Relationships between different morphological traits of panicles and seeds of *Dactylis glomerata* L. varieties

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This study was aimed to evaluate morphological characteristics of the panicle as well as seeds of *Dactylis glomerata* varieties relevant for the assessment of seed production. Six varieties different in earliness were sown in two row spacing. Panicle traits: length, number of the 1st and the 2nd order branches as well as 1000-seed weight and morphological seed traits were assessed during 4-year utilization. Significant differences between varieties were found according to the panicle length, number of the branches and 1000-seed weight depending on the year of utilization as well as with reference to evaluated seed traits, irrespectively on year and row spacing. The results showed that the main traits determining the seed weight per panicle of *Dactylis glomerata* varieties are the panicle length and the number of the 1st order branches. Whereas, seed morphological traits had impact on 1000-seed weight and seed weight per panicle only in the second year of use, in which the highest rainfall than in the other years and moderate temperatures were recorded.

Key words: orchardgrass, panicle length, seed yield, branches of panicle, row spacing

Introduction

Dactylis glomerata L. (orchardgrass) is a cool-season, persistent and perennial grass species, considered to be of major economic importance due to its high forage production (Jafari and Naseri 2007, Steward and Ellison 2011). This species is characterized by high protein content, depending on the stage of plants maturity (McEniry and O'Kiely 2013). It is recognized as grass with moderate soil requirements and considerable tolerance to periodical semi-drought and low temperature stresses as well as its adaptability to various habitat conditions (Serin and Tan 1998, Kochanowska-Bukowska 2001, Borawska-Jarmułowicz et al. 2010, Borawska-Jarmułowicz et al. 2014). According to literature (Volaire and Thomas 1995, Salis et al. 2006) *Dactylis glomerata* is a widespread grass which is well-adapted to severe water deficit conditions since it maintained longer a high photosynthetic rate even at the most severe drought treatment than most temperate forage grasses. It is a cross-pollinating grass species (Sanada et al. 2010). The genus *Dactylis* L. is the member of the *Poaceae* tribe (race) with $x = 7$ as the basic chromosome number. Most populations of this species are diploid, while others are tetraploid and hexaploid subspecies (Moser et al. 1996, Mizianty 2008, Sanada et al. 2010).

Breeding programme of this species is focused on improved agronomic characteristics such as dry matter production and quality (Volaire and Thomas 1995). Marshal and Wilkins (2003) point out that seed yield is also a trait of major interest for forage grass species and economically relevant for new grass varieties to meet the expected demand and compete in the seed market. According to Lemežiene at al. (2007) only the genotypes with a high seed production are promising for grass breeding. Majidi et al. (2016) indicate that there is a possibility to identify genotypes of *Dactylis glomerata* that have considerable seed and forage yield because of positive correlation between them under drought-stress conditions. To increase seed retention in this species backcrossing was applied as one of the breeding methods used to improve varieties for all general features, plant height and panicle traits (Falcinelli 1991, Falcinelli et al. 1994). Studies of Sahin et al. (2012) showed large variation between ecotype lines of wild *Dactylis glomerata* and the possibility to develop variety from the lines with higher hay and seed yield. Authors noticed significant differences in seed yield between the years and interaction between year and genotype. Majidi et al. (2015) also have reported high heritability levels for seed yield in varieties of this species. According to Dainese (2011) the reproductive performance of this species is highly influenced by grassland use intensity and soil nutrient availability. Meadows managed intensively (high soil nutrient availability) showed *Dactylis glomerata* individuals with a greater number of seeds and heavier seeds. Other literature data (Czyż and Kitczak 2014) show that the application of appropriate fertilization affect the morphological features of plants (number of generative shoots, inflorescence length, number of spikelet and seeds per panicle) as well as the yield of seeds and straw.

Seed yields of this species depend also on row spacing and the highest can be achieve with plants grown in 40–60 cm spaced rows. Furthermore the number of generative shoots developed per unit area exerts a significantly positive influence on seed yield (Ivany 1984, Borawska-Jarmułowicz 2011).

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In research with wild *Dactylis glomerata*, Tosun et al. (1994) found significant positive correlation coefficients between seed yield and length of panicle, as well as the number of florets and spikelet per panicle. Yahagi et al. (2000) suggest that seed weight per panicle could be used as selection index for increasing seed yield of studied breeders and seed production locations. However, knowledge about the influence of panicle traits on seed yield of *Dactylis glomerata* is inconsistent and limited. There is a lack of work about the impact of the structure of inflorescence expressed in the number of branches on seed yield. Moreover few studies have been concerned with the differences in seed size of seeds of this species (Bretagnolle et al. 1995). Variation in seed size leads to losses in the cleaning process of saleable seeds and other impurities and therefore a seed crop more uniform in seed size will realize a higher proportion of the potential seed yield (Boelt and Studer 2010). However there is still a lack of information in the literature about the influence of morphological features of *Dactylis glomerata* seeds on yield.

The present study was set up to gain new insights into relationships of morphological traits of inflorescence as well as seeds of *Dactylis glomerata* in order to determine the appropriate seed weight per panicle. Varieties of *Dactylis glomerata* were tested in reference of morphological characteristics relevant for the assessment of seed weight aspect: 1) to determine panicle traits of varieties sown in two row spacing during four-year utilization, 2) to examine various morphological traits of seeds of these varieties, and 3) to evaluate the relationships between panicle traits and inter-correlations between the seed traits.

Materials and methods

The plant material used in the study comes from the experiment established on Experimental Field of WULS-SGGW in central Poland on degraded black earth soil (pH in 1 M KCl = 4,8, the concentrations of available nutrients: K, Ca, Mg – low, P – moderate) as a split-plot design (main plot – row spacing, sub-plot – variety) with four replications (Borawska-Jarmułowicz 2011). The research covered six Polish *Dactylis glomerata* L. varieties different in earliness: 'Amera' (early), 'Areda', 'Dala', 'Rada' (semi-early), 'Astera' and 'Minora' (late). The seeds were sown in different row spacing – 50 cm and 70 cm. Fertilization was (kg ha^{-1}): N – 100 in three parts, P – 30, K – 75 in two parts. Seeds of tested varieties were collected in different terms in each year depending on their earliness and weather conditions, when single seed heads were stripped with a single sweep of the hand from the bottom to the top of the head (Simon et al. 1997). Morphological variability in panicle and seed characteristics were evaluated.

Panicle traits

Every year 20 plants of each variety of *Dactylis glomerata* randomly selected per plot were sampled. In laboratory individually the following panicle traits were measured (80 panicles per variety per row spacing per year): length (cm), number of the 1st and the 2nd order branches. Length of panicle was measured from the base of the lowest spikelet to the tip of the uppermost spikelet on the panicle, excluding awn. Then seeds were extracted and weighted and the mean total seed weight per individual panicle was determined (mg per panicle). 1000-seed weight was assessed by weighing eight samples of 100 seeds per variant (variety and row spacing) in each year of utilization.

Seed traits

Biometric research to examine the variability in morphological seed features, were carried out on 50 seeds in two replicate samples per variant (variety and row spacing) obtained from each year of utilization. In the laboratory seeds were used to be individually measured. Seed traits were recorded using a binocular and digitized images of seeds were analyzed applying microscopy Soft Imaging System GmbH analysis (Germany). The measured traits are presented in Table 1.

Statistical analysis

Data significance was assessed by analysis of variance (ANOVA) in the Statgraphics Plus. Differences between panicle and seeds traits means were compared using the Tukey's HSD multiple range test at the significance level of $p < 0.05$ and $p < 0.01$. Relations between some selected morphological traits of panicle and seeds were assessed with Pearson's correlations.

Table 1. Abbreviations of measured seed traits

Trait	Unit	Description
Area (A)	mm^2	Area of a particle is (number of pixels of the particle) times (calibration factors in X and Y direction)
Convex area (CA)	mm^2	Area of the convex cover of the particle
Equivalent circle diameter (ECD)	mm	Diameter of a circle that has an area equal to the area of the particle: $ECD = 2\sqrt{(a/\pi)}$, where a = area
Diameter mean (DM)	mm	Arithmetic mean of all diameters of particle (for angles = 1°, 2°, 3°,….180°)
Perimeter (P)		Sum of the pixel distances along the closed boundary
Convex perimeter (CP)		Perimeter of the convex cover of the particle
Shape factor (SF)		Provides information about the "roundness" of the particle. For a spherical particle the shape factor is 1, for all other particles it is smaller than 1. The formula for this calculation is: $\text{shape factor} = \frac{4\pi a}{p^2}$, where a = area, p = perimeter
Feret mean (FM)	mm	Arithmetic mean distance of parallel tangents at opposing particle borders
Martins radius mean (MRM)	mm	Mean distance of a ROI's (Region of Interest) center of gravity to its boundary points
Rectangle mean (RM)	mm^2	Area of the arithmetic mean rectangle which sides consist of tangents to the particle borders

Weather conditions

Mean temperature and the amounts of rainfall from the 1st April to the date of seed collection differed between years, mainly due to rainfall (Table 2). Date of seed collection depended not only on the sum of temperatures from the beginning of April, but also on the sum and distribution of rainfall during this period. It was noted that rainfall in the second year of use were the highest than in the other years of utilization, while temperatures were moderate. In particular years the seeds were collected within 5–10 days. The order of seed harvesting of individual varieties was the same regardless of the year of use. Relatively high temperatures and moderate rainfall in the last year decided that the seeds were collected at the same time.

Table 2. Mean and sum of temperature (°C) and the sum of rainfall (mm) from the 1st April to the date of seed collection of *Dactylis glomerata* varieties (in order according to the earliness)

Variety	Year of utilization							
	1st				2nd			
	Mean temp. (°C)	∑ temp. (°C)	Rainfall (mm)	Order of harvest	Mean temp. (°C)	∑ temp. (°C)	Rainfall (mm)	Order of harvest
Amera	13.1	1066.0	142.3	1	12.1	1112.9	191.6	1
Areda	13.4	1100.7	142.7	2	12.5	1162.2	192.4	2
Dala	13.7	1133.4	142.4	4	12.4	1197.0	193.9	4
Rada	13.7	1133.4	142.4	4	12.5	1200.0	193.9	5
Astera	13.8	1130.5	142.4	5	12.5	1234.7	196.5	6
Minora	13.5	1118.8	142.7	3	12.3	1178.7	193.6	3
Mean	13.5	1113.8	142.5		12.4	1180.9	193.7	
	3rd				4th			
Amera	12.7	1153.8	118.9	1	14.9	1480.7	130.2	1
Areda	13.0	1227.5	118.9	2	14.9	1480.7	130.2	1
Dala	13.2	1286.2	123.1	4	14.9	1480.7	130.2	1
Rada	13.3	1306.6	123.2	5	14.9	1480.7	130.2	1
Astera	13.4	1349.6	123.2	6	14.9	1480.7	130.2	1
Minora	13.1	1269.0	123.1	3	14.9	1480.7	130.2	1
Mean	13.1	1265.5	121.7		14.9	1480.7	130.2	

Results and discussion

Panicle traits

The obtained results showed that morphological traits of panicles of *Dactylis glomerata* were clearly differentiated depending on variety and year and interaction between year and variety was also significant (Table 3). It was found that the mean panicle length ranged among varieties from 12.3 cm (tetraploid 'Dala') to 15.0 cm (diploid 'Areda') and the longest panicles were formed in the third year of utilization (regardless of variety and row spacing). The previous data of Falcinelli (1991) concerning some panicle traits to evaluate the effectiveness of the backcross breeding method to increase seed retention in *Dactylis glomerata* showed no statistical differences between two studied varieties for panicle and internodes length, however the length of branches were significantly differentiated. The obtained results revealed also that varieties formed panicles of similar length, both at the narrower (50 cm) and wider spacing of rows (70 cm). This means that there were no significant differences in panicle length among the six varieties depending on row spacing. The mean panicle length of studied varieties significantly varied in the subsequent years (Table 4). In the first year early 'Amera' and late 'Minora' formed the longest panicles (16.8–17.7 cm) compared to other varieties. In the following year, only mid-early 'Areda' had significantly longer panicles (17.4 cm), while others formed inflorescence of similar length (10.5–12.3 cm). Simultaneously in the last (fourth) year no statistical differences were found for all cultivars, regardless of row spacing.

Table 3. Panicle traits of *Dactylis glomerata* depending on variety (in order according to the earliness), year of utilization and row spacing

Factors		Panicle length (cm)	1st order branches No.	2nd order branches No.	Seed weight per panicle (mg)	1000-seed weight (g)
Variety	Amera	13.7bc	10.0bc	17.9b	2.8b	0.91ab
	Areda	15.0d	10.8c	19.0b	2.2a	0.94b
	Dala	12.3a	9.3ab	15.2a	2.5ab	0.87a
	Rada	12.6ab	9.1a	14.7a	2.3a	0.91ab
	Astera	13.5abc	9.0a	15.5a	2.4a	0.87a
	Minora	14.5cd	9.9b	18.4b	2.2a	1.03c
Year of utilization	1st	13.8b	9.4b	15.2b	1.8a	1.06c
	2nd	12.5a	8.7a	12.1a	2.8b	1.06c
	3rd	15.3c	10.6d	22.4d	3.2c	0.99b
	4th	12.7a	10.1c	17.4c	1.8a	0.58a
Variety (A)		*	*	*	*	*
Year (B)		*	*	*	*	*
Row spacing (C)		NS	NS	NS	NS	NS
Interactions						
AxB		*	*	*	*	*
AxC		NS	NS	NS	NS	NS
BxC		NS	NS	NS	NS	NS
AxBxC		NS	*	*	*	*

Mean values within a column marked with different letter are significantly different at $p < 0.05$; * significant difference at $p < 0.05$; NS, not significant difference at $p < 0.05$

Majidi et al. (2015) conducting research on seed related traits in *Dactylis glomerata* under normal and drought stress conditions also revealed that the effects of year were significant for panicle length. Fraser and Acharya (1993) reported that seed yield of *Dactylis glomerata* was positively correlated with panicle length and panicle number per plant. Tosun et al. (1994) also proved that there was a significant correlation coefficients between seed yield and length of panicle. The mean data obtained for the 4-year period of utilization indicate that mid-early variety 'Areda' formed not only the longest panicles but also the highest number of the first and the second order branches (10.8 and 19.0, respectively) as well. It was also noted that panicles developed the highest number of the first and the second order branches in the third year of use, regardless of the variety and row spacing (the panicles were simultaneously the longest). However, there was no effect of the row spacing on these features, just like on the length of panicle. Furthermore there were noted significant differences between varieties in the number of branches formed in inflorescences in the first and second year of utilization (Table 4).

Table 4. Panicle traits of *Dactylis glomerata* varieties (in order according to the earliness) in the years of utilization

Variety	Year of utilization			
	1st	2nd	3rd	4th
	Panicle length (cm)			
Amera	16.8c	12.0a	13.6a	12.3a
Areda	13.9b	17.4b	15.4ab	13.1a
Dala	11.6a	10.5a	14.4a	12.6a
Rada	11.6a	11.2a	15.5ab	12.2a
Astera	11.2a	11.8a	17.0b	13.8a
Minora	17.7c	12.3a	15.7ab	12.2a
	1st order branches No.			
Amera	10.8b	8.7bc	10.7a	10.0a
Areda	10.0ab	11.1d	11.5a	10.5a
Dala	8.9ab	7.8ab	10.0a	10.7a
Rada	8.8ab	7.9ab	10.5a	9.2a
Astera	8.0a	7.4a	10.5a	10.3a
Minora	10.2b	9.4c	10.3a	9.7a
	2nd order branches No.			
Amera	18.6bc	13.0b	22.1a	18.0a
Areda	16.0abc	19.1c	23.3a	17.5a
Dala	12.9ab	8.9a	21.8a	17.2a
Rada	12.5ab	9.3a	21.1a	15.7a
Astera	11.6a	8.7a	22.7a	18.9a
Minora	19.5c	13.6b	23.5a	17.1a
	Seed weight per panicle (mg)			
Amera	1.6ab	3.4c	4.1e	2.0ab
Areda	1.7bc	2.0a	3.6d	1.6ab
Dala	2.6d	2.7ab	3.1c	1.6ab
Rada	2.0bc	3.0bc	2.8b	1.5a
Astera	2.1cd	3.0bc	2.3a	2.3b
Minora	1.1a	2.5ab	3.5d	1.6ab
	1000-seed weight (g)			
Amera	1.03ab	1.05bc	0.97ab	0.58a
Areda	0.94a	1.10c	1.07c	0.65a
Dala	0.94a	1.06bc	0.89a	0.57a
Rada	1.06d	1.02b	1.00bc	0.55a
Astera	1.04ab	0.93a	1.01bc	0.53a
Minora	1.33b	1.19d	1.01bc	0.61a

Mean values within a column marked with different letter are significantly different at $p < 0.05$.

Late variety 'Astera' were characterized by the smaller number of branches while mid-early 'Areda' formed greater number of these branches (significantly in the second year of use), which determined the length of their panicles. In contrast, in the last two years (third and fourth year of use) no differences were observed between varieties in terms of the number of branches in the panicles, regardless of the row spacing. The results of the study on morphology of *Dactylis glomerata* inflorescence indicate a clear varietal specificity of all assessed features. Irrespectively of year of utilization and row spacing mid-early 'Areda' and late 'Minora' varieties were distinguished by the long panicles with large number of branches of the first and second order, while mid-early 'Dala' and 'Rada', and late 'Astera' formed shorter panicles with less number of branches. There were also found a significant correlations between the length of panicle and the number of the first and the second order branches as well independent of the year of utilization (Table 5). The dependence between the number of the first and the second order branches varied in subsequent years but was positive and high as well (ranged from 0.73 to 0.83).

There were also found significant differences in the seed weight per panicle for variety, as well as the year of use, while the row spacing did not affect this feature (Table 3). Among varieties the greatest weight of seeds per panicle were characterized by early 'Amera' (2.8 mg). The results showed that the seed weight was significantly higher in the second and third year of utilization (mean 2.8 and 3.2 mg, respectively) because of better weather conditions for plant growth. In the first and last year of research, the mass of seeds per panicle was much smaller. Probably in the first year the plants were too young, while in the last year it was determined not only by the senescence of plants, but also by high temperatures in the period from the beginning of 1st April to the harvest of seeds. There was a clear difference in the seed weight per panicle depending on variety in each year of the study (Table 4). In the first year 'Astera', 'Dala' and 'Rada' were characterized by the highest seed weight, while 'Minora' – the smallest. In the next year the mid-early 'Areda' produced significantly less seeds from panicle compared to others, whereas in the third year of utilization, 'Amera' formed the highest yield of seeds per panicle (4.1 mg). In the last year of utilization the weight of seeds from panicles was the least diverse, only for variety 'Astera' it was significantly higher compared to 'Rada'.

There was showed significant correlation between seed weight per panicle and the panicle length as well as the number of the first order branches not only for a whole period of utilization, but also in each year and with reference to individual varieties (Table 5, Fig. 1).

Table 5. Correlation coefficients (r) between the panicle traits and 1000-seed weight of *Dactylis glomerata* using data for four-years of utilization (n=192) and for each year (n=48). Values are means for all tested varieties.

Trait	Panicle length	1st order branches No.	2nd order branches No.	Seed weight per panicle
	4-years of utilization			
Panicle length				
1st order branches No.	0.62*			
2nd order branches No.	0.61*	0.72*		
Seed weight per panicle	0.76*	0.59*	0.57*	
1000-seed weight	0.57*	0.47	0.47	0.58*
	First year of utilization			
Panicle length				
1st order branches No.	0.73*			
2nd order branches No.	0.92*	0.83*		
Seed weight per panicle	0.76*	0.63	0.64	
1000-seed weight	0.59	0.39	0.44	0.38
	Second year of utilization			
Panicle length				
1st order branches No.	0.77*			
2nd order branches No.	0.82*	0.77*		
Seed weight per panicle	0.76*	0.58	0.60	
1000-seed weight	0.45	0.57	0.45	0.63
	Third year of utilization			
Panicle length				
1st order branches No.	0.77*			
2nd order branches No.	0.77*	0.73*		
Seed weight per panicle	0.77*	0.53	0.60	
1000-seed weight	0.60	0.51	0.46	0.65
	Fourth year of utilization			
Panicle length				
1st order branches No.	0.80*			
2nd order branches No.	0.73*	0.73*		
Seed weight per panicle	0.76*	0.60	0.43	
1000-seed weight	0.63	0.43	0.53	0.68

* significant difference at $p < 0.05$

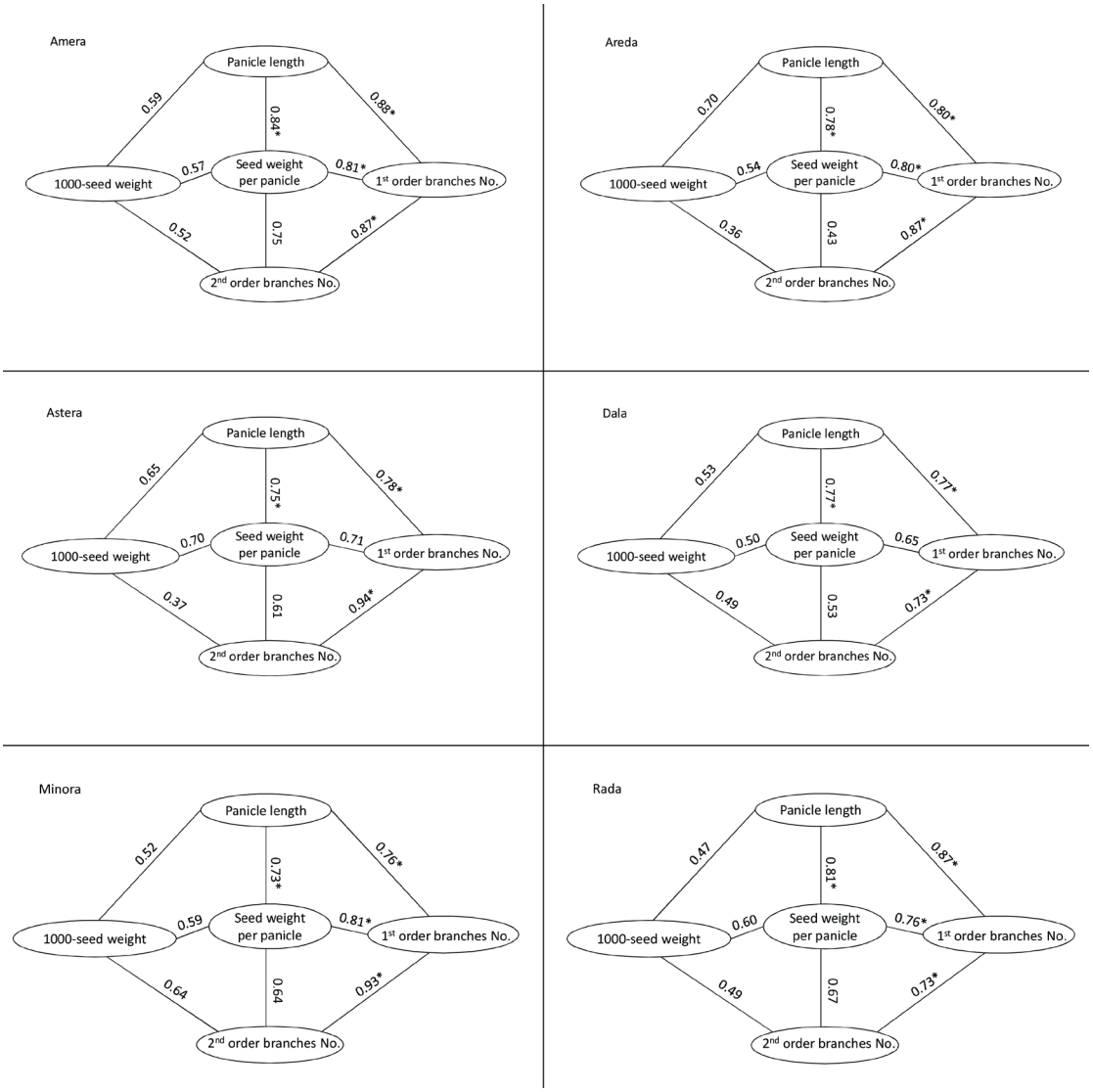

Fig. 1. Correlation coefficients (r) between panicle traits and seed weight per panicle of *Dactylis glomerata* varieties. Values are means for years of utilization; * significant difference at $p < 0.05$

Because of the obtained results it could be stated that not only increasing the length of panicle can be a useful selection objective but also the number of the first order branches in panicle have great importance in predicting mass of seeds per panicle. Jafari (2003) reported a positive correlation between seed yield and some traits, like seed weight per panicle, panicle number and seed number per panicle.

According to genetic research of Majidi et al. (2015) the highest heritability were obtained for number of panicle per plant and 1000-seed weight. The obtained results indicate a clear difference in 1000-seed weight depending on the variety and the year of use (Tables 4 and 5). This feature varied significantly among varieties in the first three years of utilization, whereas in the last year (fourth) it was similar for all varieties. Sahin et al. (2012) showed significant differences between the years and significant interaction between year and the variety with respect to seed yield. In contrast, there was no effect of row spacing on the weight of 1000 seeds of each variety. The average weight of a thousand seeds over a four year period ranged from 0.87 g (variety 'Dala') to 1.03 g (variety 'Minora'), but simultaneously it decreased significantly in subsequent years of seed production from 1.06 g to 0.58 g (mean for variety and row spacing) in the last year of utilization. Relatively small rainfall and slightly higher temperature in the period from the beginning of April to the harvest of seeds in comparison to previous years might have affected this parameter and the age of plants as well. The results of correlation analysis indicated significant correlation between 1000-seed weight of studied varieties and the panicle length as well as the weight of seeds per panicle, but only for a whole period of utilization. Whereas these relationships were not found in each year.

Table 6. Seed traits of *Dactylis glomerata* depending on variety (in order according to the earliness), year of utilization and row spacing

Factors		Area (mm^2)	Convex area (mm^2)	ECD (mm)	Diameter mean (mm)	Perimeter (mm)	Convex perimeter (mm)	Shape factor	Feret mean (mm)	Martins radius (mm)	Rectangle mean (mm^2)
Variety	Amera	4.12bc	4.88abc	2.27bc	5.14ab	14.40ab	12.59ab	0.26b	3.83ab	2.65ab	12.87ab
	Areda	3.71ab	4.43a	2.16ab	5.04ab	13.51a	12.27ab	0.26b	3.73ab	2.52a	12.14ab
	Dala	3.80ab	4.55ab	2.18ab	4.87a	13.88ab	12.00a	0.26b	3.65a	2.54a	11.86a
	Rada	4.05bc	4.99bc	2.25bc	5.35bc	15.03b	13.04bc	0.23ab	3.97bc	2.74bc	13.70bc
	Astera	3.61a	4.39a	2.12a	4.98a	14.54ab	12.15a	0.22a	3.70a	2.51a	11.97a
	Minora	4.37c	5.41c	2.34c	5.48c	14.72ab	13.43c	0.26b	4.09c	2.83c	14.64c
Year of utilization		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety (A)		*	*	*	*	*	*	*	*	*	*
Year (B)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (C)		*	*	*	NS	NS	NS	NS	NS	NS	NS
Interactions											
A x B		*	*	*	*	NS	*	NS	*	*	*
A x C		NS	NS	NS	*	NS	*	NS	*	NS	*
B x C		NS	NS	NS	NS	NS	NS	NS	*	NS	NS
A x B x C		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Mean values within a column marked with different letter are significantly different at $p < 0.05$; * significant difference at $p < 0.05$; NS, not significant difference at $p < 0.05$

The same rule was observed for individual varieties and correlation coefficients were not significant (ranged from 0.47 to 0.70). Opinions about the positive dependence between the weight of a thousand seeds and the yield are not clearly defined. Jafari (2003) showed even a negative impact of 1000-seed weight on seed yield of *Dactylis glomerata*. Whereas Seker and Serin (2004) for *Bromus inermis* (Leyss.) seed yield stated very low correlation coefficients for 1000-seed weight and seed weight per panicle as well.

Seed traits

There were stated significant differences between varieties of *Dactylis glomerata* in all evaluated seed traits, irrespectively on year and row spacing (Table 6). The results showed that 'Amera', 'Minora' and 'Rada' varieties obtained usually grater values of evaluated seed traits compared to other varieties. These varieties formed seeds with the area larger than 4 mm^2 (ranged from 4.05 to 4.37 mm^2) and with mean diameter of more than 5 mm (max. 5.48 mm for 'Minora'). There was also found small variation in the shape factor of seeds between evaluated varieties (0.22–0.26).

At the same time there were not found differences in the values of the individual traits of the seeds of studied varieties between the years. Whereas, row spacing influenced the value of only a few seed traits (area, convex area and equivalent circle diameter). Moreover there were noticed significant interactions between variety and year of utilization for most traits (accept perimeter and shape factor), while between variety and row spacing it was visible only for several traits (diameter mean, convex perimeter, feret mean and rectangle mean).

A comparison of the correlation coefficients related to studied morphological seed traits of the tested *Dactylis glomerata* varieties showed a significant relationship between them, but significant correlation with 1000-seed weight was noted only in the second year of utilization. In this year the highest rainfall and moderate temperatures were recorded during the period from the beginning of April to the term of seed collection (Tables 1 and 7). In particular, the highest positive correlation coefficients (0.99 at $p < 0.01$) were found between area and equivalent circle diameter, diameter mean and convex perimeter and feret mean as well. Similarly high correlations were for convex perimeter and feret mean and rectangle mean. In addition, correlations between other seed traits were at least r = 0.65. Only shape factor gave no significant correlation with any other seed traits except significant negative correlations with perimeter (–0.69). Significant relationships between seed traits and the weight of a thousand seeds were found except perimeter and shape factor. At the same time, these parameters were significantly correlated with the weight of seeds per panicle.

Table 7. Correlation coefficients (r) between the seed traits of *Dactylis glomerata* varieties in the second year of utilization; area (A: mm^2), convex area (CA: mm^2), equivalent circle diameter (ECD: mm), diameter mean (DM: mm), perimeter (P: mm), convex perimeter (CP: mm), shape factor (SF), feret mean (FM: mm), martins radius mean (MRM: mm), rectangle mean (RM: mm2) and 1000-seed weight (TSW: g) and seed weight per panicle (SWP: mg). Values are means for all tested varieties.

Trait	A	CA	ECD	DM	P	CP	SF	FM	MRM	RM	TSW
A											
CA	0.96*										
ECD	0.99**	0.95*									
DM	0.79*	0.83*	0.80*								
P	0.65*	0.73*	0.63*	0.66*							
CP	0.86*	0.90*	0.86*	0.99**	0.68*						
SF	0.08	–0.06	0.10	–0.55	–0.69*	–0.13					
FM	0.86*	0.90*	0.86*	0.99**	0.68*	0.99**	–0.13				
MRM	0.96*	0.95*	0.96*	0.72*	0.66*	0.80*	0.05	0.80*			
RM	0.86*	0.92*	0.85*	0.97**	0.71*	0.99**	–0.16	0.99**	0.81*		
TSW	0.37*	0.32*	0.40**	0.32*	0.07	0.34*	0.25	0.34*	0.33*	0.31*	
SWP	0.18	0.14	0.16	0.20	0.45*	0.18	–0.48*	0.18	0.15	0.17	–0.04

* significant difference at $p < 0.05$; ** significant difference at $p < 0.01$

Mean values of panicle and seed traits of *Dactylis glomerata* varieties from the period of 4-year utilization showed large diversity among panicle traits, especially for 2nd order branches number and seed weight per panicle. Variety 'Areda' showed the highest values of 2nd order branches number whereas 'Astera' and 'Rada' the smallest. Greater seed weight per panicle characterized variety 'Amera' compared to others. Changes in values of the seed traits of studied varieties were much smaller (Fig. 2).

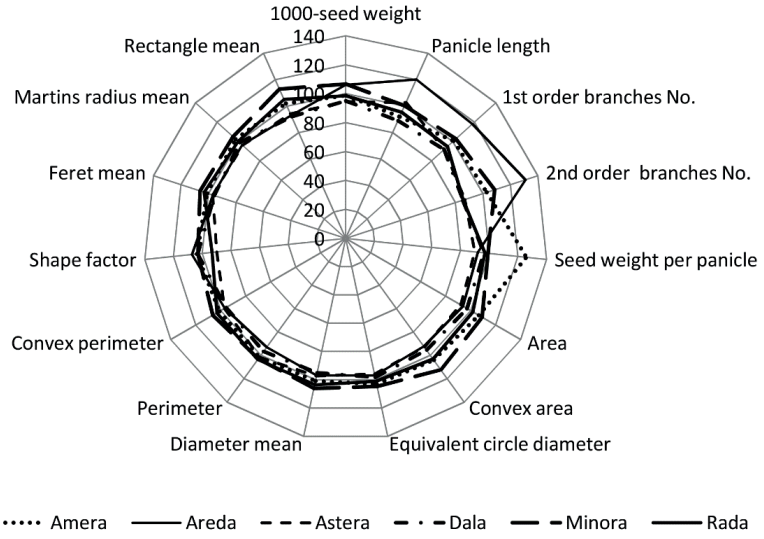

Fig. 2. Changes of panicle and seed traits of *Dactylis glomerata* varieties – means from the years of utilization. Values of each trait were treated in scale – the mean value is 100%.

Conclusions

The results of this study indicate that the number of the 1st order branches in panicle as well as panicle length have importance in predicting the seed weight per panicle of *Dactylis glomerata* varieties. Morphological seed traits depending on variety and interactions between variety and year of utilization. Significant positive correlation between seed traits (except shape factor) indicate a high dependence between them. Significant relationships between seed traits and the weight of a thousand seeds occur in conditions of higher rainfall and moderate temperatures during the period from the beginning of April to the term of seed collection (noted in the second year of use). The data obtained from this study could be useful for breeders of *Dactylis glomerata* varieties to achieve a greater seed weight per panicle.

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