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Genotypic variation in response to iso-osmotic and soil moisture stresses among old and modern cultivars of winter wheat

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Abstract. The study was performed to evaluate range of the genotypic variation in drought susceptibility at juvenile growth stages among 23 old and modern winter cultivars of *Triticum aestivum* and one old cv. of *T. spelta*. Response of germinated seeds to mannitol-simulated drought stress as well as that in seedling shoot and root growth, water use and leaf transpiration under varied soil moisture were measured. Considerable genotypic variation for all morpho-physiological traits was found between wheat cultivars. There were significant differences between the older and modern cultivars. The former showed usually an enhanced rooting ability and higher water requirements, while the newer indicated more efficient water use. The older cultivars were more resistant to both iso-osmotic stress and low soil moisture at the juvenile growth stage. However, no clear differences were found between the two groups of cultivars in the variation range of the drought susceptibility indices. Complex patterns of the response to drought were observed. Cultivars, which distinguished by both a lower shoot : root ratio and a stronger drought-induced stimulative root growth, tended to be more resistant. Although only moderate the relationships noticed, a consideration of the root plasticity screening in local wheat breeding appears to be justified.

Key words: mannitol, resistance, roots, soil drought, transpiration, *Triticum aestivum*, *Triticum spelta*, water use.

Introduction

Drought resistance may be associated with numerous exo- and endogenous factors affecting transpiration, water use as well as plant ability to tolerate desiccation and to recovery growth after water stress (rev. by STREBEYKO

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1966, GÓRECKI, GRZESIUK 1978, MORGAN 1984, BLUM 1987, JOHNSON, ASAY 1993). Among others, such plant adaptive characteristics as effective osmotic adjustments, a vigorous root development and effective water use have been reported to increase plant ability to dehydration avoidance and to support its survive under water stress at various growth stages. The complexity by which cereal plants respond to drought causes that breeding for resistant genotypes is difficult.

Plant adaptation to unpredictable and temporal drought periods appears to be an important breeding strategy in numerous countries, e.g. in the central Europe, where the autumnal sowing of winter wheat and further seedling growth frequently occur at sub-optimal soil moisture. In such conditions, juvenile shoot and root characters may contribute to an improved wheat tolerance to the early season water limitations. Therefore, a search for genetic donors which exhibit appropriate tolerance characters seems to be justified in the region.

Numerous attempts have been made to develop convenient methods for the drought tolerance screening. Different morpho-physiological criteria measured in seedling shoots and roots were proposed for this purpose (GRZESIUK, GÓRECKI 1978, LARSSON 1982, MORGAN 1989). Alternatively, simpler procedures which determine effects of enhanced concentrations of iso-osmotic treatments (e.g. non-penetrating solutes) on germinated wheat seeds or seedling growth have been also recommended (e.g. SLAVIK 1974, JARADAT, DUWAYRI 1981, GALIBA et al. 1989).

There is extremely limited knowledge on the tolerance to post-sowing water deficits among local germplasm collections of winter wheat (GNIEWKOWSKA et al. 1975). The aim of the study was to evaluate genotypic variation in drought susceptibility at juvenile growth stages in a local collection of old and modern cultivars of winter wheat released during 1912-1992.

Material and methods

Plant material

Twenty one cultivars and three breeding lines (hereafter referred in the text to as cultivars) of winter wheat were investigated. Twenty three of them belong to the species *Triticum aestivum* L., while one of them (cv. Orkisz) represents *T. spelta*. The cultivars were representative for different origin, date of release, yield potential and cultivation requirements. There were mostly Polish and rarely foreign cultivars released during 1912-1992. Some of them were previously observed for their different response and rooting ability under limited irrigation in soil boxes (GÓRNY et al. 1994).

Evaluation of the response to limited soil moisture (Exp. 1)

The wheat cultivars were investigated in Nov. 1994 in a greenhouse experiment made under controlled conditions with two soil moisture levels. A randomized design with 24 genotypes, 2 moisture treatments and 3 replications was arranged.

Plants were grown in plastic cylindrical pots (25 cm deep, diameter 9 cm) uniformly filled with 1.6 L of a mechanically prepared mixture (7:1, by vol., pH 6.5) of a sieved fertile sand-loam soil and pure quartz sand. The mixture was initially moistened with distilled water to obtain high or low soil water contents. Ten uniform, surface-sterilized (4 min, 5% natrium hypochlorite) and pre-germinated seeds (emerged radicle was about 1 mm long) were sown per each pot-replication.

There were used a 16/8 h day/night photoperiod and a supplementary light (13,000 Lux at the plant level) provided with an enhanced density of mercury (LRFR 400 W) and sodium (WLS 400 W) lamps. The maximal and minimal temperatures were maintained at 21/12°C day/night. Due to photoperiod cycling, the relative air humidity ranged between 55-85%. To minimize possible effects of light and temperature gradients, packets of splited pots were everyday displaced around the experimental area.

Two constant watering regimes responding to high (Wet) and low (Dry) soil moisture levels were maintained. The initial soil water contents (by weight) were 24% (i.e. 38.3% of field capacity) and 12% in the Wet and Dry treatments, respectively. Pots were weighed daily to record the water use (WU). Then, the recorded amount of used water was supplied (as distilled water) on the medium surface to maintain the constant moisture level. The soil surface was covered with about 2 cm thin layer of styrofoam granules to limit water evaporation (E). Since some E was monitored in control pots without plants, the daily recorded water use reflected the total evapotranspiration (ET). The true WU was calculated by subtracting E from ET.

Plants were grown to the 3-leaf stage. Transpiration rates in the stomatal (open stomata) and cuticular (closed stomata) phases were estimated on the basis of the leaf water retention (LWR) as measured by frequent weighing of detached leaves using procedures described by HYGEN (1951, 1953) and SLAVIK (1974). Detached leaves were weighed on a digital balance every 2 minutes during first 22 minutes after the cutting. From 6 h to 90 h after the cutting, the materials were weighed with 12 h intervals. To provide uniform air circulation during the weighing, the leaves were randomly placed on a thin gauze net expanded on 1 × 1 m frames. During the measurements the temperature and relative air humidity ranged at about 19 ± 1°C and 60 ± 5%, respectively. After the measurements, dry matter of shoots and roots was determined after an oven drying at 65°C for 48 h. Previously, roots were gently washed free of soil. The total length of roots was automatically measured using the Delta-T Image Analysis System (Delta-T Devices Ltd., Cambridge, UK). Water use efficiency (WUE) was calculated by dividing the whole plant dry matter by moles of water used (transpired). The transpiration rates for stomatal and cuticular phases were estimated as mgLWR per g of water content per minute. Drought susceptibility S-indices were calculated for the dry and fresh shoot matters accordingly to FISCHER and MAURER (1978).

Evaluation of the response to iso-osmotic stress (Exp. 2)

Response of germinated seeds to drought conditions simulated by a osmotic agent was studied in the laboratory experiment 2. To eliminate possible effects of the endosperm size (MIAN, NAFZIGER 1994), uniform seeds (fraction 49 ± 3 mg) of all wheat cultivars (excepting the large-sized grains of the *T. spelta* in which the fraction was 55 ± 3 mg) consisted the material. The factorial experiment was arranged as a randomized design with 24 genotypes, two osmotic potentials and three replications, and was two-times repeated using seed materials reproduced in two different locations. Germination was performed under two osmotic potentials, i.e. 0 and −12 bars, using a modification of the standard procedure described elsewhere (SLAVIK 1974, JARADAT, DUWAYRI 1981). According to the van't Hoff equation, respective concentration of the D-mannitol in iso-osmotic solution was used to induce the osmotic potential of −12 bars.

Uniform seeds were surface sterilized (4 min, 5% natrium hypochlorite) and frequently washed in distilled water. Three replications of 20 seeds for each the experimental combination were sown in the 10 cm Petri dishes on a wet filter-paper blotters saturated with 5 ml of the distilled water (0 bars) or with similar volume of the mannitol solution (−12 bars). To eliminate evaporation, the dishes were closed with M-parafilm. Seeds were germinated in darkness at 21°C. After 12 days, the germination percentage was scored. Seeds were assessed as germinated if the shoot was at least 0.5 cm long and 2-4 primary roots were normally developed (about 2 cm or longer). Similarly as in the pot experiment, susceptibility index was calculated for the germination percentage. The percentage recovery from the iso-osmotic stress was assessed for non-germinated seeds after their secondary 48 h germination at 0 bars.

Statistics

The standard MSTAT-C package was used for most data computations. A fixed model of the analysis of variance was used. Comparisons between old and modern groups of wheat cultivars were made using F-tested contrasts (KACZMAREK 1995).

Results

There were found considerable genotypic differences among winter wheat cultivars for the shoot and root growth, water use pattern and transpiration rates of detached leaves in the pot experiment 1 (Table 1). Excepting the large-sized shoot and root systems in *T. spelta* (cv. Orkisz), the strongest root system formed the cvs. Begra, Almari and Małgorzatka Udycka, while the poorest – the cvs. Grana and Kozačka. The new cvs. Elena and Wilga distinguished by the highest water use efficiency (WUE) and a relatively low amount of water used (transpired). A high water requirement and the lowest efficiency of water use showed the old cvs. Dańkowska Selekcyjna and Eka Nowa. The highest leaf transpiration rates at the stomatal phase, i.e. the fastest leaf water losses, were noticed in the cvs. KBH 241, WW 153 and STH 7597, while detached leaves of the cvs. Małgorzatka Udycka, Dańkowska Graniatka and Begra lost water at the lowest rate. At the cuticular phase, the highest water loss rate exhibited leaves of the modern cvs. KBH 241, WW 153 and Grana, whereas leaves of the old cvs. Dańkowska Graniatka, Wysokolitewka and Eka Nowa showed the highest water loss resistance at the phase.

The analysis of variance did not indicate significant (at $P \leq 0.10$) genotype-by-soil moisture interaction effects for the variation in shoot and root growth, water use and transpiration rates measured in the pot experiment 1. On average, the low soil moisture considerably reduced the all shoot dry matter (by 8%), S:R ratio (by 22%), amount of used water (by 6.5%) and stomatal transpiration rate (by 23.5%), while the total root length and root dry matter were increased by 18-19%. The water use efficiency and cuticular transpiration rate were not significantly changed by the varied soil moisture. The level of the drought-induced stimulative effects in rooting was found to be different in wheat cultivars, and ranged from 3.4-5.5% in the cvs. Emika and Zentos to 34.1-51.5% in the cvs. Wysokolitewka and Dańkowska Selekcyjna (not presented data).

Studied wheat cultivars indicated considerably different susceptibility to drought conditions simulated during the seeds germination and at the 3-leaf growth stage (Table 1). The highest resistance to the −12 bars osmotic potential exhibited the old cvs. Mironovska 808, Dańkowska Graniatka, Dańkowska

Table 1. Mean values for morpho-physiological characters and drought susceptibility S-indices measured in plants grow in pots (exp. 1) and in germination test (exp. 2)

Cultivars	Released (year, country)	Experiment 1										Experiment 2	
		Drought susceptibility indices#		Shoot dry matter	Root dry matter	S : R ratio	Total root length	Water used	Water use efficiency	Transpiration rate##		Germination at −12 bars	S_3# index
		S_1	S_2	mg/pot			m/pot	g/pot	mgDM/mol	stomatal	cuticular	%	
										mg/g/min			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Old cvs.													
Orkisz (*T. spelta*)	1930 (?)	1.34	1.05	439	87.7	5.12	26.6	91.9	104	3.17	0.58	62.7	0.70
Dańkowska 40	1955 POL	1.51	1.34	322	56.1	5.88	16.0	65.1	106	2.99	0.67	75.8	0.63
Małgorzatka Udycka	1958 POL	1.33	1.46	356	58.2	6.28	18.6	58.1	129	2.85	0.62	82.5	0.39
Ostka Mikulicka	1957 POL	1.27	0.53	398	52.6	7.86	17.2	86.4	95	3.45	0.63	84.2	0.42
Wysokolitewka Sztywn.	1953 POL	1.08	0.66	359	52.1	7.00	17.2	77.3	97	2.99	0.60	64.2	0.95
Dańkowska Graniatka	1912 POL	0.99	1.04	315	48.3	6.61	14.2	54.9	120	2.87	0.58	85.8	0.26
Mironovska 808	1967 SOV	0.70	1.14	277	50.3	5.60	13.7	56.4	106	3.33	0.63	92.5	0.20
Banatka	1930 (?)	0.71	0.92	397	57.7	7.00	16.8	76.4	108	3.11	0.67	42.1	1.52
Wysokolitewka	1935 POL	0.69	0.70	360	51.5	7.18	17.0	78.8	95	3.17	0.59	81.7	0.49
Dańkowska Selekcyjna	1956 POL	0.20	0.44	273	43.5	6.45	14.7	64.9	89	3.14	0.65	88.3	0.31
Eka Nowa	1962 POL	−0.24	0.52	328	52.2	6.36	15.6	75.4	91	3.07	0.60	71.7	0.72

Table 1, cont.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Modern cvs.													
Zentos	1990 GER	1.90	1.86	317	54.6	5.90	16.3	53.4	126	3.13	0.63	39.2	1.60
Emika	1982 POL	1.81	1.60	282	56.3	5.06	15.9	53.8	116	3.40	0.67	12.5	2.32
Elena	1990 POL	1.54	1.12	280	53.8	5.36	17.8	46.3	137	3.06	0.73	15.0	2.26
Wilga	1991 POL	1.44	1.44	257	55.0	4.71	15.5	42.1	139	3.27	0.67	48.3	1.37
Jawa	1983 POL	1.28	1.33	278	63.6	4.42	15.3	51.4	121	3.21	0.69	26.7	1.93
Grana	1970 POL	1.25	1.42	223	45.3	4.96	11.3	45.9	110	3.32	0.77	79.2	0.55
STH 7597	1992 POL	1.27	1.20	265	50.0	5.37	16.2	49.3	118	3.73	0.71	62.5	0.91
Kozačka	1974 CZE	1.03	1.30	258	43.9	6.01	11.7	56.1	98	3.35	0.61	no	no
WW 153	1975 SVE	1.01	0.61	237	47.4	5.04	12.9	42.3	129	3.80	0.78	75.0	0.67
Mikon	1989 GER	0.82	0.79	294	51.0	5.84	13.0	48.8	129	3.46	0.67	25.0	1.99
KBH 241	1985 POL	0.79	0.59	219	45.4	4.89	14.1	40.6	121	3.75	0.82	98.3	0.05
Begra	1978 POL	0.68	1.10	272	66.5	4.14	19.5	49.3	127	2.60	0.68	45.0	1.46
Almari	1989 POL	–0.55	0.06	337	60.6	5.67	18.7	57.8	125	3.19	0.67	24.2	2.02
$LSD_{0.05}$		–	–	22	6.3	0.74	2.4	8.2	21	0.61	0.08	7.3	–
Mean Wet		–	–	318	49.8	6.48	14.7	61.3	112	3.66	0.65	–	–
Mean Dry		–	–	294	58.9	5.08	17.5	57.3	116	2.80	0.67	–	–
$LSD_{0.05}$				6	1.8	0.21	0.7	2.4	ns	0.17	ns	–	–

[#] estimated for the dry (S_1) and fresh (S_2) shoot matters and germination percentage (S_3); [##] measured on detached leaves.

Table 2. Comparison between old and modern wheat cultivars for morpho-physiological characters measured in pots (exp. 1) and in germination test (exp. 2)

Groups of cultivars	Experiment 1										Experiment 2	
	Drought susceptibility indices		Shoot dry matter	Root dry matter	S : R ratio	Total root length	Water used	Water use efficiency	Transpiration rate		Germination at −12 bars	S_3 index
	S_1	S_2	mg/pot			m/pot	g/pot	mgDM/mol	stomatal (mg/g/min)	cuticular (mg/g/min)	%	
Wet (W)												
Old, *T. spelta*	–	–	463**	77.4**	6.0	23.2**	90.1**	108**	3.83	0.54**	–	–
Old, *T. aestivum*	–	–	350**	47.6	7.4**	14.6	70.9**	103**	3.64	0.61**	–	–
Modern, *T. aestivum*	–	–	282	49.3	5.8	14.2	51.7	119	3.65	0.69	–	–
Dry (D)												
Old, *T. spelta*	–	–	417**	97.9**	4.3	30.1**	93.8**	100**	2.51	0.62*	–	–
Old, *T. aestivum*	–	–	327**	56.9	5.8**	17.7*	67.9**	104**	2.56**	0.64**	–	–
Modern, *T. aestivum*	–	–	259	57.4	4.6	16.3	46.3	127	3.00	0.71	–	–
Means (over W and D)												
Old, *T. spelta*	1.34	1.05	439**	87.7**	5.1	26.6**	91.9**	104**	3.17	0.58**	62.7**	0.70
Old, *T. aestivum*	0.82	0.88	339**	52.3	6.6**	16.2*	69.4**	104**	3.10*	0.62**	76.9**	0.59
Modern, *T. aestivum*	1.09	1.11	271	53.3	5.2	15.3	49.0	123	3.33	0.70	45.9	1.43

*, ** significantly different from the mean of modern cultivars at the $P = 0.05$ and $P = 0.01$ levels, respectively.

Selekcyjna and the new cv. KBH 241, while the highest susceptibility to the iso-osmotic stress showed the modern cvs. Emika, Elena, Almari, Mikon and Jawa. There were also observed some differences in the ability to recovery germination after the stress, ranging from 33-48% in some mannitol-resistant old cultivars (Orkisz, Mironovska 808, Dańkowska Graniatka) to 96% in the mannitol-susceptible new cv. Begra (data not presented). In the pot experiment 1, the cvs. Almari, Eka Nowa and Dańkowska Selekcyjna were found to be the most resistant to limited soil moisture, whereas the most susceptible were the new cvs. Zentos and Emika.

Comparing the both old and modern wheat groups (Table 2), the older cultivars distinguished by more vigorous shoot and root systems and a higher S:R ratio than the newer genotypes. Although a decreased water retention ability by their detached leaves, the modern cultivars required less water and exhibited considerably more efficient water use than the older cultivars. Noteworthy, the relative drought-induced decrease in the stomatal transpiration rate was found to be markedly stronger in older cultivars (30% reduction) than that in the modern cultivars (18% reduction). The cv. Orkisz (*T. spelta*) reduced the transpiration rate similarly to the old cultivars of *T. aestivum*.

Generally, the older cultivars were 2-times more resistant to iso-osmotic stress and tended also to be more resistant to soil drought conditions simulated in pots (Table 2). However, no distinct differences were found between the two cultivar groups when the variation ranges in the S_1 and S_2 indices were compared (Table 1).

Results of the covariance analysis indicated complex patterns by which wheat cultivars responded to low soil moisture. As shown in Table 3, neither a slower leaf transpiration nor the both reduced water requirements and more efficient water use did not considerably affect the drought tolerance level in examined wheats. Non significant or lowly significant positive correlations between the WUE and drought susceptibility were only found in the pot experiment.

Measurements of the leaf water retention indicated some negative relations between the shoot and root size characteristics and the rate of water loss by detached leaves (Table 3). The higher were the cultivar water requirements (i.e. the less efficient water use) the slower was the rate of leaf water loss, especially under the Dry conditions. However, the leaf transpiration rates did not correlate with S-indices at the simulated soil drought.

The covariance analysis did not directly show on root size characters closely associated with S-indices and/or WUE. Only the S:R ratio indicated relatively

Table 3. Correlation coefficients between the stomatal (TRstom) and cuticular (TRcut) transpiration rates in detached leaves, shoot and root size characters and water use measured under the high (Wet) and low (Dry) soil moisture levels and drought susceptibility S-indices (Exp. 1)

Characters	TRcut	Total root length	Root dry matter	Shoot dry matter	S : R ratio	Water used	Water use efficiency	S-indices	
								S_1	S_2
Wet									
TRstom	0.18	–0.24	–0.31	–0.01	0.28	0.12	–0.17	0.08	–0.32
TRcut	–	–0.46*	–0.37+	–0.71**	–0.50*	–0.70**	0.32	–0.02	–0.11
Total root length			0.88**	0.69**	–0.05	0.48*	0.11	0.11	0.06
Root DM			–	0.54**	–0.37+	0.30	0.21	0.12	0.17
Shoot DM				–	0.60**	0.84**	–0.18	0.12	0.04
S : R ratio					–	0.68**	–0.45*	–0.19	–0.36+
Water used						–	–0.67**	–0.14	–0.29
WUE							–	0.36+	0.34+
Dry									
TRstom	0.48*	–0.60**	–0.33+	–0.58**	–0.39+	–0.57**	0.35+	0.04	0.07
TRcut	–	–0.29	–0.14	–0.59**	–0.58**	–0.55**	0.43*	0.20	0.06
Total root length			0.87**	0.62**	–0.15	0.52**	–0.05	–0.03	–0.10
Root DM			–	0.60**	–0.28	0.48*	0.02	0.11	0.14
Shoot DM				–	0.60**	0.90**	–0.47*	–0.19	–0.29
S : R ratio					–	0.62**	–0.61**	–0.33+	–0.42*
Water used						–	–0.79**	–0.19	–0.35+
WUE							–	0.22	0.30

+, *, ** significant at the P = 0.10, P = 0.05 and P = 0.01 levels, respectively.

consistent relationships with WUE and drought susceptibility, and the lower was the S:R ratio under dry conditions the higher were the both WUE ($r = 0.61$, $P < 0.01$) and drought resistance ($r = 0.33$-0.42, $P \leq 0.10$-0.05).

Although no direct correlations between root dimensions and WUE or S-indices, the cultivars that under drought conditions exhibited a higher stimulative effects in total root length (Stim 1) and root dry matter (Stim 2), tended to be more drought resistant at the juvenile growth stage ($r = 0.32$-0.54, $P \leq 0.10$-0.01), as shown in Table 4. It is noteworthy that the relationship between the Stim 1 and S_2-index was markedly closer than that between the stimulation in root DM and both S-indices. Therefore, the shoot and root dry matters appears to provide only limited information about the drought response of juvenile wheat plants. In our study, the total root length measure and the fresh shoot matter appeared to be more appropriate indices for the responsibility of local wheat germplasm.

Table 4. Correlation coefficient between the drought susceptibility S-indices and the drought-induced stimulation in the total root length (Stim 1) and in the root dry matter (Stim 2) in 24 wheat cultivars

Indices	Stim 2#	S_1-index	S_2-index
Stim 1#	0.73**	–0.32	–0.54**
Stim 2#	–	–0.34+	–0.43*
S_3-index	–	0.15	0.21
S_1-index		–	0.80**

dry/wet ratio,
+, *, ** significant at the P = 0.10, P = 0.05 and P = 0.01 levels, respectively.

As presented in the Table 1 and Table 4, a close positive correlation ($r = 0.80$, $P < 0.01$) occurred between the drought susceptibility indices calculated for the dry (S_1) and fresh (S_2) shoot matter. On the other hand, no relationship was found between the resistance of germinating seeds to iso-osmotic stress (S_3-index) and the drought resistance (S_1, S_2 -indices) at the 3-leaf stage. Some cultivars, e.g. Almari and Dańkowska 40, exhibited clearly different responses to drought stresses at the various growth stages, whereas other cultivars, e.g. Dańkowska Selekcyjna and Eka Nowa indicated a stress resistance at the both stages.

Discussion

Investigated cultivars of winter wheat showed different and complex patterns of the response to drought conditions at the juvenile growth stages. The covariance analysis did not indicate any convenient characteristic that exhibiting particularly close associations with drought susceptibility indices could be proposed as a simple selection criterion for local wheat breeders. These observations confirm findings reported in cereals by several authors (GNIEWKOWSKA et al. 1975, HEEN 1981, BLUM 1989, GRZESIAK 1990, JOHNSON, ASAY 1993, PELTONEN-SAINIO, MÄKELÄ 1995) who pointed out very complicated and interacting response mechanisms as well as their complex genetic control.

It may be assumed that the water balance and its control in wheat plants grown under water limitations could be improved by a higher water supply as due to an enhanced rooting ability. Therefore, the observed lack of direct relations between the drought susceptibility and the root size appears to be a partly unexpected result of the study. That is in an opposition to data reported in wheat at later growth stages (FARSHADFAR et al. 1993, GÓRNY et al. 1994). In the study, however, only a moderate drought was simulated at the juvenile growth stage, and under these conditions other components, i.e. a lower S:R ratio and a stronger drought-induced stimulative root growth, exhibit a higher importance. As evidenced by obtained results, an evaluation of such measures as the S:R ratio and the rooting stimulation appears to be necessary for more accurate screening of local wheat collections under drought, and the laborious handling with roots must be considered by breeders.

Similarly as in previous investigations on drought effects in crop plants (DAVIDSON 1969, HURD 1976, TURNER, KRAMER 1980, EGHBALL, MARANVILLE 1993, MCMICHAEL, QUISENBERRY 1993, RAHMAN et al. 1994), the used moderate moisture stress stimulated the both root elongation and dry matter accumulation in roots indicating that wheat roots benefit more than shoots when soil water resources are limited at the early growth stages. Noteworthy, the stimulative effects in the root size appeared to be genotypically specific ranging among wheat cultivars from about 3% to 52%. The observed significant positive relationships between these effects in rooting and drought resistance at the juvenile growth stages suggest an possible use of the root plasticity effects as a selection criterion in wheat breeding. Such a plasticity in root response to reduced soil moisture may have a special adaptive value under rainfed conditions, as recommended by O'TOOLE and BLAND (1987).

A higher water use efficiency (WUE) under drought was not closely associated with an enhanced tolerance to drought in the studied wheat collection. The absence of such a relationship may suggest that it would be possible to select modern wheat genotypes that will combine the both a high drought tolerance and a high efficiency of water use. It appears to be symptomatic that only some modern wheat cultivars, e.g. the cvs. Almari, Begra and Mikon, tended to possess the both mentioned characteristics.

The response of germinating seeds to iso-osmotic stress and the drought resistance indices at the 3-leaf stage were not correlated in studied wheat cultivars. Evidently, the both responses at the closely related developmental phases are belonging to independent specific mechanisms which seem to be regulated by various and non linked genetic factors, as suggested also by results reported in spring wheat (BLUM et al. 1980) and in maize (GRZESIAK 1990). Therefore, it could be possible to compose genetic factors responsible for the both tolerances by breeding. In the study, the older cultivars were usually more resistant to the both stresses than the newer wheats, but that seems to be rather a result of an unconscious selection or, in other words, a result of a lack of selection pressure during the development of modern breeding compositions.

The genotype-soil moisture interaction effects did not affect the variation in the most morpho-physiological characters. This may be explained by the fact that the investigated wheat cultivars consisted a specific and relatively narrow genetic pool, and some of them are partly related by their pedigree. In other studies performed on genetically broader materials of barley, maize, oat and wheat, significant effects of the interaction were observed (O'TOOLE, BLAND 1987, GÓRNY 1992, GÓRNY, PATYNA 1994, RAHMAN et al. 1994).

In conclusion, there was demonstrated that considerable genotypic variation in the rooting, water use pattern and susceptibility to early season drought exists among locally collected wheat cultivars. Although older cultivars, released before the first Polish modern cv. Grana, appeared to be more resistant to stress conditions simulated in the study than the modern ones, observed variation range in the response indicate that the newly selected cultivars (e.g. the Polish cvs. Almari and Begra) offer likely a sufficient gene pool for breeding programs concerning with an improvement of wheat ability to avoid post-sowing drought. It appears that a consideration of such attributes as the both low S:R ratio and stronger drought-stimulated root growth in the evaluation of wheat materials should likely increase the accuracy in selection of relevant genotypes. Obvious needs exist to assess whether the observed variation and covariation in the response to soil drought could be extrapolated for further growth stages as well as to determine inheritance patterns of the mentioned characters.

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