UDC 633.11:632.534
ISSN 1330-9862

original scientific paper

(FTB-1241)

Wheat Grain and Flour Quality as Affected by Cropping Intensity

Boris Varga[1], *Zlatko Svečnjak*[1]*, *Zorica Jurković*[2], *Josip Kovačević*[2] *and Željko Jukić*[1]

[1]Department of Field Crops, Forage and Grasslands, Faculty of Agriculture, Svetošimunska 25, HR-10000 Zagreb, Croatia

[2]Agricultural Institute Osijek, Južno predgrađe 17, HR-31000 Osijek, Croatia

Received: June 23, 2003
Accepted: November 10, 2003

Summary

Average grain yield of 3.93 t/ha in Croatia in the last decade (1991–2001) indicates that winter wheat (*Triticum aestivum* L.) is still widely grown under extensive production systems primarily characterized by suboptimal nitrogen fertilization. Therefore, the object of this research was to evaluate the bread-making quality of grain and flour of different wheat cultivars as influenced by cropping intensity and foliar nitrogen application at flowering. A field experiment under two cropping intensities, called intensive and extensive production systems, was conducted in the 1999/2000 growing season at the Faculty of Agriculture in Zagreb. The use of an intensive production system compared to an extensive system significantly improved hectolitre weight (1.9 %), protein content (16.9 %), wet gluten (59.7 %), sedimentation (67.2 %), falling number (7.8 %), water absorption (2.0 %), dough development time (78.2 %), dough stability (900.0 %), dough resistance (138.1%) and farinograph quality number (142.8 %), while it had no effect on gluten index, flour yield and physical grain properties (1000-grain weight, grain length, width and thickness). Under the intensive system, compared to the extensive production system, only softening degree decreased by 29.5 %, which also had positive impact on bread-making quality of wheat. Foliar nitrogen application at flowering additionally improved hectolitre weight (1.1 %), protein content (6.1 %), wet gluten (11.8 %), sedimentation (16.5 %), water absorption (2.5 %) and dough development time (28.4 %). The findings showed that wheat with better bread-making quality might be achieved under intensive production systems, particularly with high nitrogen fertilization rates.

Key words: wheat, cultivar, nitrogen, quality, grain, flour

Introduction

Average grain yield of 3.93 t/ha in Croatia in the last decade (1991–2001) (*1*) indicates that winter wheat is still widely grown under extensive production systems, primarily characterized by suboptimal nitrogen fertilization. Hazen and Ward (*2*) pointed out that wheat milling and baking quality is a function of the physical and chemical traits of grain and flour. Milling quality refers to the properties important in the process of wheat milling (*3*). One of the oldest and most frequently used criteria for the evaluation of milling quality is hectolitre weight since it may indicate potential flour yield (*4*). However, the results of Altaf *et al*. (*5*) showed that smaller grains had lower flour yield although there were no significant differences in hectolitre weight be-

* Corresponding author; Phone: ++385 (0)1 239 3774; Fax: ++385 (0)1 239 3703; E-mail: svecnjak@agr.hr

tween bigger and smaller grains for the same wheat cultivar. Hoshino *et al*. (*6*) also found that flour yield improved with increased grain size and that farinograph properties varied with different grain dimensions. The authors showed that by milling larger grains greater flour yield was achieved, although better quality of flour was obtained by milling smaller grains.

Pushman and Bingham (*7*) clearly demonstrated that intensified wheat fertilization with nitrogen resulted in better milling and baking quality through increased hectolitre weight, grain protein content, flour water absorption and bread volume. Recently, the results of Johanson (*8*) have shown that intensive management, particularly more intensive nitrogen fertilization, had a significant influence on grain nitrogen content, protein composition and falling number. Gooding *et al*. (*9*) also found that nitrogen fertilization positively affected protein content and falling number. According to McNeal *et al*. (*10*), intensive application of nitrogen fertilizers significantly improved flour farinograph properties and baking quality as a consequence of better water absorption and bread volume. Furthermore, in research conducted in England (*7*) foliar nitrogen fertilization at flowering resulted in the additional increase of protein content in wheat grain. The goal of the present research was to evaluate the bread-making quality of grain and flour of different wheat cultivars as affected by cropping intensity and foliar nitrogen application at flowering.

Materials and Methods

Field experiment

A field experiment with a winter wheat (*Triticum aestivum* L.)-corn (*Zea mays* L.)-soybean (*Glycine max* L. Merr.) crop rotation was conducted on a silt loam soil (Typic Udifluvents) at the experimental field of the Faculty of Agriculture in Zagreb, in northwestern Croatia, during the 1999–2000 growing season. Three widely grown winter wheat cultivars (Marija, Žitarka and Renan) in Croatia were planted under both intensive and extensive production systems, which were established on adjacent plots. Previous crops (corn and soybean) were also grown at these two production input levels. The experimental design for each production system consisted of four replications with two factors arranged in a randomized complete block in a split-plot design. Foliar application of nitrogen at flowering *vs*. none (non-treated plots) was the whole-plot factor, while cultivars were the sub-plot factor.

Summary of production treatments is presented in Table 1. The intensive system involved ploughing at 30–32 cm, fertilization with 194 kg/ha N including three top-dressing applications (54, 27, and 27 kg/ha N at growth stages 22, 24 and 31, respectively, while the remaining 86 kg/ha N was added during the basal fertilization) (*11*), 130 kg/ha P, 130 kg/ha K, and high input of crop protection chemicals (herbicides, fungicides and insecticides). The extensive production system consisted of ploughing at 20–22 cm, fertilization with 59 kg/ha N including one top-dressing application with 27 kg/ha N at growth stage 24 (while the remaining 32 kg/ha N was added during the basal fertilization), 104 kg/ha P and 104 kg/ha K. Weeds were controlled with less effective herbicides, while none of the fungicides and insecticides was applied in the extensive system. At seeding, plots consisted of 10 rows 11 cm apart and 7.0 m in length. Foliar application of N (30 kg/ha) was applied at flowering (GS 65) as an aqueous spray of urea, but it was not included in the above measurements because it represents an independent factor in the research.

Hectolitre weight was determined from two grain samples taken at harvest from each plot using standard procedures. Average 1000-kernel weight was determined by counting and weighing two 100-kernel samples. Average kernel length, kernel width and kernel

Table 1. Summary of agricultural practices and operations for winter wheat cropping under intensive and extensive production systems

	Intensive production system	Extensive production system
Basal fertilization	500 kg/ha N-P-K 8:26:26 100 kg/ha urea (46 % N)	400 kg/ha N-P-K 8:26:26
Ploughing depth	30–32 cm	20–22 cm
Seeding rate	770 seeds/m^2	770 seeds/m^2
Planting date	20 Oct. 1999	20 Oct. 1999
Top – dressing	54 kg/ha N at GS 22	
	27 kg/ha N at GS 24	27 kg/ha N at GS 24
	27 kg/ha N at GS 31	
Herbicide	amidosulfuron (25 g/ha a.i.) bromoxynil (225 g/ha a.i.) at GS 24	2,4-D (1.0 kg/ha a.i.) at GS 24
Fungicide	tebuconazol (250 g/ha a.i.) at GS 60	–
Insecticide	lambda cihalotrin (5 g/ha a.i.) at GS 60	–
Harvest date	4 July 2000	4 July 2000

GS, growth stage

thickness were calculated from 25 individual kernels for each grain sample.

Laboratory analyses

For the assessment of bread-making quality the grain samples taken at harvest from each plot were milled on a Brabender Quadrumat Jr. Experimental Mill. Because this mill has a very short dressing surface the weights of the fine offal and flour fractions were combined to assess flour yield (*7*). Total protein (N × 5.7), sedimentation value (Zeleny sedimentation test) and falling number were determined using standard procedures (*12*). Wet gluten and gluten index were determined by Perten Glutomatic 2200 System (Perten Instruments AB, Stockholm, Sweden, ICC 155). Water absorption, dough development time, dough stability, softening degree and farinograph quality number were determined with the Brabender Farinograph (ICC No 115/1). Farinogram evaluation was made according to Schweiz (SLMB) using Brabender Programloader Software (*13*).

Statistical analysis

Data were analyzed using the PROC MIXED procedure of SAS (*14*). The analysis of variance was made using production system, foliar N application and cultivar considered fixed. The mean values of separation were calculated using the LSD values if the F-test was significant at P=0.05. Direct relationships among grain and flour quality traits were analyzed with simple Pearson correlation coefficients.

Results and Discussion

Grain quality

Cropping intensity had no significant effect on 1000-grain weight (Tables 2a and 2b) or grain dimensions (length, width and thickness). However, it is interesting to note that 1000-grain weight, grain length, width and thickness had on average slightly lower values under extensive production system, while hectolitre weight showed an opposite trend (Tables 3a and 3b). The improvement of hectolitre weight under an intensive production system was demonstrated by Varga *et al.* (*15*) in their previous research. Although absolutely and relatively small, significantly higher hectolitre weight was found under the intensive system, which averaged 81.5 kg/hL compared to 81.0 kg/hL in the extensive production system. These results clearly demonstrate that hectolitre weight may vary depending not only on 1000-grain weight and grain shape but also on grain texture, as was also shown by Pushman and Bingham (*7*). Hectolitre weight negatively correlated (r = –0.31*) with grain length, but was strongly positively correlated (r = 0.61**) with grain thickness (Tables 4a and 4b). Schuler *et al.* (*3*) also found a negative correlation between hectolitre weight and grain length. Among cultivars, Žitarka had the shortest (5.81 mm) and the thickest (3.09 mm) grain (Tables 5a and 5b). Consequently, the highest average hectolitre weight (82.7 kg/hL) was determined for this cultivar, which was higher than for Renan (80.9 kg/hL) and Marija (80.1 kg/hL). Although average hectolitre weight was significantly higher under the intensive production system, cropping intensity had no impact on flour yield, as was also shown by McNeal *et al.* (*10*). Interestingly, hectolitre weight, which is considered to be an indicator of the potential flour yield (*4*), negatively correlated (r = –0.44**) with flour yield in our research. Similar results were obtained by Schuler *et al.* (*3*), while Hook (*16*) and Baker and Golumbic (*17*) found a poor positive correlation between hectolitre weight and flour yield. Foliar nitrogen application at flowering had no effect on flour yield, despite the fact that it significantly increased hectolitre weight, which averaged 81.7 kg/hL (Table 3a), compared to 80.8 kg/hL in non-treated plots. Pushman and Bingham (*7*) also failed to find any effect of foliar nitrogen application at flowering on flour yield. Moreover, foliar nitrogen application at flowering had no impact on 1000-grain weight, grain length, width and thickness (Table 2a). Flour yield significantly varied depending on the cultivar. The highest average flour yield was found for cultivar Renan (71.5 %), which had the longest (6.76 mm) and the widest (3.47 mm) grain (Table 5a). Schuler *et al.* (*3*) also showed a positive correlation between flour yield and grain width, but a negative one between flour yield and grain length. The smallest flour yield was obtained from cultivar Žitarka (67.6 %), which was characterized by the shortest (5.81 mm) grain length. These results are in accordance with Altaf *et al.* (*5*), who also pointed out that specific grain dimensions of wheat cultivars might have a significant influence on flour yield.

Cropping intensity significantly affected grain protein content (Table 2a). Under the intensive system, wheat cultivars had on average 11.55 % of protein compared to 9.88 % in the extensive production system, a relatively high increase of 16.9 % (Table 3a). Numerous authors (*18–21*) have obtained improved grain protein content due to more intensive nitrogen fertilization. Foliar nitrogen application at flowering additionally increased protein content by 6.1 % and averaged 11.03 % compared to 10.40 % on non-treated plots. Similar results on protein content increase due to late nitrogen application at flowering were obtained by Finney *et al.* (*4*) and Pushman and Bingham (*7*). The interaction between two different production intensities (Production system – PS) and foliar nitrogen application during flowering (Foliar N–N) was not significant (NS) for the protein content in grain (Table 2a), which indicated that foliar nitrogen application at flowering resulted in similar grain protein increase under both production systems. Grain protein significantly varied depending on the cultivar. The highest protein content was found in cultivar Renan (11.08 %) (Table 5a), followed by Žitarka (10.76 %) and Marija (10.30 %). However, an interaction between cropping intensity and cultivar was found (Table 2a), indicating that cultivars responded differently to various cropping intensity levels. Thus, under the extensive system all cultivars had similar protein content, while significant differences among cultivars were only found in the intensive production system (Table 5a). These results indicate that the differences among cultivars for grain protein are more evident under intensive production systems.

Table 2a. Analysis of variance for winter wheat grain and flour quality traits

Source of variation	n-1	1000-grain weight	Grain length	Grain width	Grain thickness	Hectolitre weight	Flour yield	Protein content	Sedimentation value
Production system (PS)	1	NS	NS	NS	NS	***	NS	***	***
Rep/ PS	6	–	–	–	–	–	–	–	–
Foliar N (N)	1	NS	NS	NS	NS	***	NS	**	***
PS × N	1	NS	NS	NS	NS	*	NS	NS	NS
Pooled error (a)	6	–	–	–	–	–	–	–	–
Cultivar (C)	2	***	***	***	***	***	***	***	***
PS × C	2	NS	NS	**	NS	*	***	**	*
N × C	2	NS	*	NS	*	NS	NS	NS	NS
PS × N × C	2	NS	NS	NS	NS	NS	NS	NS	NS
Pooled error (b)	24	–	–	–	–	–	–	–	–

* significant at P = 0.05 level
** significant at P = 0.01 level
*** significant at P = 0.001 level
NS not significant

Table 2b. Analysis of variance for winter wheat grain and flour quality traits

Source of variation	n-1	Wet gluten	Gluten index	Falling number	Water absorption	Dough development time	Dough stability	Dough resistance	Softening degree	Farinograph quality number
Production system (PS)	1	***	NS	**	***	***	***	***	***	***
Rep/ PS	6	–	–	–	–	–	–	–	–	–
Foliar N (N)	1	***	NS	NS	***	***	NS	NS	*	NS
PS × N	1	*	NS	NS	NS	***	NS	NS	**	NS
Pooled error (a)	6	–	–	–	–	–	–	–	–	–
Cultivar (C)	2	***	***	***	***	***	***	***	***	***
PS × C	2	NS	NS	***	NS	***	***	***	NS	***
N × C	2	NS	NS	NS	NS	***	**	NS	NS	NS
PS × N × C	2	NS	NS	NS	NS	***	**	NS	NS	*
Pooled error (b)	24	–	–	–	–	–	–	–	–	–

* significant at P=0.05 level
** significant at P=0.01 level
*** significant at P=0.001 level
NS not significant

Flour quality

The use of the intensive production system significantly increased wet gluten, which averaged 25.8 % compared to 16.2 % under the extensive system, a very high relative increase of 59.7 %. Similar results were obtained by Gyori and Szilagyi (*21*). Moreover, foliar nitrogen application at flowering additionally increased wet gluten, which averaged 22.7 % compared to 19.3 % on non-treated plots. However, a significant interaction between cropping intensity (intensive and extensive production systems (PS)) and late nitrogen application (Table 2b) showed that foliar nitrogen application at flowering had greater impact under the extensive system where wet gluten increased by 5.4 % compared to a smaller increase of 2.0 % under the intensive production system (Table 3b). The quantity of wet gluten is a characteristic cultivar trait (Table 2b). Žitarka had the highest wet gluten (24.4 %) despite the fact that this cultivar did not have the highest grain protein (Tables 5a and 5b). Then followed cultivar Renan with 21.8 %, and finally Marija with only 16.8 % of wet gluten. Although a strong positive correlation (r = 0.82 %**) existed between wet gluten and protein content, these results clearly demonstrate that the cultivar with the highest grain protein may not necessarily have the highest wet gluten. The absence of cropping intensity × cultivar and foliar nitrogen application × cultivar interactions (Table 2b) showed that all cultivars used in this experiment similarly improved wet gluten under the intensive production system and foliar nitrogen application at flowering.

In contrast to grain protein and wet gluten, gluten index showed the opposite pattern of response since it was slightly higher in the extensive system (94.2 %) compared to the intensive production system (89.8 %). Therefore, a poor negative correlation existed between gluten index and protein content (r = –0.20), as was also

Table 3a. Average grain and flour quality traits of winter wheat cultivars grown under extensive (EPS) and intensive (IPS) production systems

Production system	Foliar N at flowering	1000-grain weight	Grain length	Grain width	Grain thickness	Hectolitre weight	Flour yield	Protein content	Sedimentation value
		g	mm	mm	mm	(kg/hL)	%	%	cm^3
EPS	Non-treated	43.9	6.21	3.43	3.02	80.3	69.7	9.52	17.4
	Foliar N	44.7	6.21	3.39	3.02	81.6	70.0	10.24	22.7
IPS	Non-treated	43.9	6.17	3.39	2.99	81.2	69.7	11.27	32.1
	Foliar N	43.8	6.17	3.39	3.00	81.8	68.9	11.83	35.0
	LSD (0.05)†	NS§	NS	NS	NS	0.46	NS	NS	NS
	LSD (0.05)‡					0.42			
Average	EPS	44.3 NS	6.21 NS	3.41 NS	3.02 NS	81.0	69.8 NS	9.88	20.1
Average	IPS	43.8	6.17	3.39	2.99	81.5**	69.3	11.55**	33.6**
Average	Non-treated	43.9	6.19 NS	3.41 NS	3.01 NS	80.8	69.7 NS	10.40	24.8
Average	Foliar N	44.2 NS	6.19	3.39	3.01	81.7**	69.4	11.03**	28.9**

† LSD values for comparing mean values within production systems
‡ LSD values for comparing mean values across production systems
§ not significant production system × foliar N interaction at P=0.05
* significant at P=0.05 level
** significant at P=0.01 level
NS not significant

Table 3b. Average grain and flour quality traits of winter wheat cultivars grown under extensive (EPS) and intensive (IPS) production systems

Production system	Foliar N at flowering	Wet gluten	Gluten index	Falling number	Water absorption	Dough development time	Dough stability	Dough resistance	Softening degree	Farinograph quality number
		%	%	s	%	min	min	min	BU	no.
EPS	Non-treated	13.8	95.7	330	59.6	1.3	0.1	1.3	142	20
	Foliar N	18.5	92.6	335	61.4	1.4	0.1	1.5	128	27
IPS	Non-treated	24.8	91.2	356	61.2	1.9	1.2	3.2	97	56
	Foliar N	26.8	88.5	361	62.3	2.8	0.7	3.5	98	58
	LSD (0.05)†	NS§	NS	NS	NS	0.15	NS	NS	7.2	NS
	LSD (0.05)‡					0.21			8.4	
Average	EPS	16.2	94.2 NS	333	60.5	1.3	0.1	1.4	135**	23
Average	IPS	25.8**	89.8	359**	61.7**	2.4**	0.9**	3.3**	97	57**
Average	Check	19.3	93.5 NS	343	60.4	1.6	0.6 NS	2.2	119*	38
Average	Urea	22.7**	90.5	348 NS	61.8**	2.1**	0.4	2.5 NS	113	42 NS

† LSD values for comparing mean values within production systems
‡ LSD values for comparing mean values across production systems
§ not significant production system × foliar N interaction at P=0.05
* significant at P=0.05 level
** significant at P=0.01 level
NS not significant

found by Jurković *et al.* (22). Foliar nitrogen application at flowering also failed to show any effect on gluten index (Table 2b). The highest average gluten index was found for cultivar Renan (96.3 %), followed by Marija (94.3 %), while Žitarka, the cultivar characterized by the highest wet gluten (Table 5b), had a significantly lower gluten index than these two cultivars (85.4 %). Consequently, a negative correlation (r = –0.51**) between gluten index and wet gluten existed (Table 4b), as was also reported by Jurković *et al.* (22) and Ćurić *et al.* (23). The absence of production system × cultivar interaction indicated that gluten quality was a characteristic cultivar trait regardless of various cropping intensity levels.

Sedimentation value significantly improved under the intensive system by 67.2 % and averaged 33.6 cm^3

Table 4a. Simple correlation coefficients among winter wheat grain and flour quality traits

	TGW	GL	GW	GT	HW	FY	P	S
1000-grain weight (TGW)		0.71**	0.72**	0.72**	0.31*	0.31*	0.25	0.44**
Grain length (GL)	0.71**		0.64**	0.22	–0.31*	0.63**	0.15	0.28
Grain width (GW)	0.72**	0.64**		0.67**	0.04	0.22	–0.02	0.16
Grain thickness (GT)	0.72**	0.22	0.67**		0.61**	–0.15	0.08	0.20
Hectolitre weight (HW)	0.31*	–0.31*	0.04	0.61**		–0.44**	0.37**	0.42**
Flour yield (FY)	0.31*	0.63**	0.22	0.15	–0.44**		0.09	0.06
Protein content (P)	0.25	0.15	–0.02	0.07	0.37**	0.09		0.87**
Sedimentation value (S)	0.44**	0.28	0.16	0.20	0.42**	0.06	0.87**	
Wet gluten (WG)	0.31*	–0.03	0.07	0.34*	0.68**	–0.20	0.82**	0.89**
Gluten index (GI)	0.07	0.45**	0.18	–0.23	0.57**	0.58**	–0.20	–0.22
Falling number (FN)	–0.18	0.23	–0.14	0.58**	0.42**	0.44**	0.39**	0.31*
Water absorption (WA)	0.45**	–0.17	0.18	0.71**	0.93**	–0.33*	0.46**	0.53**
Dough development time (DDT)	0.35*	0.17	0.17	0.29*	0.47**	0.04	0.73**	0.80**
Dough stability (DS)	0.36*	0.28	0.02	0.02	0.17	0.31*	0.60**	0.63**
Dough resistance (DR)	0.43**	0.27	0.11	0.18	0.37**	0.21	0.80**	0.85**
Softening degree (SD)	–0.09	–0.28	–0.04	0.24	0.01	–0.14	–0.71**	–0.77**
Farinograph quality number (FQN)	0.38**	0.23	0.12	0.16	0.40**	0.16	0.82**	0.88**

* significant at P = 0.05 level
** significant at P = 0.01 level

Table 4b. Simple correlation coefficients among winter wheat grain and flour quality traits

	WG	GI	FN	WA	DDT	DS	DR	SD	FQN
1000-Grain weight (TGW)	0.31*	0.07	–0.19	0.45**	0.35*	0.36*	0.43**	–0.09	0.39**
Grain length (GL)	–0.03	0.45**	0.23	–0.17	0.17	0.28	0.27	–0.28	0.23
Grain width (GW)	0.07	0.18	–0.14	0.17	0.17	0.02	0.11	–0.04	0.12
Grain thickness (GT)	0.34*	–0.23	–0.58**	0.71**	0.29*	0.02	0.18	0.24	0.16
Hectolitre weight (HW)	0.68**	–0.57**	–0.42**	0.93**	0.47**	0.17	0.37**	0.01	0.40**
Flour yield (FY)	–0.20	0.58**	0.44**	–0.33*	0.04	0.31*	0.21	–0.14	0.16
Protein content (P)	0.82**	–0.20	0.39**	0.46**	0.73**	0.60**	0.80**	–0.71**	0.82**
Sedimentation value (S)	0.89**	–0.22	0.31*	0.53**	0.80**	0.63**	0.85**	–0.77**	0.88**
Wet gluten (WG)		–0.51**	0.08	0.76**	0.78**	0.51**	0.77**	–0.61**	0.81**
Gluten index (GI)	–0.51**		0.40**	–0.56**	–0.26	0.01	–0.15	0.02	–0.18
Falling number (FN)	0.08	0.40**		–0.39**	0.27	0.32*	0.36*	–0.58**	0.31*
Water absorption (WA)	0.76**	–0.56**	–0.39**		0.56**	0.26	0.48**	–0.05	0.46**
Dough development time (DDT)	0.78**	–0.26	0.27	0.56**		0.38**	0.82**	–0.45**	0.74**
Dough stability (DS)	0.51**	0.01	0.32*	0.26	0.38**		0.84**	–0.43**	0.73**
Dough resistance (DR)	0.77**	–0.15	0.36**	0.48**	0.82**	0.84**		–0.53**	0.88**
Softening degree (SD)	–0.61**	0.02	–0.58**	–0.05	–0.45**	–0.43**	–0.53**		–0.66**
Farinograph quality number (FQN)	0.81**	–0.18	0.31*	0.46**	0.74**	0.73**	0.83**	–0.66**	

* significant at P=0.05 level
** significant at P=0.01 level

compared to 20.1 cm^3 under the extensive production system. Web and Sylvester-Bradley (*20*) also found that nitrogen fertilization significantly increased sedimentation of two winter wheat cultivars. Moreover, foliar application of nitrogen at flowering brought about an additional increase in sedimentation, which averaged 28.9 cm^3 compared to 24.8 cm^3 on non-treated plots. The absence of an interaction between cropping intensity and late nitrogen application (Table 2a) indicated that the increase in sedimentation due to foliar nitrogen application at flowering was similar under both production systems. On average, Renan had the highest sedimentation value (31.5 cm^3), followed by Žitarka (27.3 cm^3) and finally Marija (21.7 cm^3), an identical response to that for grain protein. Consequently, a strong positive correlation (r = 0.87**) existed between sedimentation and protein content, as was also reported by Ćurić *et al.* (*23*) and Stickler *et al.* (*24*). In addition, a strong positive correlation was found between sedimentation and wet gluten (r = 0.89**). Gyori and Szilagy (*21*) and Jurković *et al.* (*22*) also found a positive correlation between wet gluten and sedimentation value.

Table 5a. Grain and flour quality traits of winter wheat cultivars grown under extensive (EPS) and intensive (IPS) production systems

Production system	Cultivar	1000-grain weight	Grain length	Grain width	Grain thickness	Hectolitre weight	Flour yield	Protein content	Sedimentation value
		g	mm	mm	mm	(kg/hL)	%	%	cm^3
EPS	Marija	37.9	5.96	3.32	2.89	79.9	70.6	9.84	15.6
	Žitarka	44.6	5.83	3.39	3.11	82.3	68.5	9.86	21.3
	Renan	50.4	6.82	3.51	3.08	80.7	70.5	9.95	23.4
IPS	Marija	38.0	6.00	3.35	2.89	80.2	68.6	10.77	27.8
	Žitarka	44.1	5.80	3.40	3.07	83.1	66.7	11.67	33.4
	Renan	49.4	6.70	3.43	3.02	81.2	72.6	12.22	39.6
	LSD (0.05)†	NS§	NS	0.049	NS	0.29	1.39	0.48	2.30
	LSD (0.05)‡			0.057		0.37	1.26	0.49	2.03
Average	Marija	38.0	5.98	3.33	2.89	80.1	69.6	10.30	21.7
	Žitarka	44.4	5.81	3.39	3.09	82.7	67.6	10.76	27.3
	Renan	49.9	6.76	3.47	3.05	80.9	71.5	11.08	31.5
	LSD (0.05)	0.56	0.076	0.035	0.027	0.20	0.99	0.340	1.63

† LSD values for comparing mean values within production systems
‡ LSD values for comparing mean values across production systems
§ not significant production system × cultivar interaction at P=0.05

Table 5b. Grain and flour quality traits of winter wheat cultivars grown under extensive (EPS) and intensive (IPS) production systems

Production system	Cultivar	Wet gluten	Gluten index	Falling number	Water absorption	Dough development time	Dough stability	Dough resistance	Softening degree	Farinograph quality number
		%	%	s	%	min	min	min	BU	no.
EPS	Marija	12.0	99.0	369	57.9	1.1	0.1	1.2	136	18
	Žitarka	20.0	84.9	296	63.4	1.5	0.1	1.6	148	27
	Renan	16.5	98.6	333	60.3	1.4	0.1	1.4	122	24
IPS	Marija	21.5	89.6	359	59.0	1.5	0.2	1.7	92	36
	Žitarka	28.8	86.0	341	64.3	2.6	0.8	3.4	108	56
	Renan	27.1	93.9	376	61.8	3.0	1.9	4.9	92	78
	LSD (0.05)†	NS	NS	19.4	NS	0.20	0.43	0.41	NS	7.7
	LSD (0.05)‡			18.8		0.24	0.45	0.55		7.9
Average	Marija	16.8	94.3	364	58.4	1.3	0.1	1.4	114	27
	Žitarka	24.4	85.4	319	63.8	2.1	0.4	2.5	127	42
	Renan	21.8	96.3	355	61.1	2.2	1.0	3.2	107	51
	LSD (0.05)	1.03	4.50	13.8	0.46	0.14	0.31	0.29	5.8	5.4

† LSD values for comparing mean values within production systems
‡ LSD values for comparing mean values across production systems

The use of an intensive production system resulted in higher falling numbers, which averaged 359 s compared to 333 s under the extensive production system (Table 3b). An almost linear increase in falling number due to more intensive nitrogen fertilization rates was shown by Gooding *et al.* (*9*). However, foliar nitrogen application at flowering had no effect on falling number (Table 2b). Falling number significantly varied depending on the cultivar. Marija had the highest average falling number (364 s), with Renan slightly lower (355 s), and Žitarka the lowest (319 s) (Table 5b). However, these results showed that all cultivars had low amylolytic activity due to falling numbers higher than 300 s. The significance of cropping intensity × cultivar interaction was found (Table 2b) since only cultivars Žitarka and Renan increased the falling number under the intensive production system (Table 5b). Marija showed the opposite response since slightly smaller falling number was determined for this cultivar under the intensive system in comparison with the extensive production system. Web and Sylvester-Bradley (*20*) also found that some cultivars failed to significantly improve the falling number under more intensive nitrogen fertilization.

Flour water absorption significantly improved under the intensive system and averaged 61.7 % compared to 60.5 % under the extensive production system (Table 3b). Pushman and Bingham (*7*) and McNeal *et al.* (*18*) also reported higher water absorption due to increased nitrogen fertilization rates. Moreover, foliar nitrogen application at flowering resulted in additional increases in water absorption, which averaged 61.8 % compared to 60.4 % on non-treated plots, as was also found by McNeal *et al.* (*18*). The absence of an interaction between cropping intensity and late nitrogen application (Table 2b) indicated that foliar nitrogen application at flowering resulted in a similar increase in water absorption under both production systems. Žitarka had the highest average water absorption (63.8 %), followed by Renan (61.1 %), while Marija had the lowest (58.4 %), an identical response as for wet gluten (Table 5b). Consequently, a strong positive correlation (r = 0.76**) existed between these two traits (Table 4b), which is in accordance with findings by Jurković *et al.* (22).

The use of the intensive production system resulted in a significantly improved dough development time (78.2 %), dough stability (900.0 %) and dough resistance (138.1 %). McNeal *et al.* (*10*) also found an increase in dough development time and dough stability under more intensive production systems. Dough development time, dough stability and dough resistance positively correlated with wet gluten content (Table 4b), as was also found by Jurković *et al.* (22). Moreover, the intensive production system brought about the decrease in softening degree by 29.5 %, which also had a positive effect on bread-making quality of wheat. Consequently, significantly higher farinograph quality numbers have been found under the intensive system, which averaged 57 compared to 23 in the extensive production system, a high relative increase of 142.8 %. Foliar nitrogen application at flowering additionally increased dough development time by 28.4 %, while it had no impact on dough stability and dough resistance (Table 2b). Softening degree significantly decreased due to foliar nitrogen application at flowering and averaged 113 Branbrender units (BU) compared to 119 BU on non-treated plots (Table 3b), which also resulted in a small improvement in farinograph quality number.

Conclusions

The use of an intensive production system significantly increased hectolitre weight (1.9 %), protein content (16.9 %), wet gluten (59.7 %), sedimentation (67.2 %), falling number (7.8 %), water absorption (2.0 %), dough development time (78.2 %), dough stability (900.0 %), dough resistance (138.1 %) and farinograph quality number (142.8 %) compared to an extensive system, whereas the intensive system had no effect on gluten index, flour yield and physical grain properties (1000-grain weight, grain length, width and thickness). Only softening degree decreased by 29.5 % under the intensive system compared to the extensive production system, which also had a positive impact on flour quality. The differences in protein content between cultivars were evident only under the intensive system, while all cultivars had similar protein contents in the extensive production system. Moreover, grain protein (9.88 %) and wet gluten (16.2 %) were below the minimum requirements for wheat bread-making quality under the extensive production system. Foliar nitrogen application at flowering additionally increased hectolitre weight (1.1 %), protein content (6.1 %), wet gluten (11.8 %), sedimentation (16.5 %), water absorption (2.5 %) and dough development time (28.4 %) in comparison with non-treated plots. Flour yields significantly varied depending on the specific grain dimensions of the cultivars. The findings clearly demonstrated that desirable level of bread-making quality of wheat in Croatia might be achieved only under an intensive production system, particularly at high nitrogen fertilization rates.

References

1. Državni zavod za statistiku, *Državni zavod za statistiku*, Zagreb (2002) p. 240.
2. S. P. Hazen, R. W. Ward, *Crop. Sci. 37* (1997) 1079–1085.
3. S. F. Schuler, R. K. Bacon, P. L. Finney, E. E. Gbur, *Crop. Sci. 35* (1995) 949–953.
4. K. F. Finney, J. W. Meyer, F. W. Smith, H. C. Fryer, *Agron. J. 49* (1957) 341–347.
5. A. Altaf, I. M. Atkins, L. W. Rooney, K. B. Porter, *Crop. Sci. 9* (1969) 329–330.
6. T. Hoshino, S. Ito, Y. Taniguchi, A. Sato, *Jap. J. Crop Sci. 63* (1994) 21–25.
7. F. M. Pushman, J. Bingham, *J. Agric. Sci. 87 (*1976) 281–292.
8. R. Johanson, *Euphytica, 126* (2002) 143–149.
9. M. J. Gooding, P. S. Kettlewell, W. P. Davies, T. J. Hocking, *J. Agric. Sci. 107* (1986) 475–477.
10. F. H. McNeal, M. A. Berg, P. L. Brown, C. F. McGuire, *Agron. J. 63* (1971) 908–910.
11. J. C. Zadoks, T. T. Chang, C. F. Konzak, *Weed Res. 14* (1974) 451–421.
12. ICC, *Standard Methoden der Internationalen Gesellschaft für Getreidechemie. Methods 105/1, 107, 115/1 and 116*, Verlag Moritz Schafer, Detmold, Germany (1994).
13. Brabender, Betreibsanteilungen, Software Programloader, Duisburg (1995).
14. SAS Institute, *SAS Inst.* Cary, NC, USA (1997).
15. B. Varga, Z. Svečnjak, A. Pospišil, *Agron. J. 93* (2001) 961–966.
16. Simon C. W. Hook, *J. Sci. Food Agric. 35* (1984) 1136–1141.
17. D. Baker, C. Golumbic, *Northwestern Miller, 277* (1970) 8–11.
18. F. H. McNeal, C. A. Watson, H. A. Kittams, *Agron. J. 55* (1963) 470–472.
19. B. Varga, *Poljopr. Znan. Smotra, 52* (1980) 285–297.
20. J. Webb, R. Sylvester-Bradley, *J. Agric. Sci. 125* (1995) 11–24.
21. S. Gyori, S. Szilagy, *Proceedings of First Croatian Congress of Cereal Technologists »Brašno-kruh 1997«*, Opatija, Croatia (1997) pp. 137–145.
22. Z. Jurković, R. Sudar, M. Galonja, G. Drezner, *Proceedings of First Croatian Congress of Cereal Technologists »Brašno-kruh 1997«*, Opatija, Croatia (1997) pp. 146–151.
23. D. Ćurić, D. Karlović, D. Tušak, B. Petrović, J. Đugum, *Food Technol. Biotechnol. 39* (2001) 353–361.
24. F. C. Stickler, A. W. Pauli, J. A. Johnson, *Agron. J. 56* (1964) 592–594.

Utjecaj agrotehničkih mjera na kakvoću pšeničnog zrna i brašna

Sažetak

Prosječni prinos zrna od svega 3,93 t/ha u razdoblju od 1991. do 2001. godine upućuje na to da se ozima pšenica (*Triticum aestivum* L.) u Hrvatskoj još uvijek uglavnom uzgaja u ekstenzivnim uvjetima proizvodnje, tj. uz nedovoljnu gnojidbu dušikom. Stoga je svrha tih istraživanja bila utvrditi utjecaj intenziteta proizvodnje i folijarne primjene dušika u fazi cvatnje na kakvoću zrna i brašna raznih sorata pšenice. Dva intenziteta proizvodnje (intenzivna i ekstenzivna) primijenjena su na pokusnom polju u vegetacijskoj sezoni 1999/2000. na Agronomskom fakultetu u Zagrebu. Intenzivna proizvodnja, u usporedbi s ekstenzivnom, statistički je značajno povećala hektolitarsku masu (1,9 %), udjel proteina (16,9 %), vlažnoga glutena (59,7 %), sedimentacijsku vrijednost (67,2 %), upijanje vode (2,0 %), vrijeme razvoja tijesta (78,2 %), njegovu stabilnost (900,0 %), otpor tijesta (138,1 %) i farinografski broj kakvoće (142,8 %), a nije bitno utjecala na glutenski indeks, prinos brašna i fizikalne osobine zrna (masu 1000 zrna, njegovu dužinu, širinu i debljinu). Intenzivnom proizvodnjom smanjen je samo stupanj omekšavanja zrna (29,5 %), što je poboljšalo pekarsku kakvoću brašna. Folijarna prihrana dušikom u fazi cvatnje dodatno povećava hektolitarsku masu (1,1 %), udjel proteina (6,1 %), vlažnoga glutena (11,8 %), sedimentaciju (16,5 %), upijanje vode (2,5 %) i vrijeme razvoja tijesta (28,4 %). Rezultati istraživanja pokazuju da se veća pekarska kakvoća pšenice može ostvariti samo intenzivnom proizvodnjom, u prvom redu primjenom velikih doza dušičnih gnojiva.