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Designing a Wheat Ideotype with Increased Sink Capacity

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With 4 tables

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Abstract

In this investigation, genotypes with branched, tetrastichon (two spikelets per node of the rachis), and normal spikes were used in order to induce changes in sink capacity, while high-yielding domestic and foreign varieties served as donors of other traits. These materials were crossed by the methods of single-, back-, and top crossing and the desirable genotypes were selected by the pedigree method. After 10 years of breeding for the desired ideotype, whose main features had been a highly fertile spike of normal structure, short straw, curved leaves, and reduced tillering, 229 lines were tested in comparative yield trials. Among them, four lines were superior in yield and other traits to the highest yielding standards. Regarding the expected changes in sink capacity, considerable progress was made in spike length, number of grains per spike, number of grains per spikelet, and the weight of grains per spike.

Key words: *Triticum aestivum* — ideotype — sink capacity — yield.

A theoretical wheat variety model for different ecological conditions was made by MACKEY in 1966. Although he started from photosynthesis as the main factor of plant growth and development, he took the morphological traits which are relevant for yield and which can be monitored in the course of ontogenesis as the most important criteria in the development of his plant model.

The ideotype for a Yugoslav program of development of high-yielding wheat varieties was designed by BOROJEVIĆ and POTOČANAC in 1966. Pursuing further this concept, BOROJEVIĆ (1971, 1980) defined the traits of the ideotype on one side and the environmental factors on the other which are needed for the final phenotype to achieve the genetic yield potential of 15 t/ha.

The most widely known and the best illustrated wheat ideotype designed so far was provided by DONALD in 1968. The main features of that model are a short, firm, uniculm stem, with small erect leaves, and a large spike with long awns.

So far, the highest increases in genetic yield potential have been achieved by inducing genetic changes in source capacity, e.g., short straw (*Rht* genes), position and size of leaves, etc., while the traits of sink capacity have not been much changed (AUSTIN et al. 1980, BOROJEVIĆ 1982, LEDENT and STOY 1988).

Taking in consideration the available knowledge and experience gained during the realization of the model of a high-yielding wheat variety, this investigation was focused on genetic changes in sink capacity because these were expected to bring further increases in genetic yield potential.

Defining the wheat ideotype

The dominant idea in defining the main characteristics of the wheat ideotype was that sink capacity limits the genetic yield potential to a much larger degree than source capacity (RAWSON 1970, BOROJEVIĆ 1980, KORIĆ 1980, LEDENT and STOY 1988, SMOČEK 1988, DENČIĆ 1990,

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DENČIĆ and BOROJEVIĆ 1992). Therefore, the proposed genotype gives emphasis to genetic changes in sink capacity which must be harmonized with other characters in order to allow full expression of the potentials of the altered spike.

Genotypes with branched spikes were used as the main source of genetic changes in sink capacity. Such genotypes are not superior to those with normal spikes because of negative characteristics such as empty, small and light grains, susceptibility to lodging, late maturity, etc. (BOROJEVIĆ 1983). However, a fair proportion of recombinations between genotypes with branched spikes and those with normal spikes have large and fertile normal spikes (DENČIĆ 1990, DENČIĆ and BOROJEVIĆ 1992). The main idea behind the development of this ideotype was to cross genotypes with branched and tetrastichon spikes, as donors of high spike productivity, to varieties and lines with normal spikes, as donors of other desirable traits, aiming the selection at a long, highly fertile, but normal spike.

In consideration of the previous papers which have pointed out the importance of increasing the spike productivity via increases in spike length, number of spikelets/spike, number of grains/spike, grain mass/spike, etc. (BOROJEVIĆ 1982, SMOČEK 1988), we defined the desired characteristics of the spike:

— normal form;
— spike length 10—15 cm;
— 20—25 fertile spikelets per spike;
— 2.5—3.0 grains per spikelet on average;
— 1,000-grain mass about 40 g.

The above values should be achieved in the stand density of ca. 600—700 spikes/m^2.

The above sink capacity should be combined with the following characteristics:

— short straw, about 70 cm (semi-dwarf and dwarf), highly resistant to lodging;
— medium size and curved leaves (in conditions of the continental part of central Europe, such leaves are the optimum optical system (BOROJEVIĆ and DENČIĆ 1986);
— reduced tillering, to decrease the competition for nutrients within the plant;
— good resistance to low temperature;
— field resistance to major diseases, e.g., such as powdery mildew, leaf rust, *Fusarium*, and *Septoria*;
— prolonged seed filling period, such as in Bezostaia 1.

Materials and Methods

Vulgare wheat genotypes which differed in spike architecture were used as parents in this investigation.

1. Genotypes with branched spikes (*turgidum* type of branching): Bologna (ITA) and ZG-8065, ZG-992, ZG-1020a, ZG-1021b, ZG-1008, ZG-1011, ZG-172, ZG-148, ZG-192, and ZG-136 from Zagreb (CRO).

2. Genotypes with tetrastichon spikes (two spikelets per node of the rachis): ZG-171/1 and ZG-224 from Zagreb (CRO).

3. Genotypes with large and fertile spikes: Forlani (ITA), S. Cerros (MEX), Buck Buck (MEX), and Panonija (YU).

4. Genotypes with normal spikes and other desirable characteristics such as:

a. earliness: NS 58-97 (gene Ppd1), NS Rana 2 (Ppd1), and Nizija (Ppd1);
b. short straw, resistant to lodging: Sava (gene Rht8), S. Cerros (Rht1), Nizija, and Bezostaia 1;
c. resistance to low temperature: Bezostaia 1, Žitnica, Panonija;
d. disease resistance, i.e., major genes for leaf (Lr), stem (Sr), and yellow rust (Yr): Bezostaia 1 (Lr3, Sr5, Yr9), Žitnica (Lr3, Sr10), NS 646 (Lr3, Sr10), and Nizija;
e. long leaf area duration (LAD): Žitnica, NS 646, ZG-172, Talent, and Sava;
f. long grain filling period: Sava, Talent, and Stephens.

First crossings were made in 1982, at the experiment field of the Institute of Field and Vegetable Crops of the Faculty of Agriculture in Novi Sad.

The methods of (1) simple crossing — SC, (2) back crossing — BC, and (3) top crossing (TC) were applied, depending on the number of desirable and undesirable characteristics of the parents.

Starting from the F_1 generation, the materials were grown by the pedigree method. In the early generations of segregation (F_2 and F_3), individual plants were selected while in the later generations, F_4 and F_5, selection was carried out at the level of progeny. The best lines were tested in comparative yield trials, in 5 m^2 plots, in five replicates.

Results

The total number of combinations made was 330. These comprised 220 single crosses, 35

Table 1. Results of crossing for increased sink capacity in wheat

Year	Gen.	Total no. of crosses	Type of crossing Single crosses	Back crosses	Top crosses	No. of discarded combinations	No. of lines
1983	F_1	56				7	
1984	F_1	136	84	12	40	96	
	F_2	49	49			25	
1985	F_1	38	38			22	
	F_2	40	16	6	16	10	
	F_3	24	24			1	
1986	F_3	31	9	6	16	6	
	F_4	23	23				6
1987	F_1	29	29			18	
	F_2	16	16			1	
	F_4	25	6	6	13	5	13
	F_5	23	23			2	37
1988	F_1	71	13	23	35	22	
	F_2	11	11			5	
	F_3	15	15			13	
	F_5	19	3	5	11	8	36
	F_6	21	21				91
1989	F_2	49	7	14	28	19	
	F_3	6	6			2	
	F_4	2	2			1	
	F_6	11	1	5	5	3	16
	F_7	21	21			15	10
1990	F_3	30	3	4	23	11	
	F_4	4	4			4	
	F_5	1	1				2
	F_7	8	1	3	4	6	3
	F_8	6	6			3	5
1991	F_4	19	3	4	12	5	10
	F_6	1	1				
	F_8	2		2			
	F_9	3	3			1	
Total		330	220	35	75	308	229

Table 2. Grain yield of lines as compared with the best standard (cv. Jugoslavija)

Year	No. of lines	Yield compared with best standard Better	Same	Lower	No. of lines for further testing
1986	6	1	3	2	3
1987	50	3	27	20	13
1988	127	8	61	52	20
1989	26	6	9	11	7
1990	10	4	2	4	4
1991	10	5	1	4	6

Table 3. Characteristics, grain yield and bread-making quality of best lines and standards (3-year average)

Character and yield	Line				Standard cultivars		LSD	
	NSP 51	NSP 52	NS 1202	NS 1204	Jugoslavija	Skopljanka	5 %	1 %
Plant height (cm)	71	70	75	78	91	88	8.5	9.9
Lodging (%)	0	0	0	5	30	20		
Earliness[1]	132	130	135	130	139	137		
Winterhardiness[2]	0/46	0/52	0/48	0/56	2/58	3/56		
Powdery mildew	20R	30R	10R	20R	30MR	50MS		
Leaf rust	10R	10R	10R	30MR	10R	40MS		
Spike length (cm)	9.7	9.5	9.9	9.2	8.2	8.6	0.89	0.98
No. spikelets/spike	17.6	18.2	18.3	18.9	16.1	17.2	1.75	1.93
No. grains/spike	41.5	39.0	42.7	38.7	33.2	35.4	3.21	4.47
No. grains/spikelets	2.43	2.11	2.32	2.01	2.05	2.03	0.19	0.26
Grain weight/spike	1.50	1.33	1.52	1.43	1.18	1.26	0.15	0.18
1000-kernel weight	40.2	38.8	39.7	38.0	43.1	45.0	4.19	4.63
No. spikes/m^2	715	724	768	711	736	748	79.1	98.6
Grain yield t/ha	8.69	7.97	8.71	7.89	7.13	7.61	0.79	0.94
Protein %	14.2	13.3	13.8	14.3	13.7	12.5	1.28	1.49
Sedimentation value	61	50	53	57	35	34	5.89	6.72
Yield of flour	70	67	69	70	69	67	6.71	7.53
Water absorb. capacity (%)	62	61	62	64	60	63	5.92	6.25
Bread yield[3]	140	139	142	140	141	140	13.0	14.2
Loaf volume	545	536	542	520	574	473	49.7	65.8
Crumb value[4]	5.0	5.6	4.7	5.9	5.2	3.6	0.41	0.61

[1] No. of days from January 1 to heading.
[2] Test in cold chamber at −15 °C for 30 h: 0/46 — 0 plants dead, 46 % leaf area damaged.
[3] g of bread/100 g flour.
[4] Loaf quality scored 0—6, for: loaf volume, spring and break of crust, cell size and distribution, resilience and softness of crumb.

back-crosses with a parent with normal spikes, and 75 top crosses in which the third parent too had normal spikes. Cross combinations started to be selected already in the F_1 generation, when those which did not include at least 60—70 % of the traits assigned by the ideotype were discarded (Table 1).

Since the crossing scheme included highly diverse genotypes, the segregation in the F_2 generation was quite high. To increase the frequency of desirable genotypes, the size of the F_2 populations was increased to 5,000—10,000 plants. The selection in the segregating generations was done at the level of individual plants, by selecting those plants which were closest to the desired ideotype.

Homogeneous F_4 and F_5 progenies of individual plants were used for the founding of lines. 229 lines were selected within this program (Table 1). Over a period of two or three years, the lines were tested for yield, quality, resistance to low temperature (cold chamber), and resistance to the prevalent diseases (natural infection and inoculation). Out of the 229 lines tested in the period 1986—1991, four were superior in yield and other characteristics compared with the standard cultivars Jugoslavija and Skopljanka (Table 2).

The four superior lines were: NSP 51 (Panonija × Bologna), NSP 52 (Panonija × Bologna), NS 1202 (Panonija × ZG-1011), and NS 1204 (Panonija × ZG-1011), all with normal spikes, and these were nominated as prospective commercial cultivars close to the desired model (Table 3).

Discussion

The underlying idea of the program was to cross genotypes with branched spikes to genotypes with normal spikes in order to select genotypes which would combine large and highly fertile but normal spikes with a short and firm straw, early maturity, resistance to low temperature and diseases, low tillering capacity, and long grain filling period.

A large number of crosses was made between highly diverse parents. The crosses were grown in large populations in the segregating generations in order to increase the efficiency of selection. A large number of NS lines were tested for most important traits. However, only four of them exhibited superiority for the larger part of the traits, compared with the standard cultivars Jugoslavija and Skopljanka.

A Yugoslav cultivar Panonija, which has large and fertile spikes, was a parent to all four lines. This seems to indicate that when crossing a genotype with branched spikes to a genotype with normal spikes it is important for the spikes of the latter to be as large and as fertile as possible.

The desired genetic changes in sink capacity were realized only partly.

The new lines had significantly longer spikes than the standard cultivars Jugoslavija and Skopljanka, but still the target value of 10—15 cm has not been achieved. Consequently, the number of spikelets was smaller than that defined by the ideotype (Table 3).

The average number of grains per spikelet in the line NSP 51 was 2.4 or very close to the desired value. Furthermore, the lines with the largest number of grains per spikelet, NSP 51 and NS 1202, were also the highest yielders (Table 3), indicating that this characteristic plays an important role in yield forming.

Progress was also made in the mass of grains per spike. In a high stand density, the new lines had significantly higher grain weight per spike than the standard varieties (Table 3).

Further work on changes in sink capacity may lead in two directions: (a) increased spike length which might bring corresponding increases in the number of spikelets per spike and grains per spike, and (b) increased number of grains per spikelet maintaining the other parameters of the spike, such as the number of spikelets per spike and 1,000-grain mass, at the level already achieved. This is in agreement with the ideotype of DONALD (1968) which contains a long and fertile spike.

The selection for the other traits defined in the ideotype was both efficient and successful. Plant height, earliness, resistance to lodging, low temperature and diseases were realized in accordance with the ideotype, simply because the parents used had already possessed these traits.

The newly developed genotypes had very good quality which was transferred into them from the parents with normal spikes (Panonija, etc.) which were used as the recurrent parent in the back crosses or the third parent in the top crosses (Table 3).

It is not simple to realize an ideotype which combines a large number of positive traits. In our case, only four lines were on a par with the requirements of the ideotype. Especially large difficulties are encountered when trying to induce balanced genetic changes in sink capacity (e.g., spike length 10—15 cm, 20—25 fertile spikelets per spike, 2.5—3.0 grains per spikelet) which should result in an increased yield potential.

Although the newly-developed lines, NSP 51, NSP 52, NS 1202, and NS 1204, do not meet all the requirements set by the ideotype, they will be useful in further work because, in addition to *Rht* genes, *Ppd* genes and some disease resistance genes, they also possess genes for long and normal fertile spikes such as *RmTsNr* (KORIĆ 1980), *nnbb* (PENNELL and HALLORAN 1983), and *RRTTNN* (DENČIĆ 1988). These genetic compositions have been obtained from crosses between genotypes with normal and branched spikes.

Zusammenfassung

Entwicklung eines Weizen-Ideotyps mit höherer Sink-Kapazität

Um eine Veränderung der Sink-Kapazität herbeizuführen, wurden Genotypen mit verzweigten, vierzeiligen (zwei Ährchen je Spindelnodium) und normalen Ähren verwendet. Hochertragreiche heimische und ausländische Sorten wurden als Spender anderer Eigenschaften genutzt. Mit diesem Material wurden Einzelkreuzungen, Rückkreuzungen und Kombinationen im Top-cross-Verfahren vorgenommen. Die erwünschten Genotypen wurden in den entsprechenden F-Nachkommenschaften ausgelesen. Nach zehn Jahren Pedigree-Züchtung und Auslese auf den erwünschten Ideotyp, dessen wichtigste Eigenschaften hochfertile, normale Ähren, kurzes Stroh, gebogene Blätter und verringerte Bestockung sein sollten, wurde die Leistungsfähigkeit von 229 Linien in Feldversuchen geprüft. Vier Linien wiesen im Vergleich zu den besten Standardsorten einen höheren Ertrag und eine Verbesserung anderer Eigenschaften auf. Hinsichtlich der Veränderungen der Sink-Kapazität wurde ein beachtlicher Fortschritt bei den Merkmalen Ährenlänge, Zahl der Körner je Ähre und je Ährchen sowie beim Gewicht der Körner je Ähre erreicht.

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