices of crumb texture confirmed the accuracy of classification into the above-mentioned classes (Wilks' λ = 0.0508, percentage of correct classification = 88.63).

The results presented of the wide-ranging statistical analysis, confirmed the evident influence of the genetic factor (variety and form of wheat) and the diverse effect of used levels of N-fertilization. The results obtained did not fully correspond with the results of other authors who found that the N-fertilization rate level had the most marked influence on grain quality indices and the increased fertilizer N rate regularly increased the grain protein content [3,12, 15]. The bread-making quality of the wheat was also found to have improved at the higher N-fertilization level [2,6,15]. Pechanek *et al*. [15] however suggested, that the protein quality, i.e., the ratio of high molecular weight (HMW) glutenins to total protein content could be the best early detectable parameter with the best predictive value for bread-making. Because the tendency of a protein content increase with increasing N-fertilization was often observed, a similar protein content found in some cultivars at all fertilization levels was probably caused by a reaction different to that in actual environmental conditions. Borghi *et al*. [2] also concluded that a statistically significant, interaction genotype × environment calls for a more precise management of

T a b l e 3. Textural properties of experimental breads

Variety	Hardness (kPa)	Elasticity	Cohesiveness	Guminess (kPa)	Recovery
			Spring wheat		
Alkora I	27.29	0.751	0.440	12.00	0.895
Alkora II	25.69	0.744	0.429	11.04	0.876
Alkora III	17.87	0.760	0.443	7.92	0.876
Jota I	29.09	0.847	0.381	11.09	0.787
Jota II	29.53	0.766	0.436	12.89	0,860
Jota III	21.06	0.781	0.464	9.77	0.885
Omega I	30.38	0.841	0.445	13.53	0.841
Omega II	21.82	0.810	0.493	10.76	0.896
Omega III	30.69	0.791	0.376	11.54	0.724
Sigma I	34.17	0.774	0.426	14.54	0.823
Sigma II	52.76	0.818	0.452	23.83	0.823
Sigma III	41.35	0.788	0.398	16.45	0.782
			Winter wheat		
Alba I	25.07	0.735	0.213	5.34	0.563
Alba II	23.50	0.778	0.241	5.66	0.548
Alba III	17.15	0.777	0.258	4.43	0.634
Begra I	35.75	0.709	0.232	8.31	0.409
Begra II	28.72	0.751	0.326	9.38	0.778
Begra III	30.85	0.764	0.326	10.05	0.736
Nike I	25.56	0.761	0.276	7.03	0.681
Nike II	20.90	0.729	0.216	4.51	0.668
Nike III	28.99	0.807	0.299	8.98	0.722
Rosa I	23.059	0.760	0.309	7.14	0.733
Rosa II	29.038	0.813	0.376	10.91	0.681
Rosa III	26.939	0.763	0.312	8.42	0.675

T a b l e 4. Results of MANOVA analysis

Grouping variables	Wilks' λ	Rao's R	df 1	df 2	p-level
			For physical properties of wheat grain		
Variety (1)	0.0002	70.6666	35	389	0.0000
N-fertilization level (2)	0.2492	18.4596	10	184	0.0000
Interaction (1) × (2)	0.0575	5.1901	70	442	0.0000
			For geometry of wheat kernels		
Variety (1)	0.0007	52.2756	35	389	0.0000
N-fertilization level (2)	0.8651	1.3830	10	184	0.1910
Interaction (1) × (2)	0.3987	1.3456	70	442	0.0416
			For quality parameters of wheat grain		
Variety (1)	0.0000	94.0195	49	95	0.0000
N-fertilization level (2)	0.0013	68.9067	14	36	0.0000
Interaction (1) × (2)	0.0000	13.5351	98	122	0.0000
			For quality parameters of experimental breads		
Variety (1)	0.0068	28.5944	35	439	0.0000
N-fertilization level (2)	0.9050	1.0648	10	208	0.3909
Interaction (1) × (2)	0.0642	5.5658	70	499	0.0000

T a b l e 5. Discrimination power for variety and fertilization of 5 groups using different characteristics of spring wheat grain

Grouping variables	Groups of independent variables			
	Physical properties	Size and shape of kernels	Quality parameters	Bread texture
Variety	$\lambda = 0.0526$[2] $p \leq 0.0495$	$\lambda = 0.0007$[1] $p \leq 0.0000$	$\lambda = 0.0000$[1] $p \leq 0.0039$	$\lambda = 0.0978$* $p \leq 0.2032$
N-fertilization level	$\lambda = 0.5093$* $p \leq 0.7603$	$\lambda = 0.2094$[3] $p \leq 0.0623$	$\lambda = 0.2749$* $p \leq 0.9864$	$\lambda = 0.6172$* $p \leq 0.8942$

1 - sharp discrimination; 2 - two groups: (Sigma) (Alkora, Jota, Omega); 3 - two groups (50 and 100, 150 kg ha^{-1}); *no discrimination.

T a b l e 6. Discrimination power for variety and fertilization of 3 groups using different characteristics of winter wheat grain

Grouping variables	Groups of independent variables			
	Physical properties	Size and shape of kernels	Quality parameters	Bread texture
Variety	$\lambda = 0.0001$[1] $p \leq 0.0000$	$\lambda = 0.0117$[2] $p \leq 0.0000$	$\lambda = 0.0000$[1] $p \leq 0.0165$	$\lambda = 0.0275$[1] $p \leq 0.0193$
N-fertilization level	$\lambda = 0.0454$[1] $p \leq 0.0002$	$\lambda = 0.5101$* $p \leq 0.1319$	$\lambda = 0.0175$[1] $p \leq 0.0213$	$\lambda = 0.4698$* $p \leq 0.6957$

1 - sharp discrimination; 2 - three groups: (Alba), (Nike), (Begra, Rosa); *no discrimination.

nitrogen fertilization in relation to the cultivar and climatic condition in the growing region. Subsequently, it could be presumed that the N-fertilization level should be classified in relation to the individual needs of the cultivars and the climatic conditions. It is known that the weather affects the behaviour of nitrogen fertilizer [5]. It has been noted that in rainy years the variation depending upon N doses were small. On the other hand Hradecka and Staszkowa [9] informed that nitrogen fertilization had a positive effect on the grain yield in the two years 1994 and 1995 of the different weather conditions.

CONCLUSIONS

The grain quality and physical properties of the cultivars examined were always strongly influenced by the variety and, above all, the form of the wheat, while the N-fertilization effects were not regular. Increasing the N-fertilization does not always improve the bread-making quality of the wheat grain but the final conclusion requires repetition of the experiment in future years.

REFERENCES

1. **Anjum F.M. and Walker C.E., 1991.** Review on the significance of starch and protein to wheat kernel hardness. J. Sci. Food Agric., 56, 1-13.
2. **Borghi B., Corbellini M., Minoia C., Palumbo M., DiFonzo N., and Perenzin M., 1997.** Effects of Mediterranean climate on wheat bread-making quality. Eur. J. Agro., 6(3-4), 145-154.
3. **Borkowska H., Grundas S., and Styk B., 1999.** Influence of nitrogen fertilization of winter wheat on its gluten quality. Int. Agrophysics, 13, 333-335.
4. **Ciaffi M., Tozzi L., Borghi B., Corbelini M., and Lafiandra D., 1996.** Effect of heat shock during grain filling on the gluten protein composition of bread wheat. J. Cereal Sci., 24, 91-100.
5. **Convertini G., Moiorana M., Di Bari V., Rizzo V., and Vonella A.V., 1998.** Effects of nitrogen fertilization and watering on grain yield, dry matter accumulation and nitrogen uptake in durum wheat. Agrochimica, 42(5), 190-199.
6. **Fornal J., Sadowska J., Grundas S., and Pasqui A.L., 1994.** Wheat grain, gluten and dough structure. Proc. 14th ICC Congress, Hague, The Netherlands, 42.
7. **Gaines S.C., Finney P.L., and Rubenthaler G., 1996.** Milling and baking quality of some wheats developed for Eastern and Northwestern regions of United States and grown at both locations. Cereal Chem., 73, 521-525.
8. **Grundas S., Godecki M., Miœ A., Borkowska H., and Styk B., 1998.** Characteristics of technological properties of grain mechanically damaged during moisturizing (in Polish). Przegl¹d Zbo¿owo-M³ynarski, XLII(4), Supl. 1, 23-26 .
9. **Hradecka D. and Staszkowa L., 1996.** Influence of application of cytokinin and nitrogen fertilization on spring wheat. Rostl. Vyr., 42(7), 301-306.
10. **Jakubczyk T. and Haber T., 1981.** Analysis of Cereal Grain and Products (in Polish), SGGW-AR, Warszawa.
11. **Klockiewicz-Kamińska E., and Brzeziński W.J., 1998.** Method of evaluation and quality classification of wheat varieties (in Polish). Przegląd Zbożowo-Młynarski, XLII (1), 2-6.
12. **Lopez-Bellido L., Fuentes M., Castillo J.E., and Lopez-Garrido F.J., 1998.** Effect of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under

rainfed Mediterranean conditions. Field Crop Res., 57 (3), 265-276.

13. **Matson P.A., Naylor R., and Ortiz-Monasterio I., 1998.** Integration of enviromental, agronomic, and economic aspects of fertilizer management. Science, 280 (5360), 112-115.
14. **Ortiz-Monasterio J.I., Pena R.J., Sayre K.D., and Rajam S., 1997.** CIMMYT's genetic progress in wheat grain quality under four nitrogen rates. Crop Sci., 37 (3), 892-898.
15. **Pechanek U., Karger A., Gröger S., Charvat B., Schöggl G., and Lelley T., 1997.** Effect of nitrogen fertilization on quantity and flour protein components, dough properties, and breadmaking quality of wheat. Cereal Chem., 74, 800-805.
16. **Rothkaehl J., 1996.** Evaluation of basic technological parameters of wheat grain harvested in 1995 (in Polish). Przegl¹d Zbo¿owo-M³ynarski, XL, 2-6.
17. **Sadowska J., Fornal J., Vidal-Valverde C., and Frias J., 1999.** Natural fermentation of lentils. Functional properties and potential in breadmaking of fermented lentil flour. Nahrung - Food, 43, 396-401.
18. **Sadowska J., Jeliñski T., and Fornal J., 1999.** Comparison of microstructure of vitreous and mealy kernels of hard and soft wheat. Pol. J. Food Nutr. Sci., 8/49, 3-15.