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EFFECT OF SEED PROCESSING, SEEDING RATE AND FOLIAR MICRONUTRIENT FERTILIZATION ON GENERATIVE CHARACTERISTICS AND YIELD OF QUINOA (*Chenopodium quinoa* WILLD.)

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ABSTRACT

Background. This study concerns the species of quinoa (*Chenopodium quinoa* Willd). The aim of the study was to learn about the effect of the seed processing method through the use of different types of seed coat, seeding rate and foliar fertilization on the seed yield and generative characteristics of quinoa plants.
Material and methods. The Faro cultivar of quinoa was used for the study. A strict three-factor field experiment was established in a randomized split-plot design in four replications. The first-order factor was foliar fertilization with the micronutrient preparation Sonata beet, the second-order factor was the seeding rate (2 and 3 kg·ha^{-1}). The third-order factor was the method of seed processing (the type of a seed coat). Its two levels were taken into account: seeds with 'vegetable' coat and 'beet' coat. The control consisted of uncoated seeds.
Results. Based on the study, it was found that fertilization with micronutrients in the form of the preparation Sonata beet resulted in reducing the size of the inflorescence. Higher yield of quinoa was obtained applying the seeding rate 3 kg·ha^{-1} as compared with 2 kg·ha^{-1}. Seed processing with the use of the „beet" coat did not have an effect on plant density and seed yield. The „vegetable" coat caused a reduction in plant density, better generative development (higher and longer inflorescence) but lower seed yield. The highest quinoa seed yield was obtained in 2011 after the use of the "beet" coat and a seeding density of 3 kg·ha^{-1}, without the micronutrient fertilizer in the form of Sonata beet.
Conclusion. Foliar fertilization with microelements did not cause an increase in the seed yield of quinoa. This characteristic was differentiated by the seeding rate and seed processing.

Key words: coated seeds, *Chenopodium quinoa*, foliar fertilization with the preparation Sonata beet, seeding rate

INTRODUCTION

Quinoa comes from South America, from the area of the former Inca state (currently Ecuador, Peru and Bolivia). It was grown by American Indians and from there it was brought to Argentina and Chile. It is one of the oldest field crops in the world. It has been grown in the Andean countries for about 5,000 years (Dębski and Gralak, 2001). The flourishing of this crop took place during the Inca Empire. At that time, it was the staple diet component in this area (Zañudo, 2015). It was then called the mother of cereals because she provided food even in years when the weather conditions were particularly unfavourable

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and the crops of maize and potatoes gave poor yields (Dębski and Gralak, 2001). Quinoa has many advantages. In addition to low soil and climatic requirements (Martínez *et al*., 2009), it is also resistant to long-lasting drought and has a high competitive strength in relation to most weeds. It is also characterized by high nutritional value, which exceeds widely grown species (Ruiz and Bertero, 2008; Gęsiński, 2009; Hirose *et al*., 2010). This applies to both high contents of minerals, including micronutrients, and high-quality protein and fat, as well as vitamins. This confirms high qualities of quinoa which became the basis for interest in this species worldwide, including European countries (Gęsiński, 2000; Iliadis, Karyotis, 2000; Jacobsen *et al*., 2000; Mastebroek and Van Loo, 2000; Ohlsson, 2000). Currently, the work is in progress aiming to improve this species genetically and increase its yield.

An important period of quinoa growth and development is germination and the growth of seedling. New solutions are being sought to eliminate the impact of adverse environmental conditions at this stage. Seed processing through their coating seems to be the easiest solution. Some species have developed a specific ability to create a mucous seed coat (Kreitschitz, 2012; Western, 2012; Kreitschitz *et al*., 2015; Kreitschitz *et al*., 2016; Kreitschitz and Gorb, 2017). The coating performs a number of functions, protects against the attack of pathogens and eating by insects (Grubert, 1974; Yang *et al*., 2012). However, the main factor that influenced the spread of coating was the possibility of precise (single-grain) sowing, especially in the case of small-seed plants, by standardizing the weight and size of seeds (Halmer, 2008). Such sowing guarantees even distribution of seeds and achieving a uniform and plump commercial seed yield. The coating allows for placement of crop protection products, fungicides and insecticides (Munkvold *et al*., 2006; FAO, 2012; Alves *et al*., 2014; Frankenbach *et al*., 2014). It is also enriched with micronutrients or plant growth regulators (Pedrini *et al*., 2017; Haoguang *et al*., 2018). A hydrophilic polymer used in coating facilitates faster and more controlled absorption, which reduces the mean germination time (Jacoba *et al*., 2016). In addition, a higher level of contact of coated seeds with the soil results in better hydration and faster swelling (Bewley *et al*., 2013; Smýkal *et al*., 2014; Blunk *et al*., 2017). It is also possible to use in coats conidial spores of the fungus *Trichoderma viride*, which has strong antagonistic properties towards a wide range of pathogens (Legro, 2004; Sadowski *et al*., 2005a, b; Sadowski *et al*., 2006; Alfano *et al*., 2007; Ebtsam *et al*., 2009). It must therefore be concluded that seed coating is used to modify the physical properties of seeds (Kaufman, 1991; Avelar, 2012) and to provide active components that support the development of young plants.

An important cultivation factor that decides about yielding is, among others, the seeding rate. It determines the amount of light falling on the leaf surface, which in turn affects the growth and development of plants. The appropriate seeding rate allows the development of strong, well branched plants. In conditions of too high density, plants compete with each other for water, light and nutrients, and therefore they are smaller. Thus, in order to determine the optimal seeding rate, various factors must be taken into account, including growth and varietal characteristics (Sanders *et al*., 1999; Cavero *et al*., 2001). The above cultivation factor should also be adapted to the type of the site. With good sowing technology and good sowing conditions, when the weather conditions during sowing and germination are favourable, the seeding rate can be reduced. The sowing date is closely related to the seeding rate, because the site conditions depend on it. As far as possible, it is best to keep the optimal sowing date. In the event of later sowing, the seeding rate should be increased. This characteristic of quinoa depends on all the above factors, among which seed quality is of primary importance.

Another important cultivation factor is fertilization with microelements. The beneficial effect of these fertilizers on the growth, development and yielding of plants has been proven. Foliar feeding provides nutrients to plants in conditions of their difficult uptake from the soil solution and during periods of increased demand (Sienkiewicz-Cholewa, 2002; Wróbel, Sienkiewicz-Cholewa, 2003; Szewczuk, Michałojć, 2003). However, the yield-forming effect of foliar application of fertilizers depends on many site and cultivation factors (Wojciechowski *et al*., 2002; Pałka *et al*., 2003; Tobiasz-Salach, Bobrecka-Jamro, 2003; Waligóra, Kruczek, 2003). These components activate physiological processes and have a positive effect on crop yield. Considering the importance of the above factors, research has been undertaken in this respect. The research hypothesis assumes that the processing of quinoa seeds, the right seeding rate and micronutrient fertilization will affect the growth, development and, as a consequence, generative characteristics and yield of this species. The aim of the study was to assess the yield level and generative characteristics of quinoa, depending on the factors studied.

MATERIAL AND METHODS

The study was conducted in 2010-2012 at the SDOO in Chrząstowo (53°11′ N; 17°35′ E), situated in the Kuyavian-Pomeranian voivodeship and belonging to COBORU. A strict three-factor field experiment was established in a randomized split-plot design in four replications. The first-order factor was foliar fertilization with the micronutrient preparation Sonata beet, the second-order factor was the seeding rate (2 and 3 kg·ha^{-1}). The third-order factor was the method of seed processing (the type of a seed coat), which was analysed on two levels: seeds with the 'vegetable' coat and the “beet” coat; and additionally, uncoated seeds as the control. The coats used in the experiment are commonly used for vegetables – the "vegetable" coat – and for beets – the "beet" coat. Quinoa, like beetroot, belongs to the *Chenopodiaceae* family. Therefore, the "beet" coat and the micronutrient fertilizer Sonata beet were selected for the study. Foliar fertilization was applied at two dates: at the beginning of the inflorescence formation and at the stage of fully developed inflorescence in the amount of 1.5 kg·ha^{-1}. The experiment was established on the soil of class IVa, brown earth proper, with the granulation of heavy loamy sand. The plot area was 17.6 m^2, row spacing 40 cm, seed sowing depth 1–2 cm. On all treatments, 141 kg·ha^{-1} NPK (21 kg·ha^{-1} P and 60 kg·ha^{-1} K was applied to the soil between the 21 and 30 April in the form of triple superphosphate and potassium salt 60% and before sowing, nitrogen in the form of ammonium nitrate (60 kg·ha^{-1}). In autumn, plowing was performed, and in spring, a combined cultivation unit was used. Quinoa sowing was carried out on: 7.05.2010, 5.05.2011 and 4.05.2012. Weeds in stands were removed from the interrows once mechanically using a hoe at the stage of 8 leaf pairs and additionally in rows by hand. Herbicides were not used, whereas in the case of occurrence of plant bugs (*Lygus* sp.), Mospilan SP 20 was sprayed with a concentration of 0.04%. In order to determine the loss of plants in the growing season, the plant density on the surface of 10m^2 was determined after sowing and before the harvest. The evaluation of the morphological structure of the plants was carried out at the full maturity stage of the seeds, before the desiccation and harvest of seeds. The inflorescence length, the inflorescence weight and the weight of seeds from one plant were determined. Measurements were made on ten plants from each replication. Biometrical measurements were used to estimate the percentage of the inflorescence length in the total shoot length, the percentage of the inflorescence weight in the total plant weight, distribution of nutrients to the generative and vegetative parts. After seed harvesting and purification, seed yield was determined from each plot. Harvest of the seeds was carried out with a combine harvester during the first ten days of October in each analyzed year after prior plant desiccation with Reglone 200 SL in an amount of 3 dm^3·ha^{-1}.

In order to compare the obtained results, an analysis of variance was carried out for individual experiments and for long-term synthesis in a mixed model, assuming the years and their interactions with constant factors as random. Significance of differences between the means were verified by Tukey's multiple comparison test. The calculations were made for the significance level of $P < 0.05$. In the preparation of the publication, we used the EXCEL computer program, the WORD text editor and the ANALWAR-5FR software.

RESULTS

In the analyzed years (2010-2012), the weather conditions during the growing season of *Chenopodium quinoa* were varied (Table 1). The total precipitation in 2010 and 2012 was at a similar level and in 2011 it was 120 mm lower than in 2012. The highest rainfall in 2010 was in August, while in the following years in July. The year 2011 was characterized by a higher mean daily temperature for the analyzed growing period (compared with the other years). It was the result of higher temperatures in September and October, the period during which *Chenopodium quinoa* seeds were formed and matured. Those conditions influenced the growth and development of the studied species, and consequently, the yield and yield components.

Table 1. Monthly total rainfall and mean daily, monthly temperature in the years of the study – during the growing period of *Chenopodium quinoa*

Month	Year					
	2010		2011		2012	
	rainfall mm	temperature °C	rainfall mm	temperature °C	rainfall mm	temperature °C
May	88.8	11.3	38.4	13.8	42.9	14.6
June	9.9	16.6	39.4	18.1	113.9	15.5
July	85.8	21.7	117.4	17.8	144.3	18.9
August	149.7	18.5	51.0	18.1	48.4	18.3
September	61.2	12.2	27.2	14.6	30.5	13.5
October	3.2	5.9	19.5	8.6	32.5	7.4
$\sum$ / $\bar{x}$	399	14.3	293	15.2	413	14.7

Based on three years of the study (2010–2012), a significant effect of years, seeding rates and the type of seed processing coat on the plant density of quinoa after emergence and before harvest (Tables 2 and 3) was found. The use of foliar fertilization with Sonata beet had no effect on this characteristic. Plant density differed significantly in the years and was the highest in 2012 and the lowest in 2010. Regardless of the year, significantly more plants were found on treatments with the higher seeding rate (3 kg·ha^{-1}). Nevertheless, they were also characterized by a larger loss of plants during the growing season (on average in 2010–2012) (Table 4). The largest one, however, occurred in 2010, in which almost twice as many plants were sown from sowing in the amount of 3 kg·ha^{-1} than after sowing 2 kg·ha^{-1}. Of the assessed coats, the treatments with the "vegetable" coat were characterized by a smaller plant density in 2010 and 2011. However, this did not have a significant impact on the loss of plants as compared with uncoated seeds and those with the "beet" coat. The treatments with seeds processed with the "vegetable" coat were characterized by worse emergence and smaller plant density before harvest (on average 22%) as compared with the "beet" coat and the control.

The length of inflorescence of quinoa was not dependent on the use of Sonata beet (Table 5). In 2011 this fertilizer had an impact on reducing the proportion of inflorescence in the shoot (Table 6). However, this was not confirmed in the other years. Of the analyzed factors, it was also found (on average, in 2010–2012) that the seeding rate had an effect on the length of the inflorescence (Table 5). At a lower seeding rate – 2 kg·ha^{-1} – the inflorescences were longer (Table 5). This is also confirmed by an increase in the inflorescence proportion in the total length of the shoot (Table 6). The length of the inflorescence was also influenced by the "vegetable" coat. It caused an increase in the length of the inflorescence part.

Table 2. Plant density of quinoa after emergences [pcs·m^{-2}]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year			Mean for 2010–2012
			2010	2011	2012	
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	26.3	31.6	37.0	31.6
		C. „vegetable”	20.0	16.2	46.1	27.4
		C. „beet”	21.9	34.7	48.7	35.1
		mean for A1B1	22.7	27.5	43.9	31.4
	B2 3 kg·ha^{-1}	without coating	34.2	41.8	54.5	43.5
		C. „vegetable”	24.9	20.0	63.6	36.2
		C. „beet”	27.2	52.0	57.6	45.6
		mean for A1B2	28.9	37.9	58.5	41.7
	mean for A1		25.7	32.7	51.2	36.5
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	34.2	27.4	44.2	35.3
		C. „vegetable”	19.3	15.5	44.1	26.3
		C. „beet”	20.6	33.9	47.5	34.0
		mean for A2B1	24.7	25.6	45.3	31.9
	B2 3 kg·ha^{-1}	without coating	41.4	49.2	46.7	45.8
		C. „vegetable”	22.7	19.1	56.6	32.8
		C. „beet”	26.4	45.6	56.1	42.7
		mean for A2B2	30.2	38.0	53.1	40.4
	mean for A2		27.5	31.8	49.2	36.1
Mean for B		B1 – 2 kg·ha^{-1}	23.7	26.6	44.6	31.6
		B2 – 3 kg·ha^{-1}	29.5	37.9	55.8	41.1
Mean for C		without coating	34.0	37.5	45.6	39.0
		C. „vegetable”	21.7	17.7	52.6	30.7
		C. „beet”	24.0	41.6	52.5	39.3
Mean			26.6	32.2	50.2	36.4
$LSD_{0.05}$						
A			ns	ns	ns	ns
B			4.0	1.9	1.0	1.7
C			5.8	5.2	4.6	4.8
interaction						
A × B			ns	ns	3.8	ns
B × A			ns	ns	1.3	ns

ns – non-significant

Table 3. Plant density of quinoa before harvest [pcs·m^{-2}]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year 2010	Year 2011	Year 2012	Mean for 2010–2012
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	23.5	31.6	31.2	28.8
		C. „vegetable"	18.6	16.2	37.7	24.2
		C. „beet"	20.1	34.7	37.9	30.9
		mean for A1B1	20.7	27.5	35.6	27.9
	B2 3 kg·ha^{-1}	without coating	18.8	36.4	45.5	33.6
		C. „vegetable"	19.1	16.8	52.3	29.4
		C. „beet"	20.2	44.6	49.4	38.1
		mean for A1B2	19.4	32.6	49.1	33.7
	mean for A1		20.0	30.0	42.3	30.8
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	30.3	25.5	36.1	30.6
		C. „vegetable"	17.2	13.3	38.3	22.9
		C. „beet"	19.4	28.5	40.8	29.5
		mean for A2B1	22.3	22.4	38.4	27.7
	B2 3 kg·ha^{-1}	without coating	31.9	38.6	39.8	36.8
		C. „vegetable"	18.1	15.9	48.5	27.5
		C. „beet"	21.6	34.1	45.4	33.7
		mean for A2B2	23.9	29.5	44.5	32.7
	mean for A2		23.1	26.0	41.5	30.2
Mean for B		B1 – 2 kg·ha^{-1}	21.5	25.0	37.0	27.8
		B2 – 3 kg·ha^{-1}	21.6	31.1	46.8	33.2
Mean for C		without coating	26.1	33.0	38.1	32.4
		C. „vegetable"	18.3	15.5	44.2	26.0
		C. „beet"	20.3	35.5	43.4	33.1
Mean			21.6	28.0	41.9	30.5
$LSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	1.5	2.0	2.1
C			4.9	4.4	3.5	3.9
interaction						
A × B			ns	ns	2.2	ns
B × A			ns	ns	2.8	ns

ns – non-significant

Table 4. Quinoa plant loss [%] during growth

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year			Mean for 2010–2012
			2010	2011	2012	
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	8.0	6.3	15.7	10.0
		C. „vegetable”	15.5	11.5	18.2	15.1
		C. „beet”	12.4	7.7	22.1	14.1
		mean for A1B1	12.0	8.5	18.7	13.0
	B2 3 kg·ha^{-1}	without coating	42.7	12.7	16.4	23.9
		C. „vegetable”	19.8	16.6	17.7	18.1
		C. „beet”	25.8	14.2	13.7	17.9
		mean for A1B2	29.5	14.5	16.0	20.0
	mean for A1		20.7	11.5	17.3	16.5
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	12.8	7.0	18.7	12.8
		C. „vegetable”	12.8	13.5	13.1	13.1
		C. „beet”	14.2	15.7	14.0	14.6
		mean for A2B1	13.3	12.1	15.3	13.5
	B2 3 kg·ha^{-1}	without coating	20.5	18.2	14.7	17.8
		C. „vegetable”	20.3	16.6	14.2	17.0
		C. „beet”	19.2	22.8	18.9	20.3
		mean for A2B2	20.0	19.2	16.0	18.4
	mean for A2		16.6	15.6	15.6	16.0
Mean for B		B1 – 2 kg·ha^{-1}	12.6	10.3	17.0	13.3
		B2 – 3 kg·ha^{-1}	24.7	16.8	16.0	19.2
Mean for C		without coating	21.0	11.0	16.4	16.1
		C. „vegetable”	17.1	14.6	15.8	15.8
		C. „beet”	17.9	15.1	17.2	16.7
Mean			18.7	13.6	16.5	16.2
$LSD_{0.05}$						
A			ns	ns	ns	ns
B			9.3	4.5	ns	3.9
C			ns	ns	ns	ns
interaction						
A × B			ns	ns	ns	ns
B × A			ns	ns	ns	ns

ns – non-significant

Table 5. Inflorescence length of quinoa [cm]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year 2010	Year 2011	Year 2012	Mean for 2010–2012
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	78.8	74.9	48.4	67.4
		C. „vegetable”	88.3	90.7	43.5	74.2
		C. „beet”	83.8	73.6	44.8	67.4
		mean for A1B1	83.6	79.7	45.6	69.6
	B2 3 kg·ha^{-1}	without coating	74.3	65.0	44.3	61.2
		C. „vegetable”	81.3	74.9	44.0	66.7
		C. „beet”	77.1	58.8	43.4	59.7
		mean for A1B2	77.6	66.2	43.9	62.6
	mean for A1		80.6	73.0	44.7	66.1
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	79.8	61.8	53.4	65.0
		C. „vegetable”	96.0	68.1	49.3	71.1
		C. „beet”	85.8	60.7	48.6	65.0
		mean for A2B1	87.2	63.5	50.4	67.0
	B2 3 kg·ha^{-1}	without coating	72.2	64.1	51.4	62.6
		C. „vegetable”	88.4	74.3	47.1	70.0
		C. „beet”	90.1	65.6	44.8	66.8
		mean for A2B2	83.6	68.0	47.8	66.4
	mean for A2		85.4	65.7	49.1	66.7
Mean for B		B1 – 2 kg·ha^{-1}	85.4	71.6	48.0	68.3
		B2 – 3 kg·ha^{-1}	80.6	67.1	45.8	64.5
Mean for C		without coating	76.3	66.4	49.4	64.0
		C. „vegetable”	88.5	77.0	46.0	70.5
		C. „beet”	84.2	64.6	45.4	64.7
Mean			83.0	69.4	46.9	66.4
$LSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	ns	2.1	2.6
C			9.8	4.5	3.6	4.2
interaction						
A × B			ns	10.1	ns	2.6
B × A			ns	8.3	ns	4.6

ns – non-significant

Table 6. Proportion of inflorescence length in the total shoot length of quinoa [%]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year 2010	Year 2011	Year 2012	Mean for 2010–2012
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	41.9	41.4	27.3	36.8
		C. „vegetable”	45.4	47.1	25.1	39.2
		C. „beet”	43.9	39.9	26.4	36.7
		mean for A1B1	43.7	42.8	26.3	37.6
	B2 3 kg·ha^{-1}	without coating	39.2	36.7	25.7	33.8
		C. „vegetable”	42.7	41.4	26.1	36.8
		C. „beet”	39.6	32.6	24.9	32.4
		mean for A1B2	40.5	36.9	25.6	34.3
	mean for A1		42.1	39.9	25.9	36.0
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	43.7	32.5	27.8	34.7
		C. „vegetable”	50.9	35.2	27.0	37.7
		C. „beet”	44.0	31.6	26.9	34.2
		mean for A2B1	46.2	33.1	27.3	35.5
	B2 3 kg·ha^{-1}	without coating	40.2	33.7	27.5	33.8
		C. „vegetable”	47.9	38.7	25.8	37.5
		C. „beet”	48.2	34.9	24.8	36.0
		mean for A2B2	45.4	35.8	26.0	35.7
	mean for A2		45.8	34.4	26.6	35.6
Mean for B		B1 – 2 kg·ha^{-1}	45.0	37.9	26.8	36.6
		B2 – 3 kg·ha^{-1}	43.0	36.3	25.8	35.0
Mean for C		without coating	41.2	36.1	27.1	34.8
		C. „vegetable”	46.7	40.6	26.0	37.8
		C. „beet”	43.9	34.7	25.8	34.8
Mean			44.0	37.1	26.3	35.8
$LSD_{0.05}$						
A			ns	3.9	ns	ns
B			ns	ns	ns	1.2
C			4.6	2.4	ns	2.0
interaction						
A × B			ns	4.8	ns	2.1
B × A			ns	3.9	ns	3.3

Significant factor interactions were also found. The use of Sonata beet at a seeding rate of 2 kg·ha^{-1} on average in 2010–2012 resulted in a reduction in the length of the inflorescence. This is also confirmed by statistically significant changes in the proportion of the inflorescence part in the total shoot length. There were no significant differences in the length of the quinoa inflorescence after the application of Sonata beet between the seeding rates of 2 kg·ha^{-1} and 3 kg·ha^{-1}. Sonata beet influenced the leveling of this characteristic. On the other hand, significant differences were found in the length of the quinoa inflorescence between the analyzed seeding rates, when Sonata beet was not used. The higher seeding rate (3 kg·ha^{-1}) stimulated a reduction in the length of the inflorescence part. This is also confirmed by changes in the proportion of the inflorescence part in the total shoot length.

Sonata beet had no effect on the inflorescence weight of quinoa (Table 7). While analyzing the changes in the inflorescence proportion in the weight of the plant under the influence of Sonata beet, they were found only in 2011. The use of this preparation caused a reduction in the proportion of inflorescence weight (Table 8). This was not confirmed in the other years of the study.

It was found, however, that the inflorescence weight of quinoa changed depending on the seeding rate and the type of the seed processing coat (Table 7). An increase in the seeding rate in the analyzed years contributed to the reduction in inflorescence weight (Table 7). The use of the "vegetable" coat resulted in an increase in the inflorescence weight in the analyzed years. In 2010 and 2011, seeds sown without a coat developed accumulating biomass in inflorescences at a similar level to plants sown with the "beet" coat, in contrast to 2012, when they significantly exceeded inflorescences with the "beet" coat. This is also confirmed by the results of a higher proportion of inflorescence in the weight of plants with the "vegetable" coat (Table 8).

There were also significant interactions between the seeding rate and the Sonata beet applied on average in the analyzed years and in 2011. An increase in the seeding rate from 2 to 3kg·ha^{-1} without using Sonata beet caused a 26% reduction in the inflorescence weight (Table 7). The use of Sonata beet while increasing the seeding rate did not significantly differentiate the inflorescence weight. This preparation affected the levelling of these characteristics. However, when Sonata beet was applied additionally with the same seeding rate (2kg·ha^{-1}) used, the inflorescence weight decreased compared with the treatment without this preparation Table 7). This regularity was confirmed statistically in 2011 and on average in the years 2010-2012.

Analyzing the proportion of the inflorescence weight in the weight of the quinoa plant before harvesting, no significant effect of the seeding rate was found (Table 8). Applying the "vegetable" coat, an increase in the inflorescence weight proportion was observed in comparison with uncoated seeds, the proportion of which remained at the same level as those with the "beet" coat.

There was no effect of applied Sonata beet on the seed yield and seed weight from one plant on average in the years of the study (2010-2012) (Tables 9 and 10). In 2011, however, a smaller yield of quinoa seed was proved after using this preparation. In contrast, the effect of the seeding rate on the mentioned characteristics was found. An increase in the seeding rate from 2 to 3 kg·ha^{-1} resulted in an increase in seed yield per unit area, despite the smaller seed weight from a single inflorescence. The use of the vegetable coat (on average from 2010-2012) significantly reduced the seed yield in relation to the control treatment and to the treatment where the beet coat was applied. The use of the beet coat, in turn, did not significantly increase the seed yield per unit area in relation to the control (Table 9).

Regardless of the factors studied, the highest seed yield (4.05 Mg·ha^{-1}) was found in 2011. As a result, the seed yield in 2012 was lower by 34% and in 2010 by 44%. The seed weight from one plant of quinoa was the largest after applying the "vegetable" coat. In plants from uncoated seeds, the weight of seeds per plant was lower and at a similar level as from the "beet" coat (Table 10).

Table 7. Inflorescence weight of quinoa before harvest [g]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year 2010	Year 2011	Year 2012	Mean for 2010–2012
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	163.6	197.0	65.6	142.1
		C. „vegetable”	289.4	342.9	58.6	230.3
		C. „beet”	169.6	194.4	62.8	142.3
		mean for A1B1	207.5	244.8	62.4	171.6
	B2 3 kg·ha^{-1}	without coating	157.8	145.2	55.6	119.5
		C. „vegetable”	198.1	206.2	55.0	153.1
		C. „beet”	150.1	116.6	54.8	107.1
		mean for A1B2	168.7	156.0	55.2	126.6
	mean for A1		188.1	200.4	58.8	149.1
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	161.0	176.4	81.1	139.5
		C. „vegetable”	243.2	166.4	68.5	159.3
		C. „beet”	194.6	146.5	67.0	136.1
		mean for A2B1	199.6	163.1	72.2	145.0
	B2 3 kg·ha^{-1}	without coating	144.9	138.0	78.1	120.4
		C. „vegetable”	236.5	207.6	69.3	171.1
		C. „beet”	229.5	149.2	54.8	144.5
		mean for A2B2	203.7	164.9	67.4	145.3
	mean for A2		201.6	164.0	69.8	145.1
Mean for B		B1 – 2 kg·ha^{-1}	203.5	203.9	67.3	158.3
		B2 – 3 kg·ha^{-1}	186.2	160.5	61.3	136.0
Mean for C		without coating	156.8	164.1	70.1	130.4
		C. „vegetable”	241.8	230.8	62.9	178.5
		C. „beet”	185.9	151.7	59.9	132.5
Mean			194.9	182.2	64.3	147.1
$LSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	28.6	ns	15.6
C			56.0	27.1	10.0	23.1
interaction						
A × B			ns	46.0	ns	22.9
B × A			ns	40.5	ns	30.2

Table 8. Proportion of quinoa inflorescence before harvest in the total plant weight [%]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year			Mean for 2010–2012
			2010	2011	2012	
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	46.6	60.2	34.8	47.2
		C. „vegetable”	51.6	62.6	35.9	50.0
		C. „beet”	47.7	61.7	38.6	49.3
		mean for A1B1	48.6	61.5	36.4	48.8
	B2 3 kg·ha^{-1}	without coating	44.9	58.8	36.8	46.9
		C. „vegetable”	48.6	62.2	38.5	49.8
		C. „beet”	45.9	59.1	37.2	47.4
		mean for A1B2	46.5	60.0	37.5	48.0
	mean for A1		47.6	60.8	37.0	48.4
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	50.3	55.2	34.5	46.7
		C. „vegetable”	53.6	53.4	35.7	47.5
		C. „beet”	49.1	52.9	36.0	46.0
		mean for A2B1	51.0	53.8	35.4	46.7
	B2 3 kg·ha^{-1}	without coating	50.6	53.5	36.4	46.9
		C. „vegetable”	51.6	57.8	36.0	48.5
		C. „beet”	53.6	55.4	33.4	47.5
		mean for A2B2	52.0	55.6	35.3	47.6
	mean for A2		51.5	54.7	35.3	47.2
Mean for B		B1 – 2 kg·ha^{-1}	49.8	57.7	35.9	47.8
		B2 – 3 kg·ha^{-1}	49.2	57.8	36.4	47.8
Mean for C		without coating	48.1	56.9	35.6	46.9
		C. „vegetable”	51.4	59.0	36.5	48.9
		C. „beet”	49.1	57.2	36.3	47.5
Mean			49.5	57.7	36.1	47.8
$LSD_{0.05}$						
A			ns	2.6	ns	ns
B			ns	ns	ns	ns
C			2.9	2.0	ns	1.4
interaction						
A × B			ns	2.8	ns	ns
B × A			ns	1.4	ns	ns

Table 9. Seed yield of quinoa [Mg·ha^{-1}]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year 2010	Year 2011	Year 2012	Mean for 2010–2012
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	2.23	4.04	2.55	2.94
		C. „vegetable"	2.18	3.53	2.46	2.72
		C. „beet"	2.40	4.29	2.69	3.13
		mean for A1B1	2.27	3.95	2.57	2.93
	B2 3 kg·ha^{-1}	without coating	2.16	4.53	2.75	3.15
		C. „vegetable"	2.17	3.78	2.73	2.89
		C. „beet"	2.36	5.06	2.75	3.39
		mean for A1B2	2.23	4.46	2.74	3.14
	mean for A1		2.25	4.20	2.66	3.04
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	2.42	4.05	2.69	3.05
		C. „vegetable"	2.14	2.73	2.67	2.52
		C. „beet"	2.28	3.94	2.69	2.97
		mean for A2B1	2.28	3.57	2.69	2.85
	B2 3 kg·ha^{-1}	without coating	2.26	4.58	2.66	3.16
		C. „vegetable"	2.31	3.64	2.63	2.86
		C. „beet"	2.23	4.39	2.66	3.09
		mean for A2B2	2.27	4.20	2.65	3.04
	mean for A2		2.27	3.89	2.67	2.94
Mean for B		B1 – 2 kg·ha^{-1}	2.28	3.76	2.63	2.89
		B2 – 3 kg·ha^{-1}	2.25	4.33	2.70	3.09
Mean for C		without coating	2.27	4.30	2.66	3.08
		C. „vegetable"	2.20	3.42	2.62	2.75
		C. „beet"	2.32	4.42	2.70	3.15
Mean			2.26	4.05	2.66	2.99
$LSD_{0.05}$						
A			ns	0.18	ns	ns
B			ns	0.22	ns	0.15
C			ns	0.32	ns	0.19
interaction						
A × B			ns	ns	0.10	ns
B × A			ns	ns	0.17	ns

Table 10. Seed weight from one quinoa plant [g]

Use of preparation Sonata beet (A)	Seeding rate (B)	Seed coating (C)	Year			Mean for 2010–2012
			2010	2011	2012	
A1 without Sonata	B1 2 kg·ha^{-1}	without coating	9.7	13.8	11.4	11.6
		C. „vegetable”	12.1	25.5	8.5	15.4
		C. „beet”	12.1	13.5	9.1	11.6
		mean for A1B1	11.3	17.6	9.7	12.9
	B2 3 kg·ha^{-1}	without coating	12.0	12.5	8.1	10.9
		C. „vegetable”	11.5	23.2	7.8	14.2
		C. „beet”	11.9	11.3	7.6	10.3
		mean for A1B2	11.8	15.7	7.9	11.8
	mean for A1		11.6	16.6	8.8	12.3
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	8.7	16.3	10.6	11.9
		C. „vegetable”	12.9	20.4	9.9	14.4
		C. „beet”	11.9	14.1	9.5	11.9
		mean for A2B1	11.2	16.9	10.0	12.7
	B2 3 kg·ha^{-1}	without coating	7.7	12.0	9.5	9.7
		C. „vegetable”	13.0	23.0	8.4	14.8
		C. „beet”	11.1	14.2	7.7	11.0
		mean for A2B2	10.6	16.4	8.5	11.8
	mean for A2		10.9	16.7	9.3	12.3
Mean for B		B1 – 2 kg·ha^{-1}	11.2	17.3	9.9	12.8
		B2 – 3 kg·ha^{-1}	11.2	16.0	8.2	11.8
Mean for C		without coating	9.5	13.6	9.9	11.0
		C. „vegetable”	12.4	23.0	8.7	14.7
		C. „beet”	11.8	13.3	8.5	11.2
Mean			11.2	16.6	9.0	12.3
$LSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	1.0	0.3	0.5
C			2.0	2.8	1.0	1.8
interaction						
A × B			ns	ns	ns	ns
B × A			ns	ns	ns	ns

DISCUSSION

The basis for the coating of small-seed plants, and such is the *Chenopodium quinoa*, is an increase in the weight and size of seeds for precise sowing, more even seed distribution in a row (Halmer, 2008). In the present experiment, the emergence was uniform. An important goal of seed processing is also the improvement of germination conditions (Jacoba *et al*., 2016; Blunk *et al*., 2017). The plant emergence from seeds treated with the "vegetable" coat was smaller compared with the control (uncoated seeds) and as a consequence, there was a smaller plant density and smaller seed yield. This means that the "vegetable" coat under the tested conditions limited the plant emergence of *Chenopodium quinoa*, thus it was unsuitable for this type of seeds. The literature in this field indicates, however, that the seed coat creates the right conditions for seed germination (Western, 2012). It is used to modify the physical properties of seeds (Kaufman, 1991; Avelar, 2012). Coated seeds of sugar beet had 17% more contact with the soil than naked seeds and this had an effect on better germination (Blunk *et al*., 2017). The high level of seed contact with the soil resulted in better hydration and faster swelling (Bewley *et al*., 2013; Smýkal *et al*., 2014). The structure of the coat is very important in seed processing, as it must be adapted to the right type of seed. The "vegetable" coat analyzed in our study was not suitable for quinoa seeds, despite its widespread use for coating vegetables. Seed coats seem to interact with many different factors, but their effect depends mainly on the coat type and its composition (Peltonen-Sainio *et al*., 2006; Richardson and Hignight, 2010). Domoradzki and Korpal (2004) obtained a beneficial effect of wood dust, with a content of 0-20% and 70-90% in a mixture of coating ingredients used to form the coat, on the germination capacity of radish seeds. Asch (2014), in turn, in the study concerning coating cereals, concluded that coating significantly reduced germination energy and capacity as compared with uncoated seeds in all the cereals tested. However, the thickness of the coat had a pronounced effect on the germination rate for most combinations of coats and species. The germination rate increased with increasing the size of the coat (Gorim and Asch, 2012). In a study conducted by Colla *et al*. (2015), it was found, however, that the number of leaves, shoots, roots, and biomass of seedlings were significantly higher after the use of coated wheat seeds in comparison with uncoated ones. The consequence was also an increase in the grain yield by 24.3% and 7.7% in subsequent seasons. Improvement in yield quantity and stability as a result of wheat seed coating was associated with an increased level of macro and micronutrient uptake. In our own study on quinoa, the "beet" coat used caused a similar plant density to uncoated seeds. The consequence of this was a similar size and weight of the inflorescence and a comparable seed yield. The above coat was better adapted to quinoa seeds as compared with the "vegetable" coat. However, it still requires refinement of its composition to the requirements and properties of seeds of this species.

The seeding rate is one of the basic cultivation factors which determine the plant architecture and what is connected, the growth and yield. In the established experiment, lower seeding rates were planned than those commonly proposed in the literature. In Ecuador, 11–13 $kg \cdot ha^{-1}$ of seeds are sown under the optimal soil conditions in experiments, while 15–17 $kg \cdot ha^{-1}$ are recommended for farmers (Grochowski, 1996). Jacobsen *et al*. (1994) growing quinoa at higher densities stated that the maximum yield can be obtained with a seeding rate of 13–17 $kg \cdot ha^{-1}$. Tan and Temel (2017) cultivated a quinoa using a seeding rate of 2.5–3 kg^{-1}. Based on these reports and previous research results with plant density regulation (Gęsiński, 2012), and assuming that in the case of the tested species, which is characterized by a heavy growth, a reduction in plant density with the precise sowing of coated seeds may increase the seed yield, the seeding rate was reduced. The higher seeding rate applied (3 $kg \cdot ha^{-1}$) resulted in higher emergence from the seeding rate 2 $kg \cdot ha^{-1}$ and in higher seed yield. Jacobsen *et al*. (1994) found that the maximum yield can be obtained with a plant density of 200–300 plants per m^2. In our own study we obtained a density of 33 plants per m^2 with the seeding rate 3 $kg \cdot ha^{-1}$. Gęsiński (2012), analyzing the effects of quinoa yielding with the plant density regulation, obtained the highest yields with a density of 50 plants per m^2. On this basis, it can be stated that the seeding rate should be twice as high to achieve a density of 50 plants per m^2.

In the established experiment, it was expected that the applied micronutrient foliar fertilizer Sonata beet will have a favourable effect on an increase in the size and weight of the inflorescence and, consequently, also on the weight of seeds from the *Chenopodium quinoa* inflorescence. In the presented studies this thesis has not been confirmed. However, the results of the research showing the beneficial effect of the Sonata micronutrient preparation on plant yield are well known. In winter wheat, the mean increase in yields as a result of foliar application of these fertilizers amounted to 100–250 $kg \cdot ha^{-1}$ of grain, and in maize cultivation 50–290 $kg \cdot ha^{-1}$ of grain. Sonata applied in winter oilseed rape caused an increase in the seed yield of 110–260 $kg \cdot ha^{-1}$, while in sugar beet growing an increase of 100–1500 $kg \cdot ha^{-1}$ of roots (Jaskulski 2004). The increase in yield under the influence of foliar feeding of field crops with micronutrient fertilizers ranges usually from a few to a dozen or so percent (Grześkiewicz and Trawczyński, 1999; Jabłoński, 1999). Therefore, the effectiveness of foliar fertilization is very important. Jaskulski (2004) reports that the highest effectiveness of applying foliar micronutrient fertilizers was in winter wheat cultivation after the application of 2 $kg \cdot ha^{-1}$ at full tillering, and in maize, at a rate of 4 $kg \cdot ha^{-1}$ with a plant height of 50-60 cm. The most effective fertilization for winter oilseed rape was based on the use of 2 $kg \cdot ha^{-1}$ of Sonata at the green bud stage, and for sugar beets 4 $kg \cdot ha^{-1}$ at closing the rows. Thus, the literature indicates that foliar application of micronutrient fertilizers improved generative characteristics and crop yields in species in which this fertilizer was used (Jaskulski, 2007). Kozera *et al*. (2006) obtained a nearly 14% increase in oat yield by applying foliar micronutrients. The positive yield-forming effect of the foliar feeding of cereal plants was also confirmed by Czuba *et al*. (1999), as well as Jaskulski *et al*. (2011). A study by Jaskulski *et al.* (2011) showed an increase in wheat grain yield by nearly 8% as a result of foliar application of urea together with macro- and micronutrients in relation to the control. These results confirm the studies of Wróbel and Hryńczuk (2004), in which soil and foliar boron application in the cultivation of spring wheat caused an increase in grain yield by 9% and 20%, respectively, in comparison with the control treatment. A study by Witek (2003) on spring barley also showed a more beneficial yield-forming effect of foliar nutrition than soil fertilization. The beneficial effects of foliar nutrition were also noted by Koziara (2004) as well as by Songin and Śnieg (1996), who emphasize that there is a close relationship between site conditions and yield-forming function of foliar fertilization. However, there are also reports on the lack of significant effect of foliar application of nutrients on the yield size (Kołota-Biesiada, 2000; Budzyński *et al*., 2003). Jaskulski and Jaskulska (2009) only in four of nine years of their study found significant (5.0-6.7%) increase in the grain yield of winter wheat under the influence of Sonata fertilizer. Based on our own research results, it was found that the use of the micronutrient fertilizer at the seeding rates 2 and 3 $kg \cdot ha^{-1}$ resulted in leveling both the inflorescence length and its weight. They were similar, while reducing the seeding rate to 2 $kg \cdot ha^{-1}$ without Sonata resulted in an increase in the inflorescence length. After applying the micronutrient fertilizer at this seeding rate, the inflorescence was smaller. In 2011, a reduction in the proportion of inflorescence weight and length in the plant was found. In the above year, also a reduction in the seed yield under the influence of this preparation was proved. Thus, the observed changes caused by Sonata beet concerned only the year 2011 and, unfortunately, showed a tendency to a decrease in the value of the analyzed characteristics. Regardless of the factors studied, the highest seed yield (4.05 $Mg \cdot ha^{-1}$) was found in 2011. The above growing period was characterized by the most optimal rainfall for this species (293mm), as well as higher average daily temperature during the growing season (15.2^{o}C), as compared with the other years (in 2010 – 14.3^{o}C and in 2012 14.7^{o}C).

Based on the analyzed results, it is necessary to state the need for further research. In respect of the seeding rate, the standard should be increased to 5–6 $kg \cdot ha^{-1}$. Of the applied methods of seed processing, the "beet" coat may be the basis for further work on adapting the type of the coat to quinoa. Fertilization with microelements in the cultivation of quinoa should be more widely studied both in terms of available preparations and a higher dose. The reduction in the inflorescence size in quinoa (a heavily growing plant) under the influence of Sonata beet indicates that the above components were used for vegetative development and they were insufficient for the development of inflorescence.

CONCLUSIONS

1. A higher yield of quinoa was obtained using the seeding rate 3 kg·ha^{-1} as compared with 2 kg·ha^{-1}. The lower seeding rate (2 kg·ha^{-1}) stimulated a better generative development of the plant, but too small plant density limited the final seed yield. The highest seed yield of quinoa was obtained in 2011 after the application of the "beet" coat and the seeding rate 3 kg·ha^{-1}, without a micronutrient fertilization in the form of the preparation Sonata beet.
2. The applied fertilization with micronutrients in the form of Sonata beet had an effect mainly in 2011 on reducing the inflorescence size and its weight as well as the seed yield.
3. The use of seed processing in the form of the "beet" coat did not have a significant effect on the plant density and seed yield in relation to the control. The "vegetable" coat caused a reduction in the plant density, better plant development, but a lower seed yield.
4. Based on the analyzed results, it is necessary to state the need for further research with different levels of the factors studied. This applies to a higher seeding rate and higher doses of foliar fertilization in the form of the preparation Sonata beet.

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WPŁYW ZABIEGÓW USZLACHETNIAJĄCYCH MATERIAŁ SIEWNY, ILOŚCI WYSIEWU I DOLISTNEGO NAWOŻENIA MIKROELEMENTOWEGO NA CECHY GENERATYWNE I PLONOWANIE KOMOSY RYŻOWEJ (*Chenopodium quinoa* WILLD.)

Celem badań było poznanie wpływu sposobu uszlachetniania nasion poprzez zastosowanie różnego rodzaju otoczki nasiennej, ilości wysiewu i nawożenia dolistnego na plon nasion i cechy generatywne roślin komosy ryżowej (*Chenopodium quinoa* Willd). Do badań użyto odmianę Faro. Założono ścisłe trójczynnikowe doświadczenie polowe w układzie losowanych podbloków w czterech powtórzeniach. Czynnikiem pierwszego rzędu było nawożenie dolistne preparatem mikroelementowym Sonata burak, drugiego – ilość wysiewu (2 i 3 kg·ha^{-1}). Czynnikiem trzeciego rzędu był sposób uszlachetniania nasion (rodzaj otoczki nasiennej). Uwzględniono jego dwa poziomy: nasiona z otoczką „warzywną” i „buraczaną”. Obiekt kontrolny stanowiły nasiona nieotoczkowane. Stwierdzono, że zastosowane nawożenie mikroelementami w postaci preparatu Sonata burak miało wpływ na zmniejszenie wielkości kwiatostanu. Stosując ilość wysiewu 3 kg·ha^{-1}, uzyskano większy plon komosy ryżowej w porównaniu z ilością 2 kg·ha^{-1}. Uszlachetnienie nasion poprzez zastosowanie otoczki „buraczanej” nie miało wpływu na obsadę roślin i plon nasion. Otoczka „warzywna” powodowała zmniejszenie obsady roślin, lepszy rozwój generatywny (większy i dłuższy kwiatostan), ale mniejszy plon nasion. Najwyższy plon nasion komosy ryżowej otrzymano w roku 2011 po zastosowaniu otoczki „buraczanej” i ilości wysiewu 3 kg·ha^{-1}, bez nawozu mikroelementowego w postaci preparatu Sonata burak. Nawożenie dolistne mikroelementami nie miało wpływu na wzrost plonu nasion komosy ryżowej. Ilość wysiewu i zabiegi uszlachetniające materiał siewny różnicowały tę cechę.

Słowa kluczowe: *Chenopodium quinoa*, ilość siewu, nasiona otoczkowane, nawożenie dolistne preparatem Sonata burak