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CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF DIFFERENT OAT FORMS AS INFLUENCE BY SPRINKLING IRRIGATION AND NITROGEN FERTILIZATION

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ABSTRACT

The aim of this study was to determine the effect of sprinkling irrigation and nitrogen fertilization on chemical composition of grain in selected forms of oat as well as yields of protein, energy and fat. Studies were conducted in the years 2010-2011 at the Teaching and Experimental Station in Gorzyń, Branch in Złotniki, belonging to Poznań University of Life Sciences, on soil classified as very good and good rye complex in the split-split-plot design in 4 replications. Experimental factors included the water treatment (non-irrigated, sprinkling-irrigated), form of oat (tall husked oat cv. 'Bingo', husked dwarf oat cv. STH 6106, hulless oat cv. 'Polar') and nitrogen fertilization (0, 50, 100 and 150 kg ha^{-1} N). It was found that sprinkling irrigation caused an increase in protein yield by 47.8%, fat yield by 99% and that of energy by 77.7%. Moreover, application of irrigation contributed to a reduction of contents of protein and fibre, and an increase in the contents of fat and nitrogen-free extractives in grain. Among the compared forms the greatest contents of protein and fat, but the lowest fibre content, were found in the hulless oat form ('Polar').

Key words: fat, energy and protein yield, oat.

INTRODUCTION

Chemical and nutritive properties of oats make this cereal an interesting object of studies in terms of both human and animal nutrition, increasingly often investigated by researchers. Introduction of new forms through breeding makes it possible to produce not only greater yields of grain, but also ensuring its better quality, which in turn provides more extensive applicability of this species for fodder, food, pharmacological, cosmetics or even energy purposes. However breeding and cultivation of oat cultivars need to target specific markets, thanks to which they may be more adapted to meet their requirements. Improvement of agronomic traits has been primary objective of the oat breeders (Dumlupinar et al., 2012). For example, food and pharmaceutical industries prefer cultivars with high contents of β-glucan, containing specific fats and antioxidants, fodder producers prefer cultivars with low contents of β-glucan and high contents of fat and protein, whereas producers of flour and groats search for cultivars with low fat contents, ensuring maximum utilization of grain. Determination and detailed evaluation of characteristics of local cultivars will definitely provide significant knowledge for oat cultivation and breeding (Hisir et al., 2012). Due to its different genotype the hulless form of oat may differ in terms of its requirements concerning certain cultivation conditions from the husked form (Maral et al., 2013). Studies by Ayub et al. (2011); Brunava et al. (2014); Khan et al. (2014) and Tobiasz-Salach et al. (2011) showed that oat forms may vary greatly in terms of their chemical composition. Also Brunava et al. (2014) stated that grain of hulless forms of both spring barley and oat, have higher protein contents than husked forms. Moreover, numerous studies indicate a varied response of oat forms to cultivation factors. Podolska et al. (2009) on soil of a good wheat complex showed that an increase in the dose of nitrogen from 60 to 90 kg ha^{-1} N had no effect on the volume of yields of protein and fat, as well as on the chemical composition of the hulless form of dwarf oat (STH 5630).

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For this reason it is crucial from the point of view of practice and science to gain extensive knowledge on the introduced forms and their cultivars under diverse environmental and cultivation conditions, particularly in terms of their water and fertilizer requirements.

The aim of the conducted study was to determine the chemical composition and yields of protein, fat and energy in selected forms of oat, depending on sprinkling irrigation and nitrogen fertilization.

MATERIAL AND METHODS

Field trials were conducted in the years 2010–2011 at the Experimental and Teaching Station in Gorzyń, the Złotniki branch (52°29′0″ N, 16°49′53″ E), belonging to the Poznań University of Life Sciences, on soil classified as very good and good rye complex in the split-split-plot design in 4 replications. The 1st order factor was the water treatment (non-irrigated, irrigated). The 2nd order factor was the form of oat (tall husked oat cv. ‘Bingo’, husked dwarf cv. STH 6106, hulless oat cv. ‘Polar’), coming from the Plant Breeding Station in Strzelce. The 3rd order factor was nitrogen fertilization applied at 0, 50, 100 and 150 kg ha^{-1} N.

Sprinkling irrigation was performed at soil moisture content decreased below 70% field capacity using a semi-stationary sprinkler with NAAN 233/91 sprinklers with nozzle diameter of 7 mm and water output of 5 mm h^{-1}. The area of the irrigated sub-block was 576 m^2, while that of the non-irrigated sub-block was 288 m^2. Doses and dates of sprinkling irrigation are presented in Table 1.

Table 1. Doses and dates of sprinkling irrigation in the years 2010-2011

Year	Date / Dose of water (mm)	Total (mm)
2010	21 06 / 40; 19 06 / 40; 14 07 / 40; 19 07 / 40.	160
2011	26 05 / 30; 31 05 / 30; 13 06 / 35; 15 06 / 35; 29 06 / 35.	165

Nitrogen fertilization was applied in the form of ammonium nitrate (34% N) at three dates: 50 kg ha^{-1} N (BBCH 00) before sowing and respective treatments at 50 kg ha^{-1} N at the tillering phase (BBCH 21) and at the heading phase (BBCH 51). Prior to oat, sowing phosphorus fertilization was applied at 80 kg ha^{-1} P2O5 (34.9 kg ha^{-1} P) and potassium fertilizer was applied at 100 kg K2O (83 kg ha^{-1} K). In the vegetation period the plantation was protected against insect pests using Karate Zeon 050 CS at 0.1 dm^3 ha^{-1}. The other cultivation measures were performed in accordance with the principles of cultivation recommended for this species.

Analyses of the chemical composition of grain were performed using the commonly accepted methods at the laboratory of the Department of Agronomy, the Poznań University of Life Sciences. Crude protein was determined according to Kjeldahl, crude fat according to Soxhlet, crude fibre was determined by hydrolization of the other components of the plant material, ash by incineration, nitrogen-free extractives by subtraction from 100% contents of the other components.

The energy value of grain was calculated using a method recommended by Deutsche Landwirtschafts-Gesellschaft (Futterwertt-abellen für Schweine, 1991, 2010), which is also applied in Poland. Digestible components were obtained using the digestibility coefficients given by DLG and they were expressed in grams per 1 kg dry matter. The energy value was expressed in the form of metabolic energy using the formula:

$$\text{EM (MJ kg}^{-1}\text{ d.m.)} = 0.021 \times \text{BSS} + 0.0374 \times \text{TSS} + 0.0144 \times \text{WSS} + 0.0171 \times \text{BNWS},$$

where: BSS is crude digestible protein (g kg^{-1} d.m.), TSS – crude digestible fat (g kg^{-1} d.m.), WSS – crude digestible fibre (g kg^{-1} d.m.), BNWS – nitrogen-free digestible extractives (g kg^{-1} d.m.).

Unit content of metabolic energy in 1 kg grain and yields of metabolic energy from 1 ha were obtained applying respective conversion factors.

Results were elaborated statistically using the analysis of variance (ANOVA) and the recorded differences were estimated by Tukey's test at the significance level $\alpha = 0.05$.

RESULTS AND DISCUSSION

Yields of protein and energy in oat depended on sprinkling irrigation, oat form as well as nitrogen fertilization and the interaction of sprinkling irrigation with nitrogen fertilization and the interaction of the oat form and nitrogen fertilization. The yield of fat significantly depended on sprinkling irrigation, nitrogen fertilization and the interaction of sprinkling irrigation with nitrogen fertilization. Analysis of results showed a significantly advantageous effect of sprinkling irrigation on protein yield of oat, as in relation to non-irrigated treatments the mean increase was 47.8%. Consistent results were reported by Nasseri et al. (2009). However, it needs to be stressed here that such an increment in the yield of protein is determined first of all by the volume of harvested yield of grain, which was also shown in an earlier study by Pecio and Bichoński (2010) on oat as well as Alazmani (2015) in investigations on barley. Nitrogen fertilization applied in this study modified protein yield of oat, an increase was recorded in the values of this trait with an increase in nitrogen doses, while a significant increase was observed up to the applied dose of 100 kg ha^{-1} N. Similarly, Nasseri et al. (2009) in their studies on wheat recorded an increase in protein yield up to a dose of 90 kg ha^{-1} N.

Yield of protein in this study calculated for grain depended also on the interaction of sprinkling irrigation with nitrogen fertilization (Table 2). The presented interaction of sprinkling irrigation and fertilization on the modification of protein yield was manifested in the fact that at cultivation of oat at natural precipitation this yield increased significantly after an increase in nitrogen fertilization to 100 kg·ha^{-1}, while in irrigated oat the yield of protein increased to 150 kg·ha^{-1}. Sprinkling irrigation, except for the treatment with no nitrogen applied, caused a significant increase in the yield of protein, while the greatest effect under the influence of this factor was observed for the fertilized treatment with the greatest of the tested doses, i.e. 150 kg ha^{-1} N, amounting to 229 kg·ha^{-1}. Also Nasseri et al. (2009) reported an interaction of sprinkling irrigation with nitrogen fertilization. Pecio and Bichoński (2010) observed an increase in protein yield of oat under the influence of nitrogen fertilization, while – as it was reported by those authors – the effect depended on the years and location of the study area. In turn, Podolska et al. (2009) when assessing the effect of nitrogen fertilization at two levels of this nutrient reported no significant increase in the yield of protein, only a trend towards higher values of this trait at the higher of the tested doses.

Table 2. Protein yield depending on irrigation, form of oat and nitrogen fertilization (kg·ha^{-1})

Factor	Level	N fertilization (C)				Average
		0	50	100	150	
Water treatment (A)	non irrigated	207	287	347	349	297
	irrigated	230	403	546	578	439
Average		218	345	446	464	-
LSD 5% A – 29.1, C – 20.3, A × C – 28.7						
Form of oat (B)	tall husked	234	363	513	537	412
	husked dwarf	219	342	452	420	358
	hulless	201	330	374	433	335
Average		218	345	446	464	-
LSD 5% B – 22.2, C – 20.3, B × C – 35.1						

Among the compared forms of oat the greatest yield of protein was recorded for the tall husked form, while it was lowest in the hulless form, which was also confirmed by earlier studies by Tobiasz-Salach et al. (2011). An interaction of oat forms with nitrogen fertilization in this study resulted from the fact that in the case of husked forms the yield of protein increased up to the dose of 100 kg ha^{-1} N, while in the hulless form it was up to 150 kg ha^{-1} N.

Iqbal et al. (2013), when investigating the effect of nitrogen fertilization recorded a significant increase in the yield of protein up to a dose of 114 kg ha^{-1} N. In the conducted study sprinkling irrigation significantly modified fat yield of oat, resulting in an increase by 101 kg ha^{-1}, i.e. 99%. Also nitrogen fertilization significantly influenced the value of this trait, with increasing doses of nitrogen causing a significant increase in fat yield up to the dose of 100 kg ha^{-1} N, while a further increase in fertilization with this nutrient by 50 kg ha^{-1} N produced a significant decrease in the value of the discussed trait (Table 3). The recorded interaction of sprinkling irrigation with nitrogen fertilization for fat yield in oat resulted from the fact that in the cultivation of oat at natural precipitation the yield of fat increased up to a dose of 50 kg ha^{-1} N, while at irrigation it was up to 100 kg ha^{-1} N, while a further increase in fertilization with this nutrient caused a significant reduction in the yield of fat.

Table 3. Fat yield depending on irrigation, form of oat and nitrogen fertilization (kg ha^{-1})

Factor	Level	N fertilization (C)				Average
		0	50	100	150	
Water treatment (A)	non irrigated	89.5	110	109	99.4	102
	irrigated	116	219	246	230	203
Average		103	164	177	165	-
LSD 5% A – 13.6, C – 9.3, A × C – 13.2						
Form of oat (B)	tall husked	99.4	156	173	169	149
	husked dwarf	102	170	179	160	153
	hulless	107	168	180	165	155
Average		103	164	175	165	-
LSD 5% B – NS, C – 9.3, B × C – NS.						

NS - not significant.

Oat forms did not differentiate significantly the yield of fat, while only trends may be indicated for a greater yield of fat in the hulless form and a lower yield for the tall husked form. Accordance to Danyte (2012) fat yield per ha of naked oat breeding lines were not higher than those of hulled oat breeding lines because of their low grain yield. Different results were recorded by Pisulewska et al. (2011), who found the greatest calculated yield of lipids in the naked form of line STH7505 grown in Przecław, while it was lowest in the husked line STH7105 tested in Lubliniec. Also in other studies no interactions between the oat form and nitrogen fertilization were observed in terms of fat yield in oat. However, it may be indicated here that in all the three oat forms the greatest fat yields were produced at the application of 100 kg ha^{-1} N.

The yield of energy in oat grain analysed in this study significantly depended on sprinkling irrigation, the form of oat and nitrogen fertilization, as well as the interactions of sprinkling irrigation with nitrogen fertilization and the form of oat with nitrogen fertilization (Table 4). On average for the other factors sprinkling irrigation caused an increase in the yield of energy by 77.7%.

The application rates of nitrogen fertilization tested in this study caused a significant increase in the yield of energy up to a dose of 100 kg ha^{-1} N, while a further increase in the nitrogen dose by 50 kg ha^{-1} N caused a significant reduction in the value of this trait.

Table 4. Energy yield depending on irrigation, form of oat and nitrogen fertilization (GJ ha^{-1})

Factor	Level	N fertilization (C)				Average
		0	50	100	150	
Water treatment (A)	non irrigated irrigated	23.7 30.7	30.6 53.3	33.5 65.4	30.6 60.9	29.6 52.6
Average		27.2	42.0	49.4	45.8	-
LSD 5% A – 3.13, C – 2.23, A × C – 3.16						
Form of oat (B)	tall husked husked dwarf hulless	32.4 28.0 21.1	47.9 43.7 34.2	58.2 52.8 37.4	55.8 44.2 37.2	48.6 42.2 32.5
Average		27.2	42.0	49.4	45.8	-
LSD 5% B – 2.59, C – 2.23, B × C – 3.87						

Forms of oat differed significantly in terms of the produced yield of energy. Similarly as in the case of protein yield, the greatest yield of energy was recorded in the tall husked form and it was greater by 6.4 GJ ha^{-1} than that of the dwarf form and by 16.1 GJ ha^{-1} than that of the hulless form.

The interaction of oat form and nitrogen fertilization presented in this study resulted from the fact that in the tall husked forms and dwarf cultivars the yield of energy increased up to a dose of 100 kg ha^{-1} N, while a further increase in fertilization rates in the dwarf cultivar contributed to a significant decrease in the value of this trait. In turn, in the hulless cultivar a significant increase was observed only up to the application of 50 kg ha^{-1} N.

Determination of the effect of sprinkling irrigation on the crop yield and qualitative composition of cereals, particularly protein content, is important and currently required, since precipitation deficit, particularly in certain regions, is a very common phenomenon (Abraha and Savage, 2008).

Based on this study it may be stated that sprinkling irrigation contributed to a reduction of contents of dry matter, protein and fibre, at the same time causing an increase in the contents of fat and nitrogen-free extractives in grain (Table 5). A decrease in protein contents under the influence of irrigation was also reported by Erecul et al. (2012). Tahir et al. (2014) showed that the production of high protein contents is connected with the date of sprinkling irrigation. As it was reported by those authors, the greatest protein content in oat grain (9.13%) was obtained after the application of early irrigation, 21 days after sowing. Dumlupinar et al. (2011) indicated that protein content varied for year, genotype and year x genotype interaction.

Table 5. Organic components and ash contents in grain of oat (in % dry matter)

Factor	Level	Dry mass	Crude protein	Crude fibre	Crude lipides	N-free extract	Ash
Water treatment	non irrigated irrigated	91.8 91.5	13.8 11.5	11.1 8.82	5.06 5.64	58.7 62.6	3.03 2.96
LSD 5%		0.19	0.64	1.53	0.36	1.75	NS
Form of oats	tall husked husked dwarf hulless	91.7 91.7 91.5	11.4 11.5 15.1	11.4 12.2 6.3	4.27 4.91 6.87	61.4 60.0 60.5	3.27 3.08 2.62
LSD 5%		NS	0.78	1.87	0.44	NS	NS
Fertilization (kg N·ha^{-1})	0 50 100 150	91.7 91.6 91.6 91.7	11.3 11.8 13.1 14.5	10.9 9.74 9.31 9.87	5.50 5.66 5.16 5.07	60.9 61.4 61.0 59.3	3.09 2.93 2.97 2.98
LSD 5%		NS	0.91	NS	NS	NS	NS

NS - not significant.

Oat forms evaluated in this study varied in terms of their chemical composition. The greatest contents of protein and fat, at the simultaneous lowest fibre content, were found for the hulless oat form (‘Polar’). In turn, no significant variation was recorded in the contents of these components between the husked and dwarf forms, except for the concentration of fat. These results are consistent with the earlier observations by Brunava et al. (2014), who stated that naked cultivars of oat contained significantly greater amounts of protein, at lower contents of starch in grain than husked forms of these species. Biel et al. (2009) indicated that fat content in grain of hulless oat may be even two-fold greater than in grain of husked oat. Moreover, according to that author due to a high fibre content in husked forms their grain is not very popular as feed for monogastric animals. Tobiasz-Salach et al. (2011), when assessing variation in the chemical composition between six dwarf cultivars and one medium-height cultivar, showed that the greatest contents of fibre and ash were recorded for the medium-height cultivar (‘Krezus’), while the greatest fat content was recorded for the dwarf form STH 75 and the greatest protein level – in the dwarf form STH5417. Zhao et al. (2009) showed that total plant DM was 21% greater for naked 'VAO-2' than for covered 'Prescott', while both genotypes produced similar grain yields.

Nitrogen fertilization is the basic yield-forming factor, which in the opinion of many authors may modify the chemical composition of grain. In this study it was stated that this factor significantly modified only the content of crude protein in oat grain. The recorded results indicate increased protein contents in grain with an increase in nitrogen application rates, as it was confirmed by earlier studies by Iqbal et al. (2013). However, Jelic et al. (2013) showed that NPK fertilization increased grain yield and test weight, but had no effect on grain protein content.

The dependence of protein, fat and energy yields in oat on nitrogen fertilization for both water variants and oat form is presented in Table 6. Based on the calculated regression equations a linear dependence was found between protein yield and nitrogen fertilization in both water variants. The coefficient of regression indicates that within the ranges of applied fertilization levels an increase in the nitrogen dose by 1 kg caused an increase in protein yield in non-irrigated oat by approx. 1 kg, while in irrigated oat it was by approx. 2.37 kg.

Table 6. Linear regression equations for protein and energy yields of oats depending on water variant, form of oats and nitrogen fertilization (x = Nitrogen fertilizer dose)

Protein yield			
Water treatment	non irrigated irrigated	$y = 0.972x + 224.6$ $y = 2.374x + 261.2$	$R^2 = 0.88$ $R^2 = 0.93$
Form of oats	tall husked husked dwarf hulless	$y = 2.118x + 252.9$ $y = -0.0155x^2 + 3.751x + 212.55$ $y = 1.48x + 223.5$	$R^2 = 0.93$ $R^2 = 0.97$ $R^2 = 0.94$
Fat yield			
Water treatment	non irrigated irrigated	$y = -0.003x^2 + 0.5089x + 90.145$ $y = -0.0119x^2 + 2.523x + 117.65$	$R^2 = 0.96$ $R^2 = 0.99$
Energy yield			
Water treatment	non irrigated irrigated	$y = -0.001x^2 + 0.1942x + 23.61$ $y = -0.0027x2 + 0.6119x + 30.395$	$R^2 = 0.99$ $R^2 = 0.99$
Form of oats	tall husked husked dwarf hulless	$y = -0.0018x^2 + 0.4295x + 32.025$ $y = -0.0024x^2 + 0.4799x + 27.445$ $y = -0.0013x^2 + 0.3025x + 21.425$	$R^2 = 0.99$ $R^2 = 0.98$ $R^2 = 0.98$

In turn, the dependence of fat yield and the yield of energy in both water variants was curvilinear. Based on the calculated regression equations it may be expected that in oat grown at natural precipitation the maximum yield of fat is ensured by the application of 84.8 kg ha^{-1} N, while the maximum yield of energy – 97.1 kg ha^{-1} N. At the application of sprinkling irrigation optimal fertilization for the yield of fat is 106 kg ha^{-1} N, while for the yield of energy – 113.3 kg ha^{-1} N, respectively.

The analysed dependence of protein yield on nitrogen fertilization for the compared oat forms indicates that in the case of both tall husked oat forms and hulless forms the relationship was linear, while each increase in the nitrogen dose contributed to an increase in the value of this trait by 2.11 and 1.48 kg, respectively. In turn, in the dwarf husked form this dependence was curvilinear and the maximum yield of protein in the cultivation of this form may be obtained after the application of 121 kg ha^{-1} N. A similar dependence was observed for all the evaluated oat forms for the yield of energy. Production of the maximum yield of energy for the tall husked form was possible after the application of 119 kg ha^{-1} N, for the dwarf husked form it is 99.9 kg ha^{-1} N, while for the hulless form – 116 kg ha^{-1} N, respectively. A similar dependence of protein and fat yield on nitrogen fertilization for oat was reported by Pecio and Bichoński (2010), where increase in the nitrogen dose by 1 kg caused an increase in protein yield by approx. 1.46 kg while for fat yield 0.32 kg.

CONCLUSIONS

Sprinkling irrigation increased the yield of protein by 47.8%, yield of fat by 99% and the yield of energy by 77.7%.

Irrigation caused a decrease in contents of protein and fibre and an increase in contents of fat and nitrogen-free extractives in oat grain.

Among the compared oat forms the greatest contents of protein and fat, at the simultaneous lowest fibre content was found for the hulless oat form (‘Polar’).

Nitrogen fertilization significantly modified protein content in oat grain, particularly at the application of high doses of this nutrient.

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