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The influence of added rye chromosomes on physical properties of kernels of addition lines *T. aestivum* Grana–*S. cereale* Dańkowskie Złote

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Abstract. The paper concerns the influence of added rye chromosomes on physical properties of kernels of the addition lines *T. eastivum* Grana – *S. cereale* Dańkowskie Złote 1R", 2R", 3R", 3RS", 4R", 5R", 6R", and 6RL", as well as initial forms: wheat cv. Grana, rye cv. Dańkowskie Złote and octoploid triticale Grana × Dańkowskie Złote. Kernels from each form, were analysed for the following features: basic geometric dimensions of kernels, 100-kernel weight and kernel volume; surface roughness, index of kernel damage and mechanical strength (determined by maximum force, force within elasticity limits, maximum deformation, elastic deformation, energy causing deterioration of kernel structure). Wheat lines with added rye chromosomes differed from one another and from the initial form wheat cv. Grana in basic geometric dimensions. The lines 6R" and 6RL" had a distinctly higher 100-kernel weight and kernel volume than their initial forms. All the addition lines and octoploid triticale were characterised by markedly higher indices of external damages than the wheat cv. Grana. The mechanical strength of addition line kernels also varied considerably.

Key words: addition lines, gene localization, physical properties, rye.

Introduction

Wheat-rye addition lines were obtained by several authors (RILEY, CHAPMAN 1958, EVANS, JENKINS 1960, DRISCOLL, SEARS 1971, MILLER 1973, BERNARD 1976). At present, only two complete series are available. These are: Chinese Spring–Imperial and Chinese Spring–King II. Addition lines are

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difficult to obtain and to sustain because of elimination of added rye chromosomes (MILLER 1983). Besides disomic addition lines with the added chromosome pair, also lines with added incomplete chromosomes, that is their arms (S – short arm or L – long arm), have been obtained.

Addition lines have no application in practical breeding. They need a continuous cytological control, because in comparison to wheat varieties, they are less viable. They can be used as initial material for production of substitution lines. They are also used for gene localization on rye chromosomes (CHANG et al. 1973, SCHLEGEL, METTIN 1982, MILLER 1984, SCHLEGEL et al. 1986, MELTZ et al. 1992, DEVOS et al. 1993, SYBENGA 1995).

Many authors analysed the influence of added rye chromosomes on the course of meiosis, on growth and development, as well as on morphological, physiological and biochemical features of wheat lines with added rye chromosomes (SEARS 1967, TANG, HART 1975, SCHLEGEL 1978, LIU 1989). The available literature contains no papers dealing with physical traits of kernels from wheat line with added rye chromosomes.

A series of Grana wheat line with added complete chromosomes of Dańkowskie Złote rye and with the chromosome arms: 1R", 2R", 3RS", 4R", 5R", 6R", 6RL", and 7R", has been obtained at the Institute of Genetics and Plant Breeding (MIAZGA, CHRZĄSTEK 1987, CHRZĄSTEK, MIAZGA 1988, MIAZGA et al. 1993).

Material and methods

The subject of the study were the addition lines Grana-Dańkowskie Złote 1R", 2R", 3R", 3RS", 4R", 5R", 6R", 6RL", as well as the initial forms: wheat cv. Grana, rye cv. Dańkowskie Złote and octoploid triticale (Grana × Dańkowskie Złote). Because of a small number of kernels, the line 7R" has not been analysed.

Physical features of kernels of the initial forms and addition lines were measured at the Institute of Agrophysics, Polish Academy of Sciences in Lublin, using previously developed methods (SZOT 1976, 1983, SZOT, GRUNDAS 1978, SZOT, STĘPNIEWSKI 1992, MOLENDA, HORABIK 1994, NIEWCZAS 1994). The studied addition lines and initial forms were grown under field conditions on the plots spaced 10 × 20 cm apart. The experiment was carried out in a completely randomized design. Each genotype was replicated five times. Kernel samples were taken from five random plants of a plot. Twenty kernels were analysed from each plant.

Kernels from each line and initial forms were analysed for the following characteristics: 1) basic geometric dimensions (thickness, width, length); 2) 100-kernel weight; 3) kernel volume; 4) kernel surface roughness; 5) index of kernel internal damage; 6) kernel mechanical strength determined by: maximum force, force within elasticity limits, maximum deformation, elastic deformation, energy causing deterioration of kernel structure; 7) kernel moisture.

Kernel samples of initial forms and addition lines were as follows:

– initial forms: wheat cv. Grana; rye cv. Dańkowskie Złote; octoploid triticale (Grana × Dańkowskie Złote)

– addition lines: 1R"; 2R"; 3R"; 3RS"; 4R"; 5R"; 6R"; 6RL".

Geometric features, i.e. kernel thickness, width and length, were measured for each kernel separately using a special prototype clock-apparatus, accurate to 0.01 mm. The weight of 100 kernels was measured on an automatic digital balance to an accuracy of 0.01 g.

The volume of kernels was calculated from the basic geometric dimensions by an adequate formula for cereal grains.

Kernel surface roughness was measured by a special double microscope BK 70 × 50, at magnification 450×. For further analyses 50 kernels were randomly selected from each sample to make five measurements on each kernel. Surface roughness is expressed in micrometres. The obtained values determine only kernel roughness, not its corrugation, which, however, occurs in the case of triticale.

In order to determine internal damage indices, the kernels were glued onto a special paper-board to subject them to fluoroscopic inspection in a special X-ray apparatus designed for this purpose. Thus obtained röntgenograms made it possible to evaluate internal cracking on the basis of the damage index (Is). At the picture magnification of each kernel on the background of a grid dividing this picture into nine fields, the cracks occurring within each individual field were counted. A scale from 0 to 9 was used, where 0 stands for the lack of damages, and 9 means damage in each field. Besides, these röntgenograms served to analyse structural changes in the examined kernels.

Mechanical kernel resistance was characterised by parameters corresponding to those of the resistance to external force (compression) action. Single kernels were measured using INSTRON universal testing machine, model 6022. Five strength parameters were determined. Statistical analyses were based on measuring data of 90 kernels from each combination.

Moisture content of kernels was determined in an automatic dryer Brabender according to the manufacturer's instructions.

The obtained results were statistically treated to calculate the mean, standard deviation and variation coefficient. Significant differences between the mean values the examined lines and parental forms were estimated using Tukey's credibility intervals (OKTABA 1972).

Results and discussion

Physical properties of cereal kernels result from their morphological and anatomical structure, as well as from chemical composition, which simultaneously affect kernel physiology and all these properties depend on their physiological properties. The length, width and thickness of kernels describe their size and shape. They vary significantly depending on the species and variety, growth conditions, grain maturity, etc. (SZOT 1976, SZOT, GRUNDAS 1978). All examined lines, except the line 4R", had well-developed kernels. On the leaves of the line 4R", necrotic spots occurred already during shooting and remained until the end of vegetation. They, however, were not disease symptoms of fungal infection. Necrotic spots occurred on all the leaves, being the largest on the flag leaf. Without doubt, their occurrence was associated with a poor development of kernels. Data on geometric dimensions of kernels

Table 1. Basic geometric dimensions of kernels of initial forms: wheat cv. Grana, rye cv. Dańkowskie Złote, octoploid triticale (Grana × Dańkowskie Złote) and eight addition lines

Genotype	Thickness			Width			Length		
	Mean (mm)	s.d.	c.v. (%)	Mean (mm)	s.d.	c.v. (%)	Mean (mm)	s.d.	c.v. (%)
Initial forms									
wheat cv. Grana	2.81	0.18	6.3	3.31	0.39	11.8	6.73	0.26	3.9
rye cv. Dańkowskie Złote	2.77	0.29	10.3	2.77	0.28	10.4	8.74	0.54	6.2
triticale (Grana ×Dańkowskie Złote)	3.24	0.40	12.2	3.24	0.30	9.5	8.34	0.60	7.2
Addition lines									
1R"	2.78	0.18	6.6	3.32	0.29	8.9	6.48	0.26	4.1
2R"	2.42	0.22	9.1	3.09	0.27	8.8	7.02	0.35	4.9
3R"	2.88	0.18	6.1	3.34	0.29	8.1	6.51	0.31	4.8
3RS"	2.93	0.21	7.3	3.65	0.27	7.4	6.72	0.36	5.4
4R"	2.53	0.25	9.9	2.62	0.33	12.6	6.19	0.39	6.2
5R"	3.09	0.21	6.9	3.63	0.28	7.8	6.91	0.34	4.9
6R"	3.27	0.21	6.5	3.89	0.32	8.1	6.69	0.32	4.7
6RL"	3.35	0.27	8.0	3.78	0.28	7.4	6.71	0.31	4.6
LSD at p = 0.05	0.11	–	–	0.14	–	–	0.17	–	–

s.d. – standard deviation, c.v. – variation coefficient.

of the addition lines and initial forms under study are given in Table 1. Variability of kernel geometric parameters was low. Kernel thickness of wheat lines with added rye chromosomes ranges from 2.33 mm (line 4R") and 2.42 mm (line 2R") to 3.35 mm (line 6RL"). Kernel thickness of the lines 5R", 6R", and 6RL" was significantly higher than that of the remaining lines as well as of rye and wheat initial forms. Only kernels of octoploid triticale were similarly thick. Kernels of the lines 6R" and 6RL" were also the widest. The longest kernels were found in the line 2R", while the shortest – in the lines 4R" and 1R".

Table 2. 100-kernel weight and approximate kernel volume of initial forms: wheat cv. Grana, rye cv. Dańkowskie Złote, octoploid triticale (Grana × Dańkowskie Złote) and eight addition lines

Genotype	100-kernel weight (g)	Approximate kernel volume		
		Mean (mm^3)	s.d.	c.v. (%)
Initial forms				
wheat cv. Grana	4.51	32.91	5.66	17.2
rye cv.Dańkowskie Złote	4.88	33.84	6.13	18.1
triticale (Grana × Dańkowskie Złote)	4.97	45.40	9.29	20.5
Addition lines				
1R"	4.25	31.36	4.39	14.0
2R"	3.96	27.46	3.60	13.1
3R"	4.93	34.89	4.12	11.8
3RS"	5.35	37.67	4.97	13.2
4R"	2.42	21.62	4.69	21.7
5R"	5.49	40.68	4.76	11.7
6R"	6.13	44.57	5.20	11.7
6RL"	6.01	44.50	5.79	13.0
LSD at p = 0.05	–	1.51	–	–

Geometric features of kernels univocally affected the 100-kernel weight and kernel volume (Table 2). In comparison to wheat cv. Grana, the most filled kernels were found in the lines 6R" and 6RL", while the most shrivelled ones were encountered in the line 4R". This points to a distinct relation between the kernel weight and its geometric features, especially thickness and width. The highest kernel volume, as compared to wheat cv. Grana, was found to occur in the lines 6R" and 6RL". According to MILLER (1984) *Rog* gene which controls round shape of kernels is located on the chromosome 6R. RILEY and CHAPMAN (1958) found that in the addition lines Holdfast-King the rye chromosome 6R contains *Reg* gene, which controls red colour of kernels. From our studies, it appears that *Reg* gene occurs on the longer arm of the chromosome 6RL. MILLER (1984) points out to genetic similarity between 6R and 3R, and the third and sixth homeologous groups of wheat. According to a recent research, the chromosome 6R was involved in multiple interchromosomal rearrangements. Genetic map of 6RL comprises a proximal region with homeology to the wheat group 6 chromosomes, an interstitial region with homeology to the long arms of the wheat group 3 chromosomes and the distal region with homeology to the long arms of the wheat group 7 chromosomes (DEVOS et al. 1993).

Table 3. Surface roughness of kernels and index of internal damages of kernels of initial forms: wheat cv. Grana, rye cv. Dańkowskie Złote, octoploid triticale (Grana × Dańkowskie Złote) and eight addition lines

Genotype	Surface roughness			Internal damage index, Is		
	Mean (mm)	s.d.	c.v. (%)	Mean (mm)	s.d.	c.v. (%)
Initial forms						
wheat cv. Grana	13.74	2.84	20.7	0.50	0.14	27.6
rye cv. Dańkowskie Złote	15.59	4.14	26.6	0.00	–	–
triticale (Grana ×Dańkowskie Złote)	14.99	3.17	21.2	3.09	0.43	14.0
Addition lines						
1R"	10.81	1.72	15.9	3.79	0.22	5.7
2R"	10.78	1.73	16.0	3.70	0.53	14.4
3R"	10.21	1.60	15.7	2.15	0.32	15.0
3RS"	12.10	2.90	23.9	3.69	0.86	23.4
4R"	11.79	2.91	24.7	1.58	0.43	27.0
5R"	11.59	1.23	10.6	2.08	0.47	22.8
6R"	11.23	2.00	17.8	1.33	0.46	34.6
6RL"	11.57	1.86	16.1	3.95	0.66	16.6
LSD at p=0.05	1.62	–	–	1.48	–	–

Kernel surface roughness is related to seed coat permeability. Seed coat constitutes a physical barrier for gas exchange, i.e. oxygen and carbon dioxide, between the embryo and ambient atmosphere. It restricts oxygen uptake which may cause seed dormancy (WEIDNER 1987). Water enters the kernel not only through the embryo but also through the seed coat. JANKOWSKI and DAOUT (1977) found that 45% of water enters the kernel through the seed coat, except the groove and embryo with the surrounding areas, which absorb 5% and 20% of water, respectively.

Surface roughness of kernels also conditions internal and external friction properties which influence the processes of kernel transport, cleaning, storage, etc. All addition lines showed a lower surface roughness than the initial forms (Table 3). At the present stage of research, a more precise explanation of this phenomenon is impossible.

Kernel internal damage, as determined by the Is index, appeared to be variable (Table 3). This is not caused by external forces. Among principal causes is the kernel moisture gradient under changing weather conditions (dew-rainfalls, rainfalls-drought), at the time of full kernel maturity, as well as uneven kernel filling, which causes local rareness of endosperm. On the basis of the obtained data, it can be inferred that all addition lines, including triticale, are characterised by distinctly higher indices of internal kernel damage in comparison to the wheat cv. Grana, with the Is index equal only to 0.50. No damage was recorded in rye kernels.

The obtained roentgenograms showed that wheat kernels were well filled and the level of their internal cracks was low, embracing endosperm fragments in some cases. The number of damaged triticale kernels is considerably higher and many kernels possess zones of rarefied endosperm in various places. Some morphological deformations were occasionally observed. The addition line 3R" has a similar seed shape as the line 1R", although the seed coat is partly corrugated and the groove is broadened. Kernels of the addition line 3RS" look similar, however, the seed coat is not corrugated. The kernel shape of the line 4R" differs from that of all other lines described above. They are smaller, deformed and have numerous zones of rarefied endosperm, despite the fact that the frequency of internal damage is lower than that in the addition lines mentioned earlier. Kernels of the addition line 5R" are large and have foldings over the seed coat and a broadened groove in its central part. Kernels of the addition lines 6R" and 6RL" are similar to those of the line 5R", but numerous zones of rarefied endosperm were found to be located along longitudinal kernel axis.

Mechanical resistance of kernels to crushing was characterised by parameters described in the Methods. Their mean values are given in Table 4. Variation of the parameters is intermediate. The values of maximum force, e.i. the force which destroys kernels, ranged from 65.9 N (Newton) (line 4R") and 83.5 N (line 3R") to 107.9 N (line 6R"). Such a distinct scatter of results testifies to a great variation of kernel physical structure. Among the most resistant to crushing are kernels of the addition lines 6R", 6RL" and 2R". The data suggest that these chromosomes probably contain genes responsible for mechanical strength of rye kernels. This trait can be related to endosperm structure. SIMONDS (1972) and GRZESIUK, KULKA (1981) described differences in the endosperm structure of rye, wheat and triticale. They paid special attention to

Table 4. Kernel mechanical strength parameters of initial forms wheat cv. Grana, rye cv. Dańkowskie Złote, octoploid triticale (Grana × Dańkowskie Złote) and eight addition lines

Genotype	Max. force (N)			Max. elasticity (N)			Max. deformation (mm)			Elastic deformation (mm)			Energy (mJ)		
	Mean	s.d.	c.v. (%)	Mean	s.d.	c.v. (%)	Mean	s.d.	c.v. (%)	Mean	s.d.	c.v. (%)	Mean	s.d.	c.v. (%)
Initial forms															
wheat cv.Grana	82.43	16.35	19.8	69.85	18.58	26.6	0.185	0.052	28.1	0.102	0.03	29.4	7.91	4.86	61.4
rye cv. Dańkowskie Złote	131.33	35.45	27.0	100.29	35.06	35.0	0.338	0.104	30.8	0.166	0.079	47.6	25.00	13.55	54.2
triticale (Grana × Dańkowskie Złote)	86.72	24.17	27.9	62.73	28.13	44.8	0.338	0.103	30.5	0.160	0.079	49.4	16.56	7.91	47.8
Addition lines															
1R"	88.64	16.62	18.8	62.97	19.42	30.8	0.268	0.065	24.3	0.135	0.057	42.2	13.46	5.87	43.6
2R"	102.72	18.51	18.0	79.74	17.59	22.1	0.221	0.070	31.7	0.113	0.041	36.3	13.04	6.36	48.8
3R"	85.27	19.57	23.0	71.82	19.00	26.5	0.177	0.063	35.6	0.106	0.032	30.2	7.68	5.82	75.8
3RS"	98.20	21.64	22.0	80.04	19.17	23.7	0.230	0.059	25.7	0.118	0.049	41.5	11.76	5.79	49.2
4R"	65.96	18.73	28.4	46.61	20.73	44.5	0.284	0.088	31.0	0.135	0.059	43.7	10.76	5.63	52.3
5R"	86.04	15.21	17.7	67.21	20.72	30.8	0.262	0.067	25.6	0.152	0.070	46.1	11.53	4.98	43.2
6R"	107.93	25.02	23.2	94.77	28.51	30.1	0.236	0.067	28.4	0.157	0.065	41.4	12.41	7.07	57.0
6RL"	107.04	26.73	25.0	90.03	32.70	36.3	0.282	0.081	28.7	0.203	0.115	56.7	14.87	7.44	50.0

distribution of proteins and starch in it. LAW et al. (1978), while analysing substitution lines, localized *Ha* gene controlling kernel hardness on the wheat chromosome 5D. THIELE et al. (1989), using kernels of the addition lines Chinese Spring-Imperial and Holdfast-King, carried out nutritive experiments. It appeared that the major gene, controlling the content of anti-nutritive factors, occurs on the chromosome 6R in rye. Anti-nutritive factors can also be controlled by genes localized on other chromosomes and point to chromosome 2R. The addition line 4R" showed the weakest mechanical resistance. Values of this force correspond to a maximum deformation obtained at the moment of kernel damage. They oscillate from 0.18 to 0.28 mm, depending on the line tested. The studies have proved that kernels of addition lines and wheat undergo destruction at a considerably lower deformation than rye and triticale kernels. Rye kernels as the most resistant require the highest energy at crushing (25.0 mJ). All the addition lines, except the line 3R", need more energy for crushing than wheat kernels. Strength parameters of the line 3R" are similar to those of wheat. Force and deformation values within the elasticity limits are typical of cereals, although smaller differences were recorded for the lines 6R" and 6RL", e.i. for kernels with the highest weight. Moisture content of kernels was determined after completing all the strength tests because of a small number of kernels deserving physical parameter testing. The mean moisture content was 8.1%. On the basis of mechanical kernel strength evaluation, these kernels can be classified as elastic-fragile, which is important for grain lots storage under optimal conditions.

Lines with added rye chromosomnes differed from one another and from the initial form – wheat cv. Grana with reference to their basic geometric dimensions. The results presented in this paper suggest that genes responsible for kernel strength parametres probably occur on the chromosomes 6R, 6RL, and 2R. The expression of these genes is observed in the rye cv. Dańkowskie Złote, octoploid triticale (Grana × Dańkowskie Złote), as well as in the addition lines 6R, 6RL, and 2R.

Conclusions

The kernels of the addition lines 6R" and 6RL" were characterised by a considerably higher weight and volume than their initial forms – the wheat cv. Grana and rye cv. Dańkowskie Złote. Kernel surface roughness of the addition lines was significantly lower than that of the initial forms of wheat, rye and triticale. All addition lines and the initial form octoploid triticale had higher indices of internal damage than the wheat cv. Grana. In rye kernels of the cv. Dańkowskie Złote no damage was recorded. Mechanical kernel strength of the addition lines, characterised by five parameters (maximum force, force within elasticity limits, maximum deformation, elastic deformation energy causing deterioration of kernel structure) differed significantly. The highest strength was shown by kernels of the addition lines 6R", 6RL", and 2R". It is very probable that genes determining mechanical strength of the rye (initial form cv. Dańkowskie Złote) kernels occur on these chromosomes.

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