Acta Sci. Pol. Agricultura 18(1) 2019, 3–19

www.agricultura.acta.utp.edu.pl pISSN 1644-0625 eISSN 2300-8504 DOI: 10.37660/aspagr.2019.18.1.1

ORIGINAL PAPER

Received: 21.08.2018
Received in revised form: 17.12.2018
Accepted: 19.12.2018

EFFECT OF FOLIAR MICRONUTRIENT FERTILIZATION, SEEDING RATE AND SEED COATING ON VEGETATIVE CHARACTERISTICS AND GREEN MATTER YIELD OF QUINOA (*Chenopodium quinoa* WILLD.)

Krzysztof Gęsiński✉

Department of Biology and Plant Protection, UTP University of Science and Technology in Bydgoszcz
prof. S. Kaliskiego 7, 85-796 Bydgoszcz, **Poland**

ABSTRACT

Background. Quinoa is a species with high nutritional value and interest has recently increased. This has been the basis of a series of studies aiming to find out its habitat and cultivation requirements to achieve higher yields and profits.

Material and methods. A strict field experiment was established to analyze the effect of foliar fertilization with the micronutrient preparation Sonata beet, as well as of two seeding rates (2.0 and 3.0 kg of seeds of Chenopodium quinoa cv. 'Faro' per hectare), on vegetative characteristics and green matter yield. Seeds processed with the "vegetable" coat and "beet" coat were also used.

Results. Based on the study, it was found that the applied preparation Sonata beet had an effect on better development of the vegetative part of quinoa shoot and the total shoot length. Lower seeding rate of quinoa (2 kg·ha^{-1}) stimulated a higher total shoot length as well as higher weight of the plants and their vegetative parts (stem and leaves). The use of the "vegetable" coat resulted in increased plant weight, as a result of increase in the weight of stem and leaves. The seeds in the "beet" coat were similar to the control (seeds without a coat) in respect of most morphological characteristics and green matter yield of plants.

Conclusion. The highest green weight yield of quinoa (101 Mg·ha^{-1}) was obtained in 2011 after the use of the "beet" coat and a seeding density of 2 kg·ha^{-1}, without the preparation Sonata beet.

Key words: coated seeds, *Chenopodium quinoa*, seeding rate, Sonata beet

INTRODUCTION

Chenopodium quinoa Willd. is a species from the family Chenopodiaceae, which is related to known agricultural crops such as sugar beet (*Beta vulgaris*) and spinach (*Spinacia oleracea*). However, it is classified as a pseudocereal, like amaranth (Iqbal, 2015). Species of this group come from subtropical regions and were important crops for the Aztec, Maya and Inca civilizations (Ixtaina *et al*., 2008; Alvarez-Jubete *et al*., 2010). However, their production and use dropped significantly after conquest by Spain. Today, these ancient crops are cultivated commercially in Mexico, Bolivia, Argentina, Ecuador, Guatemala and Peru (Ixtaina *et al*., 2008). These species are unconventional sources of proteins that have been studied in recent years. They have biological and functional properties that provide nutritional benefits due to the fact that their amino acid composition is well balanced, with a high content of essential exogenous amino acids and high bioavailability. The food protein deficit is currently

✉ gesinski@utp.edu.pl

© Copyright by Wydawnictwa Uczelniane Uniwersytetu Technologiczno-Przyrodniczego w Bydgoszczy BY-NC

small, but the demand for it is constantly growing, therefore research focuses on its new alternative sources (Batista *et al*., 2005). Recently, researchers have paid particular attention to quinoa protein, because quinoa seeds have a higher amount of protein than other seeds, high levels of lysine and methionine, and are gluten-free and anti-allergic (Nongonierma *et al*., 2015). In addition to the valuable protein, quinoa is also rich in other valuable ingredients, and not only its seeds, but also the whole plant. The quinoa leaves contain the sufficient amount of ash (3.3%), fiber (1.9%), nitrates (0.4%), vitamin E (2.9 mg$\cdot$100 g^{-1}) and Na (289 mg$\cdot$100 g^{-1}). Quinoa flour is characterized by an average of 11.2% moisture and contains 13.5% crude protein, 9.5% crude fiber, 1.2% total ash and 58.3% carbohydrates (Iqbal, 2015). The quinoa potential also results from a high tolerance to abiotic stresses: it has a high level of resistance to adverse factors such as soil salinity, drought, frost, diseases and pests (Jacobsen *et al*., 2003). It can tolerate soil pH from 4.8 to 9.5. Due to mycorrhizal capabilities, in turn, it maximizes the use of hardly available nutrients (Tapia, 1979). The recent interest in quinoa in many countries has been the basis of a series of studies aiming to improve it genetically, as well as improve the seed to achieve higher profits.

For some time, as part of improving the seed material, the seed coating method has emerged. It has its origins in the pharmaceutical industry and the multi-component mineral fertilizer industry. The seed granulation method derives from these industries, based on the increase of their volume with material applied to the seed (Poćwiadowski *et al*., 2016), to which over time were added: seed protection agents, fillers, peat, growth regulators, seed fertilizers, microorganisms (Tonkin, 1984), as well as coats that reduce friction and dyes on the surface of seeds (Domoradzki, 1999, Domoradzki, 2011). The coat may also contain aqueous solutions of some chemical compounds that stimulate the germination process (Domoradzki and Korpal, 2004). Coating gives the possibility of precise sowing, which is another advantage in creating the optimal conditions for the growth and development of cultivated plants. For this purpose, a study has been undertaken with the use of coated seeds in quinoa cultivation. In addition, an attempt was made to evaluate the application of the micronutrient fertilizer Sonata beet and different seeding rates. The research hypothesis assumes that the processing of quinoa seeds, the proper seeding rate and micronutrient fertilization will improve the germination conditions and, consequently, the vegetative characteristics and green weight yield of this species. The aim of this study was to assess the possibility of increase in quinoa yield under the influence of the analyzed factors.

MATERIAL AND METHODS

The study was conducted at the Central Research Center for Cultivar Testing – the Experimental Station for Cultivar Testing in Chrząstowo (53°11′ N; 17°35′ E) situated in the Kuyavian-Pomeranian voivodeship in 2010-2012 on the soil of class IVa, brown earth proper, with the granulation of heavy loamy sand.

The assessment was based on a strict three-factor field experiment established in a randomized split-plot design in four replications. The plot area for harvest was 17.6 m^2, row spacing 40 cm, and seed sowing depth 1–2 cm. The effect of foliar fertilization with the micronutrient preparation Sonata beet (with the content in % by weight: MgO – 15, B – 0.8, Cu – 0.15, Zn – 0.8, Mn – 0.8, Fe – 0.4, Mo – 0.08) were analyzed, as well as two seeding rates (2.0 and 3.0 kg seeds of cv. ‘Faro’ per hectare). Processed seeds were also used (coated with the “vegetable” coat and “beet” coat”) as well as uncoated seeds, for comparison. 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$\cdot$$ha^{-1}$. On all treatments, 141 kg$\cdot$$ha^{-1}$ NPK (21 kg$\cdot$$ha^{-1}$ P and 60 kg$\cdot$$ha^{-1}$ K in the form of triple superphosphate and potassium salt 60% and 60 kg$\cdot$$ha^{-1}$ N in the form of ammonium nitrate) was applied before sowing to the soil. Quinoa sowing was carried out on: 7.05.2010, 5.05.2011, 4.05.2012 with a plot drill. Green mass was harvested at the end of plant flowering stage at the first ten days of August.

There were determined as follows:

– the total length of shoot and its vegetative part – stem,

– the proportion of stem in the total shoot length,
– the total weight of plant and its vegetative parts (the weight of stem, leaves),
– the proportion of stem weight in the total plant weight,
– the green weight yield of plants.

Measurements were made on ten plants from each replication. 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 $P < 0.05$. This publication was prepared with the use of the EXCEL computer software, the WORD text editor and the ANALWAR-5FR software.

RESULTS

The growing season of *Chenopodium quinoa* in the years of the study (2010–2012) was characterized by varied weather conditions (Table 1). The lowest total precipitation was in 2011 (293 mm). In 2010 and 2012 it was similar and higher than in 2011 by almost 40%. The highest rainfall in 2010 was in August, while in the following years of the study it was in July. The year 2011 was characterized by a higher mean daily temperature for the analyzed growing period, compared with the other years. Those conditions affected the growth and development of *Chenopodium quinoa* as well as the significance of the analyzed experimental factors.

On average in the three analyzed years of the study (2010–2012), there was diversity of the plant density of quinoa cultivar 'Faro' before harvest as affected by the seeding rate and the type of seed processing coat (Table 2). The preparation Sonata beet, however, had no effect on the number of plants per m^2. 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 ($3\ kg \cdot ha^{-1}$). The seeds with the "vegetable" coat were characterized by worse emergence and consequently, smaller plant density before harvest (on average more than 20%) as compared with the "beet" coat and the control. The above forms of seed processing had an impact on plant architecture.

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

Table 2. Plant density of quinoa before harvest [pcs·m^{-2}] (Gęsiński, 2018)

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	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
$HSD_{0.05}$						
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

When analyzing the shoot of quinoa in the years, it was found that the use of Sonata beet significantly affected its elongation in 2011 (Table 3). These changes also concerned its structure. The vegetative part of the shoot was lengthened (Table 4) and therefore its proportion in the total shoot length increased (Table 5). It was also found (on average, in 2010–2012) the effect of the seeding rate on the shoot length (Table 3). The lower seeding rate – 2 $kg \cdot ha^{-1}$ – stimulated a higher total shoot length. There was no effect found of the analyzed coat types on the total shoot length on average in the years of the study, whereas in 2011, the plant shoot with the "vegetable" coat was significantly longer than the control. The "vegetable" coat applied at the same time caused a reduction in length of the vegetative part of the shoot in relation to the other coats. This is also confirmed by the significance of the proportion of this part in the total shoot length (Table 5).

Significant factor interactions were also found. The use of Sonata beet at a seeding rate of 2 $kg \cdot ha^{-1}$ on average in 2010-2012 resulted in an increase in the length of the vegetative part as compared with the treatment without this preparation. This is also confirmed by statistically significant changes in the proportion of the vegetative part in the total shoot length. There were no significant differences found in the length of the vegetative part of quinoa stem after the application of Sonata beet between the seeding rates of 2 $kg \cdot ha^{-1}$ and 3 $kg \cdot ha^{-1}$. The foliar fertilizer Sonata beet affected the leveling of values of these characteristics. On the other hand, significant differences were found in the length of the vegetative part of quinoa stem induced by the analyzed seeding rates, when Sonata beet was not used. The higher seeding rate (3 $kg \cdot ha^{-1}$) stimulated an increase in the length of the vegetative part of the shoot. This is also confirmed by changes in the proportion of the vegetative part in the total shoot length.

It was found that the plant weight of quinoa and of its vegetative parts changed depending on the seeding rate and the type of the seed processing coat (Tables 6–9). An increase in the seeding rate on average in the analyzed years contributed to a reduction in the weight of the plant (Table 6) and all its vegetative parts (the weight of stem – Table 7, and leaves – Table 8). The use of the "vegetable" coat resulted in an increase in plant weight (Table 6) as the result of an increase in stem weight (Table 7) and leaf weight (Table 8). In 2010 and 2011, plants sown from seeds without a coat developed accumulating biomass at a similar level to plants sown with the "beet" coat, in contrast to 2012, when they significantly exceeded the plants with the "beet" coat. Irrespective of this, the proportion of the stem in the plant weight was smaller in the treatment with the "vegetable" coat as compared to the control and the "beet" coat (Table 9).

Changes in the weight of the plant and its vegetative parts under the influence of Sonata beet were found only in 2011, when the proportion of the stem weight before harvest increased (Table 9).

Significant interactions of the seeding rate and Sonata beet used were also found in 2011, but also on average in the analyzed years (2010–2012). The increase in the seeding rate from 2 to 3 $kg \cdot ha^{-1}$ without the use of Sonata beet fertilizer resulted in an average for years reduction in plant weight by 22% (Table 6), including leaf weight reduction by 21% (Table 8). No significant reaction was observed in the case of stem weight. The use of Sonata beet while increasing the seeding rate did not significantly differentiate the weight of the plant and its parts. The preparation affected the leveling of values of these characteristics. However, when Sonata beet was additionally applied at the same seeding rate (2 $kg \cdot ha^{-1}$), this resulted in a reduction in the plant weight in 2011 and on average in the years compared with the treatment without the preparation (Table 6).

There was no significant effect of the seeding rate on the proportion of the stem weight in the quinoa plant weight before harvest (Table 9). However, using the "vegetable" coat, it was found a reduction in proportion of the stem weight compared with the treatment with sowing uncoated seeds. The proportion of plant stem weight from uncoated seeds remained at the same level as from the "beet" coat.

There was also a significant interaction of the Sonata beet used and the seeding rate in relation to the proportion of the stem weight in the quinoa plant (Table 9). The increase in the seeding rate from 2 to 3 $kg \cdot ha^{-1}$ after applying Sonata beet caused an average reduction in the proportion of the stem weight in the plant. The use of the same seeding rate (2 $kg \cdot ha^{-1}$) and Sonata beet, compared to the treatment without this preparation, resulted in an increase in the proportion of the stem weight in the quinoa plant.

Table 3. Shoot length of quinoa plants [cm]

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	188.2	181.1	177.5	182.2
		C. „vegetable”	193.5	192.5	173.9	186.6
		C. „beet”	189.9	184.4	170.0	181.4
		mean for A1B1	190.5	186.0	173.8	183.4
	B2 3 kg·ha^{-1}	without coating	190.1	177.3	172.8	180.0
		C. „vegetable”	189.4	180.9	168.2	179.5
		C. „beet”	194.7	180.3	174.4	183.1
		mean for A1B2	191.4	179.5	171.8	180.9
	mean for A1		191.0	182.8	172.8	182.2
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	182.0	189.9	191.2	187.7
		C. „vegetable”	188.6	193.6	182.3	188.2
		C. „beet”	194.3	191.8	180.6	188.9
		mean for A2B1	188.3	191.8	184.7	188.3
	B2 3 kg·ha^{-1}	without coating	179.3	190.0	187.3	185.5
		C. „vegetable”	185.5	191.7	183.0	186.7
		C. „beet”	186.9	187.8	180.7	185.1
		mean for A2B2	183.9	189.8	183.7	185.8
	mean for A2		186.1	190.8	184.2	187.0
Mean for B		B1 – 2 kg·ha^{-1}	189.4	188.9	179.2	185.8
		B2 – 3 kg·ha^{-1}	187.6	184.7	177.7	183.3
Mean for C		without coating	184.9	184.6	182.2	183.9
		C. „vegetable”	189.2	189.7	176.8	185.2
		C. „beet”	191.4	186.1	176.4	184.7
Mean			188.5	186.8	178.5	184.6
$HSD_{0.05}$						
A			ns	6.4	ns	ns
B			ns	2.6	ns	1.7
C			ns	3.9	ns	ns
interaction						
A × B			ns	ns	ns	ns
B × A			ns	ns	ns	ns

ns – non-significant

Table 4. The vegetative part length of quinoa shoot [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	109.4	106.2	129.1	114.9
		C. „vegetable”	105.3	101.8	130.3	112.5
		C. „beet”	106.2	110.8	125.2	114.1
		mean for A1B1	107.0	106.3	128.2	113.8
	B2 3 kg·ha^{-1}	without coating	115.8	112.3	128.5	118.8
		C. „vegetable”	108.2	106.0	124.2	112.8
		C. „beet”	117.6	121.6	131.0	123.4
		mean for A1B2	113.9	113.3	127.9	118.3
	mean for A1		110.4	109.8	128.1	116.1
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	102.2	128.2	137.8	122.7
		C. „vegetable”	92.6	125.5	133.0	117.0
		C. „beet”	108.6	131.2	132.0	123.9
		mean for A2B1	101.1	128.3	134.3	121.2
	B2 3 kg·ha^{-1}	without coating	107.1	125.9	135.9	123.0
		C. „vegetable”	97.0	117.3	135.9	116.8
		C. „beet”	96.8	122.3	135.8	118.3
		mean for A2B2	100.3	121.8	135.9	119.4
	mean for A2		100.7	125.1	135.1	120.3
Mean for B		B1 – 2 kg·ha^{-1}	104.0	117.3	131.2	117.5
		B2 – 3 kg·ha^{-1}	107.1	117.6	131.9	118.8
Mean for C		without coating	108.6	118.2	132.8	119.9
		C. „vegetable”	100.8	112.7	130.9	114.8
		C. „beet”	107.3	121.5	131.0	119.9
Mean			105.6	117.4	131.6	118.2
$HSD_{0.05}$						
A			ns	5.7	ns	ns
B			ns	ns	ns	ns
C			ns	5.4	ns	3.9
interaction						
A × B			ns	7.2	ns	7.0
B × A			ns	6.5	ns	3.6

ns – non-significant

Table 5. Proportion of the vegetative part length in the total shoot length of quinoa [%]

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	58.1	58.6	72.7	63.1
		C. „vegetable”	54.6	52.9	74.9	60.8
		C. „beet”	56.1	60.1	73.6	63.3
		mean for A1B1	56.3	57.2	73.7	62.4
	B2 3 kg·ha^{-1}	without coating	60.8	63.3	74.3	66.1
		C. „vegetable”	57.3	58.6	73.9	63.2
		C. „beet”	60.4	67.4	75.1	67.6
		mean for A1B2	59.5	63.1	74.4	65.7
	mean for A1		57.9	60.2	74.1	64.0
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	56.3	67.5	72.2	65.3
		C. „vegetable”	49.1	64.8	73.0	62.3
		C. „beet”	56.0	68.4	73.1	65.8
		mean for A2B1	53.8	66.9	72.8	64.5
	B2 3 kg·ha^{-1}	without coating	59.8	66.3	72.5	66.2
		C. „vegetable”	52.1	61.3	74.2	62.5
		C. „beet”	51.8	65.1	75.2	64.0
		mean for A2B2	54.6	64.2	74.0	64.3
	mean for A2		54.2	65.6	73.4	64.4
Mean for B		B1 – 2 kg·ha^{-1}	55.0	62.1	73.3	63.4
		B2 – 3 kg·ha^{-1}	57.0	63.7	74.2	65.0
Mean for C		without coating	58.8	63.9	72.9	65.2
		C. „vegetable”	53.3	59.4	74.0	62.2
		C. „beet”	56.1	65.3	74.2	65.2
Mean			56.0	62.9	73.7	64.2
$HSD_{0.05}$						
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

ns – non-significant

Table 6. One plant weight of quinoa before harvest [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	345.9	327.2	188.9	287.3
		C. „vegetable"	548.7	547.5	164.1	420.1
		C. „beet"	354.3	316.3	161.2	277.3
		mean for A1B1	416.3	397.0	171.4	328.2
	B2 3 kg·ha^{-1}	without coating	351.7	247.0	150.0	249.6
		C. „vegetable"	404.9	329.5	142.5	292.3
		C. „beet"	327.3	196.2	146.3	223.3
		mean for A1B2	361.3	257.6	146.3	255.0
	mean for A1		388.8	327.3	158.8	291.6
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	315.2	321.6	234.2	290.3
		C. „vegetable"	450.0	311.0	193.2	318.1
		C. „beet"	395.4	278.8	187.7	287.3
		mean for A2B1	386.9	303.8	205.0	298.6
	B2 3 kg·ha^{-1}	without coating	288.2	257.7	214.5	253.5
		C. „vegetable"	458.7	358.0	194.3	337.0
		C. „beet"	424.5	267.2	162.2	284.6
		mean for A2B2	390.4	294.3	190.3	291.7
	mean for A2		388.7	299.1	197.7	295.1
Mean for B		B1 – 2 kg·ha^{-1}	401.6	350.4	188.2	313.4
		B2 – 3 kg·ha^{-1}	375.9	275.9	168.3	273.4
Mean for C		without coating	325.2	288.3	196.9	270.2
		C. „vegetable"	465.6	386.5	173.5	341.9
		C. „beet"	375.4	264.6	164.4	268.1
Mean			388.7	313.2	178.3	293.4
$HSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	47.2	15.4	25.2
C			96.7	44.1	23.5	39.6
interaction						
A × B			ns	80.5	ns	29.0
B × A			ns	66.8	ns	48.2
A × B × C						s

ns – non-significant; s – significant

Table 7. One stem weight of quinoa before harvest [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	122.9	111.2	101.3	111.8
		C. „vegetable”	167.1	161.5	87.9	138.9
		C. „beet”	124.7	100.8	81.1	102.2
		mean for A1B1	138.2	124.5	90.1	117.6
	B2 3 kg·ha^{-1}	without coating	133.7	85.6	78.3	99.2
		C. „vegetable”	140.6	103.9	72.2	105.6
		C. „beet”	119.8	67.8	75.8	87.8
		mean for A1B2	131.4	85.8	75.4	97.5
	mean for A1		134.8	105.1	82.8	107.6
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	108.1	121.4	128.4	119.3
		C. „vegetable”	133.1	124.2	103.9	120.4
		C. „beet”	145.4	114.8	100.6	120.2
		mean for A2B1	128.9	120.1	111.0	120.0
	B2 3 kg·ha^{-1}	without coating	97.6	104.7	113.4	105.2
		C. „vegetable”	145.9	125.9	104.2	125.3
		C. „beet”	123.5	103.9	90.0	105.8
		mean for A2B2	122.3	111.5	102.5	112.1
	mean for A2		125.6	115.8	106.8	116.1
Mean for B		B1 – 2 kg·ha^{-1}	133.6	122.3	100.5	118.8
		B2 – 3 kg·ha^{-1}	126.9	98.6	89.0	104.8
Mean for C		without coating	115.6	105.7	105.4	108.9
		C. „vegetable”	146.7	128.9	92.1	122.5
		C. „beet”	128.4	96.8	86.9	104.0
Mean			130.2	110.5	94.8	111.8
$HSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	14.5	7.5	6.8
C			27.1	16.0	12.5	12.0
interaction						
A × B			ns	25.3	ns	ns
B × A			ns	20.6	ns	ns
A × B × C						s

ns – non-significant; s – significant

Table 8. One plant leaf weight of quinoa before harvest [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	59.4	19.0	22.0	33.5
		C. „vegetable”	92.2	43.0	17.6	50.9
		C. „beet”	60.1	21.0	17.3	32.8
		mean for A1B1	70.6	27.7	19.0	39.1
	B2 3 kg·ha^{-1}	without coating	60.2	16.2	16.1	30.9
		C. „vegetable”	66.2	19.3	15.3	33.6
		C. „beet”	57.4	11.9	15.7	28.3
		mean for A1B2	61.3	15.8	15.7	30.9
	mean for A1		65.9	21.7	17.3	35.0
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	46.1	23.8	24.8	31.6
		C. „vegetable”	73.7	20.5	20.7	38.3
		C. „beet”	55.4	17.6	20.1	31.0
		mean for A2B1	58.4	20.6	21.9	33.6
	B2 3 kg·ha^{-1}	without coating	45.6	15.0	23.0	27.9
		C. „vegetable”	76.3	24.5	20.8	40.6
		C. „beet”	71.4	14.2	17.4	34.3
		mean for A2B2	64.4	17.9	20.4	34.2
	mean for A2		61.4	19.3	21.1	33.9
Mean for B		B1 – 2 kg·ha^{-1}	64.5	24.2	20.4	36.4
		B2 – 3 kg·ha^{-1}	62.9	16.9	18.1	32.6
Mean for C		without coating	52.8	18.5	21.5	30.9
		C. „vegetable”	77.1	26.8	18.6	40.8
		C. „beet”	61.1	16.2	17.6	31.6
Mean			63.7	20.5	19.2	34.5
$HSD_{0.05}$						
A			ns	ns	ns	ns
B			ns	5.5	2.0	3.7
C			17.7	5.6	2.8	6.6
interaction						
A × B			ns	ns	ns	5.2
B × A			ns	ns	ns	6.8

ns – non-significant

Table 9. Proportion of quinoa stem weight 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	35.9	34.1	53.7	41.2
		C. „vegetable”	31.4	29.5	53.4	38.1
		C. „beet”	35.3	31.8	50.7	39.3
		mean for A1B1	34.2	31.8	52.6	39.5
	B2 3 kg·ha^{-1}	without coating	37.8	34.9	52.5	41.7
		C. „vegetable”	35.1	32.2	50.8	39.4
		C. „beet”	37.1	34.8	52.0	41.3
		mean for A1B2	36.7	34.0	51.8	40.8
	mean for A1		35.4	32.9	52.2	40.2
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	35.1	38.0	54.9	42.7
		C. „vegetable”	30.4	40.2	53.6	41.4
		C. „beet”	36.8	40.8	53.3	43.6
		mean for A2B1	34.1	39.7	53.9	42.6
	B2 3 kg·ha^{-1}	without coating	33.8	40.8	52.9	42.5
		C. „vegetable”	32.0	35.1	53.3	40.1
		C. „beet”	29.5	39.5	55.9	41.6
		mean for A2B2	31.8	38.5	54.0	41.4
	mean for A2		32.9	39.1	54.0	42.0
Mean for B		B1 – 2 kg·ha^{-1}	34.2	35.7	53.3	41.1
		B2 – 3 kg·ha^{-1}	34.2	36.2	52.9	41.1
Mean for C		without coating	35.7	37.0	53.5	42.0
		C. „vegetable”	32.2	34.3	52.8	39.8
		C. „beet”	34.7	36.7	53.0	41.5
Mean			34.2	36.0	53.1	41.1
$HSD_{0.05}$						
A			ns	3.3	ns	ns
B			ns	ns	ns	ns
C			2.9	2.2	ns	1.4
interaction						
A × B			4.8	3.6	ns	2.9
B × A			2.1	2.0	ns	1.2

ns – non-significant

The effect of the use of Sonata beet on the green weight yield of quinoa was found only in 2011 (Table 10). This was the result of a decrease in biomass accumulation under the influence of this agent. There was no effect of the seeding rate in the analyzed years on the value of this characteristic. However, the effect of the seed coating type on the green weight yield was proven. The lowest yield both on average in the years 2010–2012 and in 2011 and 2012 was found after the use of the "vegetable" coat, in contrast to the "beet" coat, where the green weight yield was higher. Seeds in the "beet" coat were similar in respect of this characteristic to the control (uncoated seeds) (Table10).

In the three analyzed years of the study (2010–2012), significant interactions were also found. The use of Sonata beet at the higher seeding rate (3 kg·ha^{-1}) compared to the treatment without this preparation resulted in an increase in the green weight yield. However, the increase in the seeding rate, without the Sonata beet preparation, on average for years, resulted in a decrease in the biomass yield. Regardless of the factors studied, the highest green weight yield was recorded in 2010 and 2011. It was at a similar level (79 Mg·ha^{-1}). In 2012, in turn, it was by 56% lower.

Table 10. Green weight yield of quinoa (Mg·ha^{-1})

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	79.8	95.7	40.9	72.1
		C. „vegetable”	97.6	79.3	20.2	65.7
		C. „beet”	71.0	101.0	37.6	69.9
		mean for A1B1	82.8	92.0	32.9	69.2
	B2 3 kg·ha^{-1}	without coating	64.6	89.9	38.8	64.4
		C. „vegetable”	74.7	55.5	17.6	49.3
		C. „beet”	67.0	87.5	44.4	66.3
		mean for A1B2	68.8	77.6	33.6	60.0
	mean for A1		75.8	84.8	33.2	64.6
A2 Sonata – 1.5 kg·ha^{-1}	B1 2 kg·ha^{-1}	without coating	90.1	82.7	43.6	72.2
		C. „vegetable”	77.4	41.6	18.1	45.7
		C. „beet”	76.1	78.1	36.6	63.6
		mean for A2B1	81.2	67.5	32.8	60.5
	B2 3 kg·ha^{-1}	without coating	88.1	99.7	55.8	81.2
		C. „vegetable”	81.3	57.1	22.5	53.6
		C. „beet”	87.8	84.5	38.9	70.4
		mean for A2B2	85.7	80.4	39.1	68.4
	mean for A2		83.5	74.0	35.9	64.4

Table 10. continue

Mean for B	B1 – 2 kg·ha^{-1}	82.0	79.7	32.8	64.9
	B2 – 3 kg·ha^{-1}	77.3	79.0	36.3	64.2
Mean for C	without coating	80.7	92.0	44.8	72.5
	C. „vegetable”	82.8	58.4	19.6	53.6
	C. „beet”	75.5	87.8	39.4	67.5
Mean		79.6	79.4	34.6	64.5
$HSD_{0.05}$					
A		ns	6.9	ns	ns
B		ns	ns	ns	ns
C		ns	13.3	7.3	9.2
interaction					
A × B		ns	12.8	ns	8.4
B × A		ns	15.4	ns	7.6

ns – non-significant

DISCUSSION

The analyzed vegetative characteristics of the quinoa plants and the green weight yield were largely dependent on the plant density. It was varied both in the years of the study and under the influence of the analyzed factors (Gęsiński, 2018). The year 2011 was characterized by lower rainfall and higher mean daily temperature during the growing season (293 mm, 15.2°C) and in such conditions the density was lower. A higher seeding rate was associated with a higher density. On the other hand, the “vegetable” coat stimulated a lower density as compared with plants with the “beet” coat. These factors differentiated the vegetative growth of quinoa. In the present experiment, the micronutrient preparation Sonata beet was used. The effectiveness of using foliar fertilizers depends on many factors including habitat, cultivation technology and individual properties of the field crop species (Jaskulski, 2007). Wadas and Łęczycka (2010) growing potato found that the effectiveness of fertilization depended on the cultivar. However, foliar nutrition of carrots resulted in a significant reduction in the one root weight and increase in dry weight of green tops (Smoleń *et al.*, 2006). Foliar nutrition provides nutrients to the plants in conditions difficult to take them up from the soil solution and during periods of increased demand [Sienkiewicz-Cholewa, 2002; Szewczuk and Michałojć, 2003; Wróbel, Sienkiewicz-Cholewa, 2003]. Hence, the highest efficiency of these fertilizers can be found in conditions of their shortage. There are known results of studies on the micronutrient preparation Sonata. It improved generative characteristics and yield of the crops in which it was applied (Jaskulski, 2004, 2007). In the conducted experiment, it affected the reduction of inflorescence of quinoa (Gęsiński, 2018). It turns out, however, that it had an effect on a better development of the vegetative part of quinoa shoot and on the total shoot length. Thus, it affected more vegetative rather than generative characteristics of this species. The lower seeding rate (2 kg·ha^{-1}) resulted in an increase in the vegetative characteristics of quinoa plants. The shoot length, the plant weight, and the weight of the stem and leaves increased. Comparing the results of a previous study (Gęsiński, 2012), it was found that more than five times higher plant density (162 plants per m^2) than in the analyzed experiment resulted in about three times lower yield of green weight (35.1 Mg·ha^{-1}). Hence the conclusion that quinoa for green mass should be grown at low sowing densities, because as a plant that grows strongly, it better accumulates biomass in such conditions. In the case of excessive sowing density, a shortage of light reveals as a result of shading, which results in a negative impact on the plant and crop structure design and yield. The seeding rate is one of the most important cultivation factors. It affects plant growth and productivity (Maynard and Scott, 1998; Leskovar *et al*., 2000; Cha *et al*., 2016). In order to determine the optimal seeding rate, various factors must be taken into account, such as solar radiation, growth and varietal characteristics (Sanders *et al*., 1999; Cavero *et al*., 2001). In contrast to growing on green mass, the seeding rate in quinoa cultivation for seeds should be higher. Previous research shows that a higher seeding rate resulted in a higher seed yield (Gęsiński, 2018). This is the opposite situation of the general trend in other species of thinning the field to increase seed yield (Dubis and Budzyński, 2006). This is how cereals react to reducing the seeding rate (Weber and Podolska, 2009; Podolska and Wyzińska, 2011). Quinoa is rather similar to oilseed rape in terms of the seeding rate in cultivation for seeds. In the case of this species, higher seed yields were also found at higher seeding rates (Ladek and Wałkowski, 2000; Gugała *et al*., 2017; Wójtowicz *et al*., 2017).

CONCLUSIONS

1. The applied preparation Sonata beet had an effect on a better development of the vegetative part of quinoa shoot and on the total shoot length.
2. The lower seeding rate of quinoa (2 $kg \cdot ha^{-1}$) stimulated a higher total shoot length and a higher weight of the plant and its vegetative parts (stem and leaves).
3. The use of the „beet" coat resulted in an increase in plant weight, including stem and leaf weight.
4. The highest green weight yield of quinoa was obtained in 2011 after the application of the "beet" coat and the seeding rate 2 $kg \cdot ha^{-1}$, without the preparation Sonata beet (101 $Mg \cdot ha^{-1}$).
5. Plants from seeds with the "beet" coat were similar to plants from seeds without a coat (control) in respect of most morphological characteristics and green weight yield.

REFERENCES

Alvarez-Jubete, L., Arendt, E.K., Gallagher, E. (2010). Nutritive value of pseudocereals andtheir increasing use as functional gluten-free ingredients. Trends Food Sci. Technol., 21(2), 106–113.

Batista, A.P., Portugal, C.A.M., Sousa, I., Crespo, J.G., Raymundo, A. (2005). Accessing gelling ability of vegetable proteins using rheological and fluorescence techniques. Int. J. Biol. Macromol., 36(3), 135–143.

Cavero, J., Ortega, R.G., Gutierrez, M. (2001). Plant density affects yield, yield components, and color of direct-seeded paprika pepper. Hort. Science, 36, 76–79.

Cha, M.K., Joun, Y.A., Son, J.E., Cho, Y.Y. (2016). Development of planting-density growth harvest (PGH) charts for quinoa (*Chenopodium quinoa* Willd.) and sowthistle (*Ixeris dentata* Nakai) grown hydroponically in closed-type plant production systems. Hortic. Environ. Biotechnol., 57(3), 213–218.

Domoradzki, M. (1999). Determination of germination capability of coated seeds. Int. Agrophys., 13, 431–433.

Domoradzki, M. (2011). Doskonalenie technologii pozbiorowej obróbki nasion ekologicznych na przykładzie roślin baldaszkowatych. Bydgoszcz: Wyd. Uczel. UTP.

Domoradzki, M., Korpal, W. (2004). Badania procesu podkiełkowania otoczkowanych nasion marchwi. Acta Agrophys., 4(2), 269–282.

Dubis, B., Budzyński, W. (2006). Reakcja pszenicy ozimej na termin i gęstość siewu. Acta Sci. Pol., Agricultura, 5(2), 15–24.

Gęsiński, K. (2012). Biologiczne i agrotechniczno--użytkowe uwarunkowania uprawy komosy ryżowej (*Chenopodium quinoa* Willd). Bydgoszcz: Wyd. Uczel. UTP, Rozprawy 157, 92.

Gęsiński K., (2018). Wpływ zabiegów uszlachetniających materiał siewny, ilość wysiewu i dolistnego nawożenia mikroelementowego na cechy generatywne i plonowanie komosy ryżowej. Acta Sci. Pol. Agricultura, 17(4), 175–194.

Gugała, M., Sikorska, A., Zarzecka, K., Krasnodębska, E., Kapela, K. (2017). Wpływ gęstości siewu rzepaku na opłacalność produkcji. Rocz. Nauk. Stow. Ekon. Rol. Agrobiz., 19(2), 66–69.

Iqbal, M.A. (2015). An assessment of Quinoa (*Chenopodium quinoa* Willd.) potential as a grain crop on marginal lands in Pakistan. American-Eurasian J. Agric. & Environ. Sci., 15(1), 16–23.

Ixtaina, V.Y., Nolasco, S.M., Tomas, M.C. (2008). Physical properties of chia (*Salvia hispanica* L.) seeds. Ind. Crops Prod., 28(3), 286–293.

Jacobsen, S.E., Mujica, A., Jensen, C.R. (2003). The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. Food Rev. Int., 19(1–2), 99–109.

Jaskulski, D. (2004). Efektywność dolistnego stosowania nawozów „Sonata", Ann. UMCS, 59(1E), 431–439.

Jaskulski, D. (2007). Porównanie wpływu dolistnego stosowania nawozów na efekty produkcyjne i ekonomiczne uprawy niektórych roślin polowych. Fragm. Agron., 1(93), 106–112.

Ladek, A., Wałkowski, T. (2000). Wpływ gęstości nasion na wschody i plonowanie rzepaku ozimego. Rośl. Oleiste, 21, 409–418.

Leskovar, D.I., Stein, L.A., Dainello, F.J. (2000). Planting systems influence growth dynamics and quality of fresh market spinach. Hort. Science, 35(7), 1238–1240.

Maynard, E.T., Scott, W.D. (1998). Plant spacing affects yield of 'Superstar' muskmelon. Hort. Science, 33(1), 52–54.

Nongonierma, A.B., Le Maux, S., Dubrulle, C., Barre, C., Fitzgerald, R.J. (2015). Quinoa (*Chenopodium quinoa* Willd.) protein hydrolysates with in vitro dipeptidyl peptidase IV (DPP-IV) inhibitory and antioxidant properties. J. Cereal Sci., 65, 112–118.

Poćwiadowski, W., Szulc, J., Domaradzki, M. (2016). Granulacja niskocisnieniowa wieloskładnikowa. Granulki wielonasienne i wielozarodnikowe. Inż. Przet. Spoż., 20, 22–27.

Podolska, G., Wyzińska, M. (2011). Reakcja nowych odmian pszenicy ozimej na gęstość i termin siewu. Pol. J. Agron., 6, 44–51.

Sanders, D.C., Cure, J.D., Schultheis, J.R.(1999). Yield response of watermelon to planting density, planting pattern, and polyethylene mulch. Hort. Science, 34(7), 1221–1223.

Sienkiewicz-Cholewa, U. (2002). Znaczenie mikroelementów w nawożeniu rzepaku. Post. Nauk Rol., 5, 19–28.

Smoleń, S., Wojciechowska, R., Sady, W., Szura A. (2006). Wpływ formy azotu nawozowego i dokarmiania dolistnego na plon i gospodarkę azotową korzeni spichrzowych marchwi (*Daucus carota* L.). Acta Agrophys, 7(3), 721–732.

Szewczuk, C., Michałojć, Z. (2003). Praktyczne aspekty dolistnego dokarmiania roślin. Acta Agrophys., 85, 19–29.

Tapia, M.E. (1979). Historia Distribucion geographica. Quinua Kaniwa. Cultivos Andinos. In: Serie Libros Materiales Educativos, Instituto Interamericano de Ciencias Agricolas, Bogota, Colombia, 49, 11–15.

Tonkin, J.H.B. (1984). Pelleting and other pre-sowing treat-ments. Adv. Res. Tech. Seeds, 9, 94–127.

Wadas, W., Łęczycka T. (2010). Efektywność stosowania wieloskładnikowych nawozów kompleksowych w uprawie bardzo wczesnych odmian ziemniaka. Biul. IHAR, 257/258, 167–175.

Weber, R., Podolska, G. (2009). Wpływ terminu i gęstości siewu na wielkość i strukturę plonu pszenicy ozimej. Biul. IHAR, 252, 81–90.

Wójtowicz, M., Jajor, E., Wójtowicz, A., Korbas, M., Wielebski, F. (2017). Wpływ gęstości wysiewu nasion i poziomu nawożenia azotem na rozwój i plonowanie rzepaku ozimego. Fragm. Agron., 34(3), 130–141.

Wróbel, S., Sienkiewicz-Cholewa, U. (2003). Potrzeby nawożenia borem roślin uprawnych w Polsce. Post. Nauk Rol., 1, 103–118.

WPŁYW DOLISTNEGO NAWOŻENIA MIKROELEMENTOWEGO, ILOŚCI WYSIEWU I OTOCZKOWANIA NASION NA CECHY WEGETATYWNE I PLON ZIELONEJ MASY KOMOSY RYŻOWEJ (*Chenopodium quinoa* WILLD.)

Streszczenie

Komosa ryżowa jest gatunkiem o wysokich walorach odżywczych, którym zainteresowanie w ostatnim czasie wzrosło. Stanowi to podstawę szeregu prac mających na celu poznanie wymagań siedliskowych i agrotechnicznych dla osiągnięcia większych plonów i zysków. Założono ścisłe doświadczenie polowe, w którym analizowano wpływ nawożenia dolistnego preparatem mikroelementowym Sonata burak, a także dwóch ilości wysiewu (2,0 i 3,0 kg nasion *Chenopodium quinoa* odmiany 'Faro' na hektar) na cechy wegetatywne i plon zielonej masy. Zastosowano również nasiona uszlachetnione z otoczką „warzywną" i „buraczaną". Na podstawie badań stwierdzono, że zastosowany preparat Sonata burak miał wpływ na lepszy rozwój części wegetatywnej pędu komosy ryżowej i długość pędu ogółem. Mniejsza ilość wysiewu komosy ryżowej (2 kg·ha^{-1}) stymulowała większą długość pędu ogółem oraz większą masę rośliny i jej części wegetatywnych (łodygi i liści). Zastosowanie otoczki „warzywnej" skutkowało wzrostem masy rośliny jako efekt wzrostu masy łodygi i liści. Nasiona w otoczce „buraczanej" pod względem większości cech morfologicznych i plonu zielonej masy roślin były podobne do obiektu kontrolnego (nasion bez otoczki). Najwyższy plon zielonej masy komosy ryżowej (101 Mg·ha^{-1}) otrzymano w roku 2011 po zastosowaniu otoczki „buraczanej" i ilości wysiewu 2 kg·ha^{-1}, bez preparatu Sonata burak.

Słowa kluczowe: *Chenopodium quinoa*, ilość wysiewu, nasiona otoczkowane, Sonata burak