TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2016, Vol. 16, No. 4, 43–48

The Effect of Different Sowing Rate, Foliar Fertilization and Chemical Composition on the Mechanical Properties of Narrow-Leaved Lupine Seeds (*Lupinus angustifolius* L.)

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Received December 05.2016; accepted December 21.2016

Summary. The aim of the studies was to evaluate the influence of sowing rate, foliar fertilization (Basfoliar fertilizer 6-12-6) and chemical composition on the mechanical properties of narrow-leaved lupine seeds of cultivars Bojar and Regent. Single seeds were burdened in the direction perpendicular to the parting plane of cotyledons with constant speed 10 mm·min^{-1}. The crop year and cultivar have significantly differentiated the value of all the analyzed strength parameters of narrow-leaved lupine seeds. The seeds of cultivar Bojar had significantly higher values of all the strength parameters. The designated strength parameters of lupine seeds were negatively correlated with ash content, fiber and protein except for the destructive force. They were also positively correlated with the fat content.

Key words: narrow-leaved lupine, sowing rate, foliar fertilization, lupine seeds, chemical composition, mechanical properties.

INTRODUCTION

Pulses are characterized by a favorable chemical composition, including the content of bioactive substances, which have a beneficial effect on human health. They are recommended for consumption as food preventive [12, 19]. Narrow-leaved lupine is a relatively "young" crop, but well adapted to the soil and climate of the temperate climate zone. The increase in the economic importance of lupine was mainly due to the breeding of new cultivars. Research is also conducted on improving its agricultural technology to achieve high yield with more enduring seeds. Podleśny [16] noticed that more and more farmers decide to apply ecological and integrated production methods, in which legumes, including lupine, play a very important role. Podleśny [17] added that one of the factors limiting the yield of legumes is insufficient knowledge of cultivation practices, especially concerning new cultivars with altered morphological conformation. This was confirmed by the difference in yield obtained under the experimental conditions and production. Podleśny [18] and Bieniaszewski et al. [2] drew attention to the difficulties of precise sowing seeds of leguminous plants and the need for adaptation of the sowing rate standard to new genotypes. Research in this area [2, 10] has suggested that for the conventional and self-completing cultivars of lupine, determination of the correct amount of seed sowing is especially important and depends on habitat conditions.

An important problem in the cultivation of legumes is their high sensitivity to mechanical damage of seeds produced during the harvesting and processing, which is reflected in considerable loss of quantity and quality. The high susceptibility of leguminous seeds to mechanical damage is mainly due to their construction. In contrast to cereal grains, they have two cotyledons between which, with low content of water, a fissure can occur facilitating, among others, the division of seeds into halves [8, 20, 21]. A significant influence on seed damage is their moisture content, which determines the elasticity and resistance to damage not only of the cotyledons, but also the seed coat [3, 9]. The formation of seed damage also influences their weight, size and shape, seed coat thickness and composition [3–5, 9, 15]. The aim of the studies was to determine the effect of different sowing rate, foliar fertilization and chemical composition on the mechanical properties of narrow-leaved lupine seeds.

MATERIAL AND METHODS

In the years 2011-2013, a field experiment was carried out using split-plot design at the Cultivar Assessment Experimental Station in Nowy Lubliniec (50°16' N, 23°06' E, height 217 m AMSL), which is part of the Research Centre for Cultivar Testing in Słupia Wielka. The study factors were: I – sowing rate; normal sowing, dense sowing 25% and 50%, II – foliar fertilization: control and Basfoliar 6-12-6 and III – cultivar; Bojar (conventional) and Regent (self-completing). For sowing, dressed qualified seeds were used from the Smolice Plant Breeding Ltd., Przebędowo

Branch. Lupine was grown on IVb[th] class soil of good rye complex. Contents of assailable phosphorus and potassium were medium or high, and soil pH was acid or lightly acid. The analysis of the chemical composition of the soil was carried out at the Regional Chemical and Agricultural Station in Rzeszów. Seeds were sown on April 6 2011, April 5 2012, and April 12 2013. Normal sowing rate was 120 seeds per m^2 for cultivar Regent and 110 seeds per m^2 for cultivar Bojar. Lupine was sown at the row spacing of 21.4 cm, at the depth of 3-4 cm. Plot area was 19.5 m^2 (16.5 m^2 for harvest). Winter wheat was the fore crop. Cultivation and caring treatments were carried out according to the agrotechnological requirements of narrow-leaved lupine, taking into account the differences between the conventional cultivar (Bojar) and the self-completing cultivar (Regent). Phosphorus and potassium fertilization amounted to 26.2 kg P·ha^{-1} and 74.7 kg K·ha^{-1}. Nitrogen mineral fertilization was not applied but Nitragina was used for seed inoculation. Foliar fertilization with fertilizer Basfoliar 6-12-6 was made twice, i.e. before and after flowering (2 x 10 l·ha^{-1}). Manual harvesting was carried out in 2011 in the third decade of August, and in the years 2012 and 2013 in the first decade of August.

Weather conditions in the study years were diversified (Tab. 1). In 2011, moderate monthly temperatures and precipitation sums were noted, with the exception of too humid July. The second study year was characterized by intensive precipitation in June and a hot July. In March 2013, high precipitation was noted (including snow), as well as minus temperatures. Moreover, in July and August 2013, monthly precipitation sums were low and differed significantly from the multi-annual average.

The year 2011 was characterized by the lowest rainfall (slightly larger than the multi-annual). In 2013 the highest amount of rainfall was observed and the lowest temperature. The year 2012 was characterized by the highest temperatures (Tab. 1).

The resistance of individual seeds to mechanical damage was determined under conditions of quasi-static loads with the use of a Zwick Z010 universal testing machine, in accordance with the previously developed methodology [13]. The following parameters were accepted as measurements of the seeds' resistance to mechanical loads: maximum force resulting in the seed's destruction [N], maximum deformation at the moment of the seed's fracture [mm], modulus of elasticity [MPa] and compressive energy [mJ]. Relative deformation per destructive force was calculated using the measured values in the following formula [13, 15]:

$$\varepsilon = \frac{\Delta L}{T} 100\% , \tag{1}$$

where:
ε – relative deformation [%], ΔL – maximum deformation [mm], *T* – thickness of seed [mm].

The seeds were submitted to loads perpendicular to the plane of cotyledon separation, with a steady velocity v = 10 mm·min^{-1}. The sample size was 20 seeds per each variant. Before testing, the seeds were weighed with 0.001 g tolerance.

The results were analyzed statistically in Statistica 10, with multivariate analysis of variance (ANOVA) and the NIR significance test at the level of α = 0.05.

RESULTS AND DISCUSSION

Four-factor analysis of variance showed a significant effect of the crop year, cultivar and sowing density on the mass lupine seeds and their thickness. They did not show the effect of foliar fertilization. The seeds of cultivar Bojar had a significantly greater weight and thickness than the cultivar Regent (Tab. 2). These traits were significantly higher for the maximum density of sowing and not significantly greater for foliar fertilization. Kuźniar et al. [14] showed that the use of foliar fertilization significantly increased the mass of yellow lupine seed cultivar Mister only for the third sowing date, while Faligowska and Szukała [6] found no effect of foliar fertilization on the size of yellow lupine seed. The crop year had the biggest influence on the thickness and weight of the seeds of narrow-leaved lupine. The analyzed biometrical properties of lupine seeds were significantly higher in 2011, and the lowest in 2012.

The analysis of variance showed a significant effect of the crop year and cultivar on the value of all the analyzed strength parameters of narrow-leaved lupine seeds. The seeds of narrow-leaved lupine cultivar Bojar had significantly higher values than all the analyzed parameters of strength (Tab. 3). Relative deformation, energy and modulus of elasticity of narrow-leaved lupine seeds were significantly higher in 2011, while the destructive force in 2011 and 2013. The lowest value of destructive force and the modulus of

Table 1. Weather conditions in Nowy Lubliniec in the years 2011-2013

Month	Rainfall (mm)				Mean temperatures (°C)			
	2011	2012	2013	Multi-annual average	2011	2012	2013	Multi-annual average
III	13.2	26.7	72.9	33.2	2.2	4.6	-1.5	2.7
IV	52.2	39.2	40.8	46.5	9.9	9.7	9.6	8.3
V	31.2	92.0	124.1	73.2	14.0	14.6	15.8	14.4
VI	86.9	148.9	150.4	80.3	18.4	17.8	18.5	17.3
VII	201.5	50.6	37.1	101.2	19.2	21.4	19.2	19.5
VIII	25.4	59.2	18.3	69.8	18.9	18.9	19.2	18.3
III-VIII	410.4	416.6	443.6	404.2	13.8	14.5	13.5	13.4

Source: Cultivar Assessment Experimental Station in Nowy Lubliniec elasticity were recorded in 2012, while the deformation and energy in 2013 (Tab. 3).

Table 2. Weight and thickness of narrow-leaved lupine seeds

Factor	Combination	Weight [mg]	Thickness [mm]
Cultivar	Bojar Regent	182.8b 153.5a	5.34b 5.15a
Sowing rate	Normal Dense 25 % Dense 50 %	165.5a 166.3a 172.6b	5.22a 5.21a 5.30b
Foliar fertilization	Control Basfoliar 6-12-6	167.9a 168.4a	5.24a 5.25a
Years	2011 2012 2013	193.9c 148.9a 161.7b	5.57c 5.06a 5.12b
Average		168.2	5.25

*Values in columns marked with the same letter do not differ significantly at α = 0.05

The configuration of humidity and thermal conditions had a significant effect on plant growth and development, the occurrence of plant pathogens and seed yield. Bieniaszewski et al. [1] and Faligowska and Szukała [6] in earlier research confirmed that seed yield, yield components, and seed sowing value of yellow lupine [7] highly depend on the weather conditions.

The dependence of relative deformation of narrow-leaved lupine seeds on compression force for three years of research can be fitted by a linear function (Fig. 1). In the year of the highest total rainfall and lowest average air temperature during the growing, lupine seeds were less deformed with the use of the same force. This is evidenced by the smallest slope of the curve describing the dependency of the analyzed parameter in the year 2013.

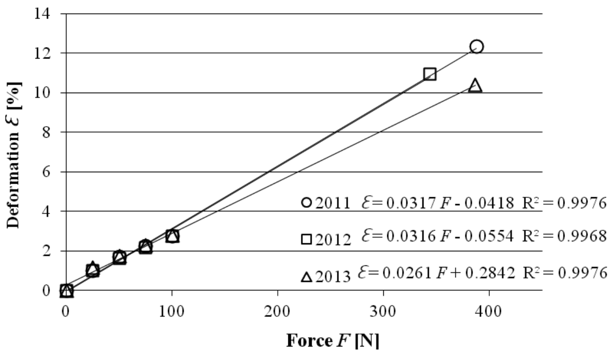

Fig. 1. The dependency of the relative deformation of the lupine seeds by compression forces during three years of research

Table 3. The values of strength parameters of narrow-leaved lupine seeds for the years 2011-2013

Factor	Combination	Destructive force [N]	Deformation [%]	Energy [mJ]	Modulus of elasticity [MPa]
Cultivar	Bojar Regent	398.6b 347.1a	11.8b 10.6a	140.0b 106.8a	4896b 4766a
Sowing rate	Normal Dense 25 % Dense 50 %	373.0a 371.1a 374.4a	11.2a 11.4a 11.0a	122.2a 126.8a 121.2a	4880a 4799a 4814a
Foliar fertilization	Control Basfoliar 6-12-6	370.7a 374.9a	11.18a 11.24a	122.7a 124.2a	4835a 4827a
Years	2011 2012 2013	387.9b 344.1a 386.5b	12.3c 10.9b 10.4a	155.1b 109.3a 105.9a	5143c 4557a 4793b
Average		372.8	11.21	123.41	4831

*Values in columns marked with the same letter do not differ significantly at α = 0.05

Table 4. The correlation coefficients of strength parameters of the tested cultivars of seed of narrow-leaved lupine with the content of protein, fat, ash and fiber for the three years of research

Chemical component	Cultivar	Destructive force [N]	Deformation [%]	Energy [mJ]	Modulus of elasticity [MPa]
Protein	Bojar Regent	0.028 0.703*	-1.000* -0.238	-0.971* -0.047	-0.441* -0.022
	Average	0.106	-0.926*	-0.827*	-0.480*
Fat	Bojar Regent	0.420* 0.724*	0.889* 0.967*	0.976* 0.998*	0.794* 0.999*
	Average	0.638*	0.917*	0.980*	0.963*
Ash	Bojar Regent	-0.823* -0.999*	-0.533* -0.492*	-0.729* -0.650*	-0.993* -0.670*
	Average	-0.948*	-0.570*	-0.727*	-0.960*
Fiber	Bojar Regent	-0.992* -0.965*	0.169 -0.281	-0.086 -0.460*	-0.818* -0.483*
	Average	-0.978*	-0.073	-0.278	-0.685*

*Significant at α = 0.05

Lupine seed of Bojar cultivar contained more crude protein, crude fat and ash, and the cultivar Regent contained more fiber [11]. All the designated strength parameters of lupine seeds were correlated negatively with ash content, fiber and protein except for the breaking force and a positive fat content (Tab.4). That is, the period in which the seed themselves showed a higher fat content and lower ash and fibers were more resistant to damage – required greater force and energy to be damaged, underwent greater deformation and were characterized by a greater modulus of elasticity. In contrast, more protein resulted in the growth of destructive force and lowering of the other designated strength parameters. These correlations were statistically significant only for the destructive force except the protein content of the seed cultivar Bojar and deformation, energy, modulus of elasticity and the protein content of the seeds of the Regent cultivar. There were also significant correlations deformation of the fiber content in the seeds of both the cultivars studied.

CONCLUSIONS

1. The weight and thickness of the seed of narrow-leaved lupine was significantly dependent on cultivar, sowing density and crop year. Greater weight and thickness characterized the seeds of Regent cultivar. Higher density of sowing resulted in an increase of the weight and thickness of lupine seeds. Seeds from 2011 were characterized by a higher weight and thickness.
2. All the determined strength parameters of lupine seeds were significantly higher for the cultivar Bojar. During the three years of research they were significantly higher in 2011, and the lowest in 2012 (with exception of the deformation, which was the smallest in 2013).
3. All the determined strength parameters of lupine seeds were correlated negatively with ash, fiber and protein content (with exception of the breaking force) and positively correlated with fat content.

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WPŁYW ZRÓŻNICOWANEJ ILOŚCI WYSIEWU, NAWOŻENIA DOLISTNEGO I SKŁADU CHEMICZNEGO NA WYBRANE WŁAŚCIWOŚCI MECHANICZNE NASION ŁUBINU WĄSKOLISTNEGO (*LUPINUS ANGUSTIFOLIUS* L.)

Streszczenie. Celem pracy była ocena wpływu gęstości siewu, nawożenia dolistnego nawozem Basfoliar 6-12-6 i składu chemicznego na właściwości mechaniczne nasion dwóch odmian łubinu wąskolistnego. Pojedyncze nasiona obciążano w kierunku prostopadłym do płaszczyzny podziału ich liścieni ze stałą prędkością 10 mm·min^{-1}. Rok uprawy i odmiana różnicowały istotnie wartość wszystkich analizowanych parametrów mechanicznych nasion łubinu wąskolistnego. Nasiona odmiany Bojar charakteryzowały się istotnie większymi wartościami wszystkich parametrów mechanicznych. Wyznaczone parametry wytrzymałościowe nasion łubinu były skorelowane ujemnie z zawartością popiołu, włókna i białka za wyjątkiem siły niszczącej, a dodatnio z zawartością tłuszczu.
Słowa kluczowe: nasiona łubinu wąskolistnego, gęstość siewu, nawożenie dolistne, skład chemiczny, właściwości mechaniczne.

The study was carried out as a grant from the National Science Centre, number 030/B/P01/2011/40, N N310 003040.