EVALUATION OF MIXTURES OF YELLOW LUPINE (*LUPINUS LUTEUS* L.) WITH SPRING CEREALS GROWN FOR SEEDS

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(Received 27th Sep 2017; accepted 27th Feb 2018)

Abstract. Cultivation of legume-cereals mixtures is considered a good agricultural practice in many European countries, especially in organic and low-input farming systems. The aim of the study was to determine the productivity of mixtures of yellow lupine (*Lupinus luteus* L.) with spring cereals, depending on the species of grain component and its percentage in mixture. Field experiments were carried out in the years of 2011-2013 at the Agricultural Experimental Station Grabów in Poland, using the system of random sub-blocks, with a control treatment, in four replications. The study included three species of cereals: wheat (*Tricicum aestivum* L.), barley (*Hordeum vulgare* L.), and triticale (*Triticosecale* Wittm. ex A. Camus), as well as three percentages of lupine in the weight of sown seeds: 40, 60, 80%. The experiment was conducted on the soil of good wheat complex, class IIIa. The studies showed that the highest yield was obtained from the mixture of yellow lupine with wheat. Increasing the percentage of lupine seeds resulted in lower mixture yields, regardless of cereal species. Lupine grown in mixtures with cereals formed less pods, seeds per pod and per plant and produced a lower seed weight compared with their counterparts grown in pure stands. Legumes grown in mixture with cereals favorably affected morphological characteristics of cereals, contributing to their higher tillering and producing a higher number of grains per plant. The grain of cereals grown in mixtures with lupine had higher contents of total protein and crude fibre than the grain of cereals grown in pure stands.

Keywords: *legume, share of components, yield, structure of yield, chemical composition*

Introduction

Growing legume-cereal mixtures for grain is one of the ways of obtaining concentrated feed both in organic and in integrated production systems (Watson et al., 2002). Such sowings allow for a rational use of environmental resources, positively affect soil environment and provide a strong competition for weeds (Tofinga and Snaydon, 1992; Cremer et al., 1996; Büyükburç and Karadağ, 2002; Hauggaard-Nielsen and Jensen, 2004; Lithourgidis et al., 2006; Hauggaard-Nielsen et al., 2008; Corre-Hellou et al., 2011). Yielding and crop quality of legume-cereal mixtures largely depends on the selection of components and their participation. Generally, yield of mixture seeds decreases with increasing percentage of legumes at sowing, but interspecies interactions are largely determined by the characteristics of the components, which may, change during plant growth under the influence of variable habitat factors (Rudnicki and Kotwica, 2006). Cultivation of mixed crops increases the content of crude protein in the yield of the seeds mixture, but it is also related to selection and participation of the individual components (Staniak et al., 2014). Creating favorable conditions for cereals and legumes in mixture stands and reducing a competition between them during the period of vegetation are important agri-ecological and agri-technological issues.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1602_16831696

Species grown in mixed crops should have similar soil and climatic requirements, a similar maturation date and a similar height. A good component for mixtures with spring cereals is yellow lupine, which is characterized by a high protein content (over 40%) rich in lysine and crude fat (over 50%), which significantly increases the nutritional value of feed from such mixtures. In addition, it has low water and soil requirements thanks to a well-developed root system. According to Rudnicki and Kotwica (2006), on light soils, yellow lupine is a much better component for mixtures than blue lupine. The level of mixtures yielding and the share of seeds of individual components in the yield, and thus the value of fodder, depends not only on the selection of species, but also on their share in sown mixture.

The aim of the study was to determine the productivity and quality of mixtures of yellow lupine (*Lupinus luteus* L.) with spring cereals, depending on the species of grain component and its percentage in the weight of sown seeds.

Review of literature

Mixtures of spring cereals with legumes are considered good agricultural practice, especially in organic and low-input farming system (Hassen et al., 2017). Cultivation of mixtures contributes to the complementary use of habitat resources and compensatory growth of individual plant species, causing an increased productivity and greater stability of yield (Niggli et al., 2008; Doré et al., 2011). Cereals sown with legumes are a strong competitor to the legume which causes that the share of legume seeds in the mixture yield is often variable and low. Increasing the percentage of legume seeds in the sowing norm increases their share in the yield, but the yield of grain cereals and the total yield of mixtures generally decreases (Rudnicki and Wenda-Piesik, 2007). The competitiveness of the plants in legume-cereals mixtures for the access to environmental resources intensifies in the conditions of reduced soil moisture (Gałęzewski, 2006). Under these conditions, many authors observed increased fallout of lupine plants from the stand. Also, these plants formed a low number of pods, which resulted in low legume yields (Kotwica and Rudnicki, 2003).

The yield and stability of the mixtures are therefore determined by the cereals, and to a lower extent – by legumes, but when determining the quality of the mixtures, the share of legume seeds in the mixture yield is crucial. One of the most important criteria for grain quality evaluation is concentration of crude protein. The seeds of legumes are significantly different from the grains of cereals. They contain large amounts of total protein and crude fibre and considerably higher amount of minerals compared to the cereals (Johnston et al., 1978; Staniak et al., 2012). According to Księżak and Staniak (2013) increasing the share of blue lupine in two-species mixtures with barley, wheat and triticale resulted in an increase in the total protein content in the yield of mixtures seeds, and the concentration of crude fibre and crude fat has been also increased. The same relationships have been found in the studies on mixtures of wheat and spring barley with peas (Pozdísek et al., 2011).

Materials and methods

Location of the experiment

Field experiments with the mixtures of yellow lupine (*Lupinus luteus* L.) with spring cereals were carried out in the years of 2011-2013 at the Agricultural Experimental Station

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Grabów [51°21′18″N 21°40′09″E] in Poland, using the system of random sub-blocks, with a control treatment, in four replications. The plot size for the harvest was 27.0 m^2.The experiment was conducted on the silty soil developed on the light loam, good wheat complex, class IIIa. The content (mg kg^{-1}) of available phosphorus was from 13.3 to 16.0, potassium – from 8.1 to 8.4, magnesium – from 3.9 to 4.1, while pH was close to neutral (6.4-6.6).

Plant materials

The first factor was a species of spring cereals: wheat (*Tricicum aestivum* L.), barley (*Hordeum vulgare* L.), triticale (*Triticosecale* Wittm. ex A. Camus), and the secondary factor was the percentage of yellow lupine in the sown mixture: 40, 60 and 80%. The density of components in pure sowing for which the density of plants in the mixtures was calculated was: lupine (variety Mister) – 100 plants·m^{-2}, barley (variety Skarb) – 300 plants·m^{-2}, wheat (variety Bamberka) and triticale (variety Nagano) – 500 plants m^{-2}.

Agrotechniques

Winter plowing was carried out to a depth of 25 cm, in the spring a cultivator and passive agricultural set (drag, spring-tine harrow, land roller) was used. The following mineral fertilizer doses were used (kg·ha^{-1}): P–19.6, K–45.6 and N–40. The sowing was carried out from 11 to 23 April with the usage of Amazone grain drill. Before the sowing, the seeds were treated with a seed dressing Funaben T. Basagran 1.25 dm^3·ha^{-1} or Stomp 330 EC at a dose of 3.5 dm^3·ha^{-1}; it was used to remove weeds from the mixture. Harvest of mixtures was carried out in the period from 8 to 23 August with the usage of Sedmaster plot harvester.

Measurement and testing methods

Before the harvest, a number of pods and seeds per pod, and a number and weight of seeds per plant were determined in 10 randomly selected plants of lupine per each sub-plot. While in cereals, a number and weight of grains per plant, a number of grains per ear, the height of culms and a number of productive culms were specified. After the harvest, the seed yield of lupine-cereal mixture and thousand seed weight of its components were determined. The percentage of seeds of both species in the mixture was marked after the separation of the yield from the entire plot. The contents of total protein and crude fibre in cereal grains and yellow lupine seeds were also determined.

The impact of the examined experimental factors on the determined characteristics were assessed using the analysis of variance, the half-intervals of confidence being determined by Tukey’s test at the significance level of $\alpha = 0.05$. The results were statistical analysis of variance using Statistica v.10.0 program.

Results and discussion

Weather conditions had a significant impact on the yield of cereals and yellow lupine in pure stands, while the yield of mixtures additionally depended on the selection and percentage of the components. The highest seed yields, especially of yellow lupine, were obtained in 2013, when the sum of precipitation during the period from April to August amounted to about 400 mm. There was a favorable distribution of rainfall in

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June, a small amount of precipitation in July and August and the largest relative air humidity during flowering of plants (*Table 1*). That year also saw a slightly higher average air temperature during the growing season, compared with the mean from a multi-year period. In 2012, a small amount of rainfall in the third decade of June and the first decade of July caused strong inhibition of the growth and development of yellow lupine, and consequently, a very low yield of seeds. Rojek (1989) pointed out large water requirements and sensitivity of yellow lupine, especially in the period from flowering until the end of pod formation. Gałęzewski (2006**)** stated that competition for water of lupine and oats is stronger when they are grown in mixtures compared to pure stands. According to Podleśny and Podleśna (2010) mixtures of blue lupine with barley are less sensitive to droughts than lupine grown in pure stands. Also Księżak and Magnuszewska (1999) confirmed that under reduced soil moisture, growing legume-cereal mixtures provides a greater stability and higher level of yielding than the cultivation of these plants in pure stands. In 2011, with not very favorable weather conditions, the obtained seed yields were by about 25% lower compared to the yields of 2013. July and early August of that year saw a large amount of precipitation, which caused the strong lodging of plants, extended the period of plant maturing, impeded harvesting and caused higher seed shedding.

Table 1. *Course of weather conditions during the vegetation periods*

Months	**Mean monthly of temperature (°C)**				**Sum of monthly precipitation (mm)**			
	2011	**2012**	**2013**	**Average of multi-year period**	**2011**	**2012**	**2013**	**Average of multi-year period**
April	10.3	9.6	8.3	7.7	35.9	37.8	29.9	39
May	13.9	15.3	15.3	13.4	74.5	36.5	112	57
June	18.5	17.7	18.6	16.7	52.4	54.3	116.3	71
July	18.4	20.9	19.7	18.3	298.8	81.6	20.8	84
August	18.8	18.8	19.2	17.3	35.6	64.2	11.6	75

The yields of cereals grown in pure stands were similar and significantly higher than the yields of lupine grown in pure stands (*Table 2*). Among the studied mixtures, the highest seed yields were obtained from stands of lupine with wheat compared with mixtures with barley and triticale; they were higher by approximately 10 and 7% (average for three years) (*Table 3*). The yield of spring cereals mixed with yellow lupine, especially with the 80% share of this species, was generally lower than the yield of cereals grown in pure stands. Rudnicki and Gałęzewski (2007b) showed that the yields of oats-yellow lupine mixtures were lower than the yields of oats in pure stands, and that they depended mainly on the yield of oats. Different results were presented by Rudnicki and Kotwica (2006**)**, who recorded higher yields of spring cereals mixed with lupines (yellow and blue) compared with the yields of these components in pure sowings. These authors also indicated that yellow lupine was a more favorable component for mixtures with these cereals than blue lupine.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Table 2. *Seeds yield of yellow lupine and spring cereals grown in pure sowing (t·ha^{-1})*

Cereal species	2011	2012	2013	Mean
Barley	3.18 b*	3.59 bc	4.18 b	3.61
Wheat	3.29 b	3.40 b	4.44 c	3.71
Triticale	3.36 b	3.72 c	4.13 b	3.73
Lupine	1.56 a	0.90 a	2.20 a	1.55

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

Table 3. *Seeds yield of yellow lupine-cereal mixtures depending on cereal species and percentage of lupine (t·ha^{-1})*

Years	Lupine percentage (%)	Barley	Wheat	Triticale
2011	40	2.95 b*	3.58 c	3.14 c
	60	2.94 b	3.33 b	2.93 b
	80	2.24 a	3.17 a	2.64 a
	Mean	2.71	3.36	2.90
2012	40	3.33 c	3.92 c	3.30 b
	60	3.12 b	3.42 b	3.13 b
	80	2.65 a	3.00 a	2.94 a
	Mean	3.03	3.45	3.12
2013	40	4.03 c	3.99 c	4.06 c
	60	3.78 b	3.67 b	3.64 b
	80	3.37 a	3.32 a	3.41 a
	Mean	3.73	3.66	3.70

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

The seeds yield of yellow lupine and its percentage in mixtures with cereals varied depending on weather conditions during the growing season, a species of cereal component in the mixture, and its percentage in the weight of sown seeds. The seeds yield of legumes in the mixtures with any cereal in the first and second year of the experiment was significantly lower compared to pure stands (on average by 50% in the first and 41% in the second year), while in the third year, it was higher only in mixtures with wheat (by about 36%) (*Table 4*). Increasing the percentage of lupine in the weight of sown seeds caused an increase in its percentage in the mixture yield, but only in the third year, with favorable moisture conditions. Its percentage in the yield was similar to the number of sown seeds. In the studies of Rudnicki and Gałęzewski (2007a), the yield of lupine seeds in mixtures with cereals was several times lower than in pure stands. At the same time, it significantly varied during individual years of the study. Increasing the sowing rate of lupine seeds in the mixtures caused an increase in the percentage of its seeds in mixture yield, but at the same time, this percentage was negatively correlated with the mixture yield. According to numerous authors, legume-cereal mixtures yield best when legume seeds constitute from 30 to 50% of seeds at the sowing (Jaranowski, 1997; Szczukowski, 1989). Księżak (2006) obtained significantly higher yields of mixtures of peas with spring wheat at 30% share of legume seeds at sowing. The yields

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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decreased together with increasing the percentage of peas up to 40 and 50%. Księżak and Magnuszewska (1999) however, did not record any effect of increasing the percentage of pea at sowing on the seed yield of pea-wheat mixtures grown conventionally. According to the literature data, triticale is the least competitive spring cereal against lupine (Kotwica and Rudnicki, 2003, 2004).

Table 4. *Yield of lupine seeds and percentage of lupine seeds in yield of mixtures with cereals depending on cereal species and percentage of lupine*

Years	Lupine percentage (%)	Yield of lupine seeds ($t \cdot ha^{-1}$)			Percentage of lupine seeds (%)		
		Barley	Wheat	Triticale	Barley	Wheat	Triticale
2011	40	0.49 a*	0.67 a	0.57 a	16.6	18.5	17.5
	60	0.75 b	0.84 b	0.84 b	24.9	25.0	26.7
	80	0.76 b	1.13 c	0.93 c	32.1	34.3	33.4
	Mean	0.67	0.88	0.78	24.5	25.9	25.9
2012	40	0.10 a	0.13 a	0.11 a	3.0	3.2	3.2
	60	0.21 b	0.24 b	0.22 b	6.8	7.1	6.8
	80	0.22 b	0.29 b	0.23 b	8.2	9.6	9.4
	Mean	0.18	0.22	0.19	6.0	6.6	6.5
2013	40	1.57 a	2.81 a	1.66 a	39.3	70.5	40.9
	60	1.84 b	3.08 b	1.69 a	49.4	83.8	46.1
	80	1.93 b	3.12 b	2.09 b	57.5	93.8	61.1
	Mean	1.78	3.00	1.81	48.7	82.7	49.4

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

The lowest number of pods per plant and seeds per pod, both in pure stands and in mixtures, was produced by lupine plants grown in 2012, while the highest - in 2013, the year with favorable weather conditions (*Table 5*). The most seeds per pods were set by lupine grown in the mixture with triticale, while the least - in the stand with wheat. A species of cereal had a relatively small effect on the number and weight of seeds per plant, although in all the years of the research, smaller values of these characteristics were recorded for lupine grown in a mixture with wheat compared to the stands with barley and triticale (*Table 6*). In the first two years of the experiment, lupine in mixtures set a lower number of pods and seeds, and produced a lower seed weight per plant than in pure stand. These values considerably increased in the third year of the study, regardless of the used cereal species. In 2011 and 2012, increasing the percentage of lupine in the mixture positively affected the number of pods, seeds, and seed weight per plant, while in the third year, there was a decrease in the number of pods. According to Rudnicki and Gałęzewski (2007a), all the features of yellow lupine in mixtures (except for height) were much less developed than in the cultivation in pure stands. Lupine grown in pure stand and in mixtures in 2013 had the highest weight of thousand seeds, regardless of the species of a cereal component of the mixture (*Table 7*). Moreover, lupine has larger seeds when grown in a mixture with triticale than the lupine grown with other cereal species. Increasing the percentage of lupine in the mixture with barley and wheat reduced the size of seeds, while triticale had a much lower influence on this feature.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1602_16831696

Table 5. *Number of yellow lupine pods per plants and seeds per pod depending on cereal species and percentage of lupine in mixture*

Years	Lupine percentage (%)	Number of pods per plants (unit)			Number of seeds per pod (unit)		
2011	100	5.15 b*			3.67 b		
2012	100	1.74 a			2.52 a		
2013	100	6.37 b			3.53 b		
		Barley	**Wheat**	**Triticale**	**Barley**	**Wheat**	**Triticale**
2011	40	2.90 a	1.17 a	2.45 a	2.84 a	2.24 a	3.14 a
	60	3.20 b	2.10 b	2.45 a	2.85 a	2.22 a	3.18 a
	80	3.65 c	3.10 c	2.55 a	3.12 b	2.21 a	3.39 b
	Mean	3.25	2.12	2.48	2.94	2.22	3.24
2012	40	0.53 a	0.48 a	0.66 a	2.19 a	2.14 a	2.15 a
	60	0.62 a	0.66 b	0.94 b	2.26 a	2.10 a	2.50 b
	80	0.95 b	0.87 c	1.04 b	2.43 b	2.33 b	2.45 b
	Mean	0.70	0.67	0.88	2.29	2.19	2.37
2013	40	8.17 c	8.83 c	7.96 c	3.66 a	3.70 b	3.74 b
	60	7.30 b	7.80 b	7.27 b	3.58 a	3.60 b	3.57 a
	80	6.40 a	7.30 a	7.17 a	3.71 b	3.45 a	3.62 a
	Mean	7.29	7.98	7.47	3.65	3.58	3.64

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

Table 6. *Number and weight of yellow lupine seeds on plant depending on cereal species and percentage of lupine in mixture*

Years	Lupine percentage (%)	Number of seeds (unit)			Weight of seeds (g)		
2011	100	19.00 b*			2.38 b		
2012	100	4.38 a			0.53 a		
2013	100	22.47 b			3.13 c		
		Barley	**Wheat**	**Triticale**	**Barley**	**Wheat**	**Triticale**
2011	40	8.20 a	2.50 a	7.70 a	0.98 a	0.30 a	0.89 a
	60	9.21 a	4.80 b	7.85 a	1.12 a	0.62 b	0.94 a
	80	11.55 b	6.80 c	8.65 b	1.32 b	0.78 c	1.02 b
	Mean	9.65	4.70	8.06	1.14	0.57	0.95
2012	40	1.16 a	1.03 a	1.43 a	0.14 a	0.12 a	0.18 a
	60	1.40 a	1.39 a	2.35 b	0.16 a	0.17 a	0.29 b
	80	2.31 b	2.03 b	2.56 b	0.26 b	0.25 b	0.31 b
	Mean	1.62	1.48	2.11	0.19	0.18	0.26
2013	40	29.83 c	32.60 c	29.70 b	3.70 b	3.94 c	3.70 b
	60	26.10 b	28.03 b	25.95 a	3.06 a	3.31 b	3.24 a
	80	23.73 a	25.17 a	25.96 a	2.88 a	2.44 a	3.37 a
	Mean	26.55	28.60	27.20	3.21	3.23	3.44

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Table 7. *Weight of thousand seeds of yellow lupine depending on cereal species and percentage of lupine in mixture*

Years	Lupine percentage (%)	Weight of 1000 seeds (g)		
2011	100	126.0		
2012	100	121.9		
2013	100	142.3		
		Barley	**Wheat**	**Triticale**
2011	40	119.4 a	121.1 a	113.7 a
	60	118.9 a	122.9 a	114.4 a
	80	117.8 a	119.1 a	111.7 a
	Mean	118.7	121.0	113.3
2012	40	117.5 b	118.9 a	122.0 a
	60	114.4 a	121.4 b	122.4 a
	80	113.4 a	125.0 c	122.3 a
	Mean	115.1	121.8	122.2
2013	40	125.6 b	122.8 a	127.4 a
	60	120.0 a	119.4 b	125.2 a
	80	121.7 a	117.5 b	130.1 b
	Mean	122.4	119.9	127.6

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

Growing yellow lupine in mixtures with cereals, as well as increasing its percentage had a beneficial effect on the number and weight of grains per plant (*Table 8*). In all years of the study, the smallest seed weight in the mixtures was recorded for wheat, while significantly largest, for barley. All species of cereals, grown both in mixtures and in pure stands, produced the smallest weight and number of grains per plant in 2012. Cereals in mixtures tillered slightly better than those grown in pure stands, and the tillering of cereals was positively affected by increasing the percentage of lupine in sowing. Barley grown in mixtures formed a similar number of grains per ear as barley grown in pure stand, while wheat and triticale - slightly higher (*Table 9*). Both, weather during the growing season and the share of components in the mixture, had little impact on the development of this feature, as well as on the height of culms (*Table 10*). The percentage of lupine in the mixture also had a relatively small effect on the thousand grains weight of cereals. Only in 2011, wheat and triticale reacted positively to increasing the percentage of legumes in the mixture. According to Rudnicki and Gałęzewski (2007b), the reaction of oats to sowing in the mixture with lupine was relatively weak, and the composition of the mixture affected only productive tillering, and grain yielding of oats. Rudnicki and Kotwica (2007) reported that yellow lupine generally shows little competitive potential against oats, but increasing its percentage in the stand caused an increase in its competitive strength against that cereal.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1602_16831696

Table 8. *Number and weight of cereals grain per plant depending on cereal species and percentage of lupine in mixture*

Years	Lupine percentage (%)	Weight of grain per plant (g)			Number of grain per plant (unit)		
		Barley	Wheat	Triticale	Barley	Wheat	Triticale
2011	0	3.30 b*	2.16 b	2.93 b	72.8 b	61.4 b	69.3 c
2012	0	2.63 a	1.46 a	1.58 a	60.8 a	46.0 a	43.7 a
2013	0	2.96 a	1.58 a	2.23 a	61.2 a	47.4 a	56.8 b
2011	40	3.77 a	1.97 a	2.83 a	73.2 a	54.8 a	66.3 a
	60	4.12 b	3.61 b	3.10 b	81.6 b	94.3 b	73.8 b
	80	4.43 b	4.14 c	3.38 c	83.0 b	100.4 c	76.4 b
	Mean	4.11	3.24	3.10	79.3	83.2	72.2
2012	40	2.37 a	1.87 a	1.86 a	54.5 a	60.1 a	52.0 a
	60	2.95 b	2.03 ab	1.94 a	70.0 b	64.8 b	52.8 a
	80	3.14 b	2.28 b	1.91 a	72.6 b	70.5 c	51.9 a
	Mean	2.82	2.06	1.90	65.7	65.2	52.2
2013	40	2.84 a	2.46 a	2.93 a	64.8 a	73.5 a	74.8 a
	60	3.00 a	2.50 a	3.19 b	69.8 b	74.3 a	81.9 b
	80	2.96 a	2.65 a	3.41 c	67.4 b	77.6 b	89.1 c
	Mean	2.93	2.54	3.18	67.3	75.1	81.9

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

Table 9. *Number of grain per ear and thousand grain weight of cereals depending on cereal species and percentage of lupine in mixture*

Years	Lupine percentage (%)	Number of grain per ear (unit)			Wight of 1000 grains (g)		
		Barley	Wheat	Triticale	Barley	Wheat	Triticale
2011	0	16.1 a*	30.4 b	33.5 c	48.2 b	35.2 b	42.3 c
2012	0	16.6 a	26.7 a	24.7 a	43.2 a	31.8 a	36.1 a
2013	0	16.1 a	27.9 a	28.4 b	48.4 b	33.4 ab	39.3 b
2011	40	17.0 a	31.1 a	34.6 a	52.0 a	35.6 a	42.6 a
	60	18.1 a	33.9 b	34.2 a	51.4 a	38.1 b	42.0 a
	80	17.1 a	32.6 ab	35.5 a	52.8 a	40.8 b	44.3 b
	Mean	17.4	32.5	34.8	52.1	38.2	42.9
2012	40	16.0 a	30.1 a	28.9 a	43.4 a	31.1 a	35.8 a
	60	16.8 a	31.0 a	28.7 a	42.2 a	31.4 a	36.7 a
	80	16.5 a	32.4 a	27.5 a	43.3 a	32.4 a	36.8 a
	Mean	16.4	31.2	28.4	42.9	31.5	36.4
2013	40	17.1 b	31.0 a	29.7 a	44.9 a	33.4 a	39.1 a
	60	16.9 b	32.3 a	31.2 a	43.1 a	33.6 a	39.0 a
	80	15.2 a	33.3 a	33.4 b	43.9 a	34.1 a	38.3 a
	Mean	16.4	32.2	31.4	44.0	33.7	38.8

*Values in the same column followed by a different letter are significantly different ($p < 0.05$)

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Table 10. *The height of cereals culm in mixture with lupine and number of shoot production*

Years	Lupine percentage (%)	Height of cereals (cm)			Number of shoot production (unit)		
		Barley	Wheat	Triticale	Barley	Wheat	Triticale
2011	0	57	69	75	4.55	1.95	2.15
2012	0	58	64	75	3.67	1.73	1.87
2013	0	61	64	78	3.80	1.70	2.00
2011	40	57	68	77	4.1	1.70	1.87
	60	57	70	76	4.5	1.90	1.90
	80	58	70	75	4.6	1.90	2.10
	Mean	57 a	69 b	76 b	4.40 b	1.83 a	1.95 a
2012	40	57	62	76	3.40	2.00	1.80
	60	59	63	77	4.17	2.09	1.84
	80	61	62	74	4.37	2.17	1.89
	Mean	59 a	62 a	76 b	3.98 b	2.09 a	1.84 a
2013	40	71	69	78	3.80	2.37	2.52
	60	72	69	79	4.12	2.30	2.63
	80	73	70	80	4.43	2.33	2.67
	Mean	72 a	69 a	79 b	4.12 b	2.33 a	2.61 a

*Values in the same rows followed by a different letter are significantly different ($p < 0.05$)

The grain of spring cereal grown in mixtures with yellow lupine contained more total protein than when it is grown in pure stands (*Table 11*).

Table 11. *Contents of total protein (%) in seeds depending on cereal species and percentage of lupine in mixture*

Specification	Cereal			Mean	Lupine			Mean
	2011	2012	2013		2011	2012	2013	
Lupine	-	-	-	-	36.8	40.8	43.4	40.3
Barley – PS*	11.3	11.6	9.9	11.0	-	-	-	-
Mixtures								
40%	11.9	12.5	11.6	12.0	36.6	40.5	43.4	40.2
60%	11.8	12.4	11.8	12.0	36.9	40.2	43.6	40.3
80%	13.5	13.9	12.2	13.2	36.8	39.7	44.4	40.3
Wheat – PS	13.2	13.1	13.2	13.2	-	-	-	-
Mixtures								
40%	13.6	13.7	13.4	13.6	36.9	40.9	43.1	40.3
60%	14.1	14.1	13.5	13.9	36.1	40.1	43.5	39.9
80%	14.2	14.6	13.5	14.1	36.2	40.2	43.8	40.1
Triticale – PS	12.8	13.2	12.7	12.9	-	-	-	-
Mixtures								
40%	13.4	14.1	13.3	13.6	36.2	41.8	43.5	40.5
60%	13.8	14.2	14.0	14.0	36.2	41.2	43.5	40.3
80%	13.4	13.9	14.2	13.8	36.1	41.6	43.7	40.5

*PS – pure sowing

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1602_16831696

In the year with lower rainfall (2012), cereal grains accumulated slightly more protein than in other years. There was also an increase in the amount of this component in cereal grains in the mixtures with a higher percentage of lupine. Grains of wheat and triticale contained a similar amount of protein, but it was larger than in grains of barley. Cereals only slightly affected the accumulation of total protein by lupine seeds (a similar content); weather conditions were more important. In 2011 lupine seeds contained much less protein. The grains of cereals, grown in mixtures with lupine, contained more crude fibre than the ones from cereals grown in pure stand, while cereals did not affect the accumulation of this component by lupine seeds (*Table 12*). Cereals generally accumulated more crude fibre in 2013, while in the years of 2011 and 2012 there was a tendency to store more fibre in cereal grains with a higher percentage of yellow lupine in mixture. Legume seeds, in turn, contained significantly less crude fibre in dry year of 2012 compared to other years of vegetation.

Table 12. *Concentrations of crude fibre (%) in seeds depending on cereal species and percentage of lupine in mixture*

Specification	Cereal			Mean	Lupine			Mean
	2011	**2012**	**2013**		**2011**	**2012**	**2013**	
Lupine	-	-	-	-	12.9	12.4	12.8	12.7
Barley – PS*	3.57	3.52	4.67	3.92	-	-	-	-
Mixtures								
40%	3.47	3.80	4.80	4.02	13.4	12.3	13.1	12.9
60%	3.61	3.87	4.60	4.03	13.3	12.1	12.3	12.6
80%	3.55	3.96	4.75	4.09	12.4	12.2	13.2	12.6
Wheat – PS	2.25	2.25	2.52	2.34	-	-	-	-
Mixtures								
40%	2.22	2.22	2.74	2.39	13.2	12.4	13.4	13.0
60%	2.34	2.34	2.70	2.46	13.0	12.2	13.2	12.8
80%	2.38	2.58	2.64	2.53	12.8	12.8	13.1	12.9
Triticale – PS	2.19	2.20	2.59	2.33	-	-	-	-
Mixtures								
40%	2.39	2.50	2.74	2.54	13.1	12.5	12.8	12.8
60%	2.31	2.50	2.80	2.54	12.9	12.3	13.2	12.8
80%	2.48	2.45	2.77	2.57	13.0	12.2	13.3	12.8

*PS – pure sowing

Conclusions

1. Yields of the mixtures of spring cereals with yellow lupine, especially with the 80% share of legumes, were lower than that of the cereals grown in pure stands.
2. The yellow lupine-wheat mixture yielded better than that with barley and triticale, regardless of the percentage of components.
3. Increasing the percentage of lupine seeds at sowing resulted in a significant decrease in the level of mixture yields, regardless of the species of cereal.

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4. The percentage of lupine seeds in mixture yields was much lower than at the sowing, regardless of the species of cereal, while its average percentage in the yield of the mixture with wheat was much larger than with barley and triticale.

5. Yellow lupine grown in a mixture set a lower number of pods, seeds per pod and per plant, and produced a lower seeds weight compared to the plants grown in pure stands.

6. Growing yellow lupine in a mixture with spring cereals positively affected morphological characteristics of cereals. Increasing the percentage of legume seeds at the sowing caused a better tillering of cereals and producing a higher number and weight of grains per plant.

7. The grain of cereals grown in mixtures with lupine had a higher content of total protein and crude fibre than when they were grown in pure stands. There was no significant impact of the cereal plant on the content of total protein and crude fibre in legume seeds. Weather conditions, especially humidity had a greater impact on the chemical composition of legume seeds.

8. Future research aimed at selection of compatible species and varieties, appropriate plant geometry and temporal arrangement of the various components of mixture under different locations and soil conditions could enhance adoption of legume-cereal mixtures in Europe.

Acknowledgements. This work was supported by the Ministry of Agriculture and Rural Development of Poland under multi-annual program "Improving domestic sources of vegetable protein, their production, trading and use in animal feed".

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DOI: http://dx.doi.org/10.15666/aeer/1602_16831696