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INFLUENCE OF SPRINKLER IRRIGATION AND NITROGEN FERTILIZATION ON THE QUALITY OF MALT AND WORT FROM BARLEY GRAINS

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Abstract

The aim of the research was the evaluation of sprinkler irrigation and nitrogen fertilization on some selected features of the quality of malt and wort from 'Marthe' and 'Mauritia' malting barley grains. The field experiment was carried out in the years 2010–2012 at the Research Station of the University of Science and Technology in Mochełek near Bydgoszcz. As a result of 3-year field experiment and laboratory test of grain, malt and wort, it was found that introducing sprinkler irrigation into the production process of malting barley is a step justified by the obtained quality effects. It was found that in the case of irrigated malting barley cultivations nitrogen fertilization at the rate of 30 kg·ha^{-1} provides (in relation to control, non-irrigated treatment) the highest values of such parameters as weight of the technical barley crops, content of protein, extractivity of Pilsen type malt, amount of obtained wort and simplified mashing efficiency. The combination of sprinkler irrigation of malting barley plants with their nitrogen fertilization at the increased rates of 60 and 90 kg·ha^{-1}, resulted in the following effect – high mass of the usable grain of crops remained but their quality deteriorated. Malt produced from malting barley fertilized with nitrogen at the rates of 60 and 90 kg·ha^{-1}, in spite of applied sprinkler irrigation, was characterized by unacceptable – from the technological point of view – increased content of protein in malt in the amount of over 11.5% d.m., as well as huge decrease in malt extractivity (even by 2%) and lower, simplified mashing efficiency (below 70%).

Key words: malting barley, sprinkler irrigation, nitrogen fertilization, malt, wort, simplified mashing efficiency

INTRODUCTION

Production of malting barley grain of suitable quality in the region covering the area of central Poland is difficult due to often occurring drought periods (Łabędzki 2009, Koźmiński and Michalska 2010). Drought in the period of intensified water demand by malting barley contributes, as a rule, to worse crops, regarding both their quality and quantity. According to Bertholdsson (1999) it is connected with unfavourable influence of soil water shortages on extracting nitrogenous compounds from the soil and their excessive accumulation in the form of protein in a grain. Research results by many authors confirm that drought periods, both in the stages before blooming and when grain is filled, result in the deterioration of its quality features which are relevant in malting industry (Halvorson and Reule 2007, Pecio 2002, Rzemieniuk 2007, Qureshi and Neibling 2009, Thompson *et al.* 2004).

From among many cerealcereal grains used in industry, malting barley has the most restrictive quality requirements (Kunze 1999). It results from the need to ensure a suitable raw material within the chain of dependencies, which include a malt house and brewhouse supplies. The quality of malting barley grain is evaluated considering the features that ensure the possibility of obtaining Pilsen type malt in automatic malt houses. The malt is evaluated by brewers in terms of a raw material for gaining the wort of a specified quality, which many features of the final product (beer) are conditioned on. (Kunze 1999). In most Polish and foreign experiments, sprinkler irrigation provided proper rhythm of growth and development of plants as well as suitable nitrogen economy. This resulted in crop increase and stabilization of grain quality (Albrizio *et al.* 2010, Borówczak and Rębarz 2010; Halvorson and Reule 2007, Mollah and Paul 2011, Moreno *et al.* 2003, Nowak *et al.* 2005, Wojtasik 2004).

The present work discusses the broaden evaluation of the influence of sprinkler irrigation on malting barley features, which are of importance from the practical point of view: content of protein and extractivity (for malt), as well as simplified mashing efficiency (for wort) (Szwed *et al.* 2014).

The research hypothesis assumed that the application of sprinkler irrigation in the process of malting barley cultivation would result in increased grain cropping and contribute to the stabilization of features influencing its malting applicability, irrespective of periods of rain shortages (precipitation) occurring in a given vegetation season. It was assumed that under sprinkler-irrigated conditions it would be possible to apply some higher rates of nitrogen (60 or even 90 kgN·ha^{-1}) than in the case of traditional cultivation (30 kgN·ha^{-1}), which would probably contribute to increased crop production, possibly without deteriorating the quality of grain destined to be processed in malt houses.

MATERIAL AND METHODS

In order to verify the research hypotheses, field experiment was carried out. They concerned the influence of sprinkler irrigation and nitrogen fertilization on crop volume and malting value of grain of two kinds of spring barley (*Hordeum vulgare*) – 'Mauritia' and 'Marthe', cultivated on sandy soil near Bydgoszcz, so in the area with the highest average shortages of rainfall in Poland, and hence highest needs to apply additional sprinkler irrigation. The evaluation of barley grain quality, malt of Pilsen type produced from it in laboratory conditions as well as wort obtained with the use of the „congress method" was carried out in the malting laboratory of the Department of Fermentation Technology of the Faculty of Fermentation Technology and Corns at the Wroclaw University of Environmental and Life Sciences.

The experiment was carried out in three successive vegetation seasons: 2010, 2011, and 2012 at the Research Station of the Faculty of Agriculture and Biotechnology of the University of Science and Technology in Bydgoszcz, located in Mochełek near Bydgoszcz. (φ = 53˚13', λ = 17° 51', h = 98.5 m over sea level). The experiment was performed in Haplic Luvisol, representing IVa soil valuation class and very good rye soil suitability complex. In terms of the level of compactness, it is a light soil deposited on compact formation (sand on shallow-deposited sandy clay loam).Two cultivars of spring barley 'Marthe' and 'Mauritia' were tested. Barley was cultivated after potato, in the second year after manure application. Two-factor field experiment for each of the kind was conducted with the use of random sub-blocks method in a dependent split-plot system, in four replications. The area of the field for barley crops amounted to 10 m^2. The first factor was sprinkler irrigation, containing two experimental variants: W_0 – no sprinkler irrigation (control treatment), W_1 –optimal sprinkler irrigation, providing plants with readily available water (RAW) (it is the water that a plant can easily extract from the soil; the soil moisture held between field capacity and a nominated refill point for unrestricted growth; in this range of soil moisture, plants are neither waterlogged or water-stressed) in the whole period of their vegetation. The sprinkler irrigation was carried out with the use of a portable sprinkler irrigation system equipped with low pressure, Nelson-type sector sprinkler heads with unit efficiency of 200 dm^3·h^{-1}. Water for sprinkler irrigation was taken from the village water pipe system. The irrigation intervals were scheduled on the basis of standard measurements of rainfall and readily available water in soil. Constant monitoring of topsoil moisture was conducted using the method of readily available water balance, according to meteorological parameters, (Drupka 1976) as well as direct measurements of the soil water content with the use of Fieldscout TDR 300 Soil Moisture Meter probe.

The number of irrigation rates and a seasonal dose of irrigated water depended on the course of atmospheric conditions, mainly on amounts and distribution of rainfall. In 2010, in the period form full earing (heading) to yellow ripeness 105 mm water was applied in 5 one-time rates. In the following vegetation seasons of 2011 and 2012, agricultural drought occurred in the period of plant vegetative growth – before the stage of full earing, in the third decade of May and first decade of June. In both these seasons 3 rates of irrigation were applied – in 2011 a total of 75 mm and in 2012 – a total of 70 mm.

Growing seasons of the barley (IV–VII) were characterized by slightly higher air temperature as compared to the long-term average of 1981–2010, and considerably higher rainfall amounting to 251.9, 285.2 and 301.3 mm in the successive years, which accounted for 127, 143 and 151% of the climatic norm, respectively. In spite of the occurrence of higher rainfall than the long-term average, in each season there was a need to apply sprinkler irrigation, since uneven rainfall distribution resulted in periods of atmospheric and agricultural droughts. As it results from the balances of soil water content carried out in the periods of increased demand for water of the barley (from 10 May to 20 July), the sprinkler irrigation prevented the depletion of easily available water in the topsoil, where the water content was under control. Throughout the whole period of sprinkler irrigation the storage of water in the topsoil remained within the range of readily available (Żarski *et al.* 2013). There was an atmospheric and agricultural drought that in the vegetation season of 2010 comprised over one month period after full earing till yellow ripeness (16 June – 20 July) and affected the control treatments. In the following years of 2011 and 2012, periods of droughts were shorter than in the first year of tests. They occurred in the plant vegetative growth period before full earing, comprising the third decade of May and first decade of June; in 2011, 9 days with run-out supplies of readily available water were detected and in 2012 – 17 such days.

The second experimental factor was nitrogen fertilization in four variants: N_0 – no fertilization (control treatments), N_1– pre-sowing fertilization 30 $kg{\cdot}ha^{-1}$, N_2 – pre-sowing fertilization 60 $kg{\cdot}ha^{-1}$, N_3 – fertilization of 90 $kg{\cdot}ha^{-1}$ (pre-sowing of 60 $kg{\cdot}ha^{-1}$ and main one of 30 $kg{\cdot}ha^{-1}$). The dates of the main fertilization in the following vegetative seasons fell on: 20 May 2010 (at the end of tillering stage) and 30 May 2011 (stem extension stage) and 22 May 2012 (stem extension stage). The cultivation of barley was conducted according to the rules of proper agro-technology, containing optimization of PK fertilization and chemical plant protection. Sowing of qualified material was made in optimal periods, i.e. on 2 April 2010, 8 April 2011 and 29 March 2012. The crop was harvested with the use of field harvester and was calculated for 1 ha, taking into account grain humidity of 15%.

Technological evaluation of the grain was made in the malting laboratory of the Faculty of Technology of Fermentation and Corns at the Wrocław University of Environmental and Life Sciences. Standard technological analysis comprised tests applied during the evaluation of malting usability of the malting barley grain according to Molina-Cano method, elaborated at the request of EBC (European Brewing Convention) (Molina-Cano 1987, Klockiewicz-Kamińska 2007). From many differentiating factors of quality evaluation, this paper uses only: grain uniformity according to I and II sieve (%), crop of technical barley grain ($Mg \cdot ha^{-1}$), content of protein in malt (% d.m.), malt extractivity (% d.m.) and simplified mashing efficiency (%). Grain uniformity according to I and II sieve was determined in Pfeuffer Sortimat laboratory separator. Content of protein in malt was established using Infratec TM1241 Grain Analyzer manufactured by the company Foss. Malt extractivity was established according to the results of extract content in laboratory wort obtained with the use of the „congress method" acc. to EBC analytics (Analytica-EBC 1998). Simplified mashing efficiency (%) was calculated on the basis of extract content and volume of congress wort according to the formula suggested by Szwed *et al.* (2014). Statistical calculations were performed with the analysis of variance of a two-factor experiment in split-plot, with the Tukey test, applying the ANALWAR – 5.1. FR software package. Analyses of technological value of grain were carried out based on bulk samples of the individual combinations of the experiment factors.

RESULTS AND DISSCUSSION

Crop of the barley grain is an important differentiating factor that characterizes potential possibilities of cropping of the tested kinds depending on the applied cultivation variants. It does not, however, reflect fully its malting usefulness. When evaluating malting barley grain destined for obtaining malt of Pilsen type, one determined grain uniformity according to I and II sieve, i.e. the share of grains of over 2.5 mm thick. According to the requirements of the malting industry, minimum total share of grains of over 2.5 mm thick (sieve II) and 2.5 mm thick (sieve I) should amount at least 90% of the weight of grains sent to malt houses (Kunze 1999).

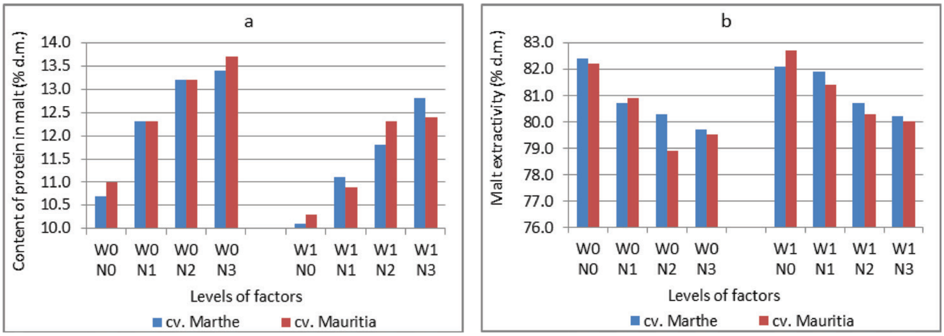
Table 1. Impact of nitrogen fertilization and sprinkler irrigation of the plants of malting barley on uniformity and crop of technical barley grain (average for vegetation seasons 2010–2012)

Cultivar	Irrigated (W) and nitrogen fertilized (N) treatments	Average for growing seasons 2010–2012		
		Grain yield ($Mg \cdot ha^{-1}$)	Grain uniformity acc. to I and II sieve (%)	Crop of technical barley grain ($Mg \cdot ha^{-1}$)
Marthe	W_0N_0	3.85	90.6	3.46
	W_0N_1	4.31	79.1	3.35
	W_0N_2	3.98	73.6	2.89
	W_0N_3	3.77	72.1	2.70
	W_1N_0	4.45	95.2	4.23
	W_1N_1	5.85	88.4	5.14
	W_1N_2	5.62	82.6	4.52
	W_1N_3	5.55	80.5	4.43
	Average W_0	**3.98**	**78.9**	**3.10**
	Average W_1	**5.37**	**86.7**	**4.58**
	$LSD_{0.05}$ irrigation	0.25*	0.9*	0.19*
	$LSD_{0.05}$ fertilization	0.12*	2.2*	0.14*
	$LSD_{0.05}$ interaction	0.17*	3.1*	0.20*
Mauritia	W_0N_0	3.62	88.6	3.23
	W_0N_1	3.95	77.5	3.14
	W_0N_2	4.06	77.0	3.19
	W_0N_3	4.04	77.5	3.17
	W_1N_0	3.92	94.7	3.72
	W_1N_1	5.18	92.1	4.78
	W_1N_2	5.37	89.0	4.78
	W_1N_3	5.76	88.5	5.10
	Average W_0	**3.92**	**80.2**	**3.18**
	Average W_1	**5.06**	**91.1**	**4.60**
	$LSD_{0.05}$ irrigation	0.25*	1.0*	0.28*
	$LSD_{0.05}$ fertilization	0.15*	1.6*	0.15*
	$LSD_{0.05}$ interaction	0.21*	2.3*	0.22*

*statistically significant difference p=0.05
Source: own results and elaboration

In the malting sector, a more precise description of barley cropping is the crop of technical barley grain, i.e. containing grains of minimum 2.5 mm thick, from which chaff (grains up to 2.5 mm thick) was separated. The data contained in Table 1 clearly indicate that, in relation to plants from non-irrigated treatments (W_0), irrigated plants of barley (W_1) produce better crops and hence better grain uniformity. This is due to the higher grain yield of technical barley than from non-irrigated plots. The main reason is less uniformity of grain obtained from non-irrigated plants, as well as less resistance to lodging of plants on N_3 treatment. Contrary to expectations, increased nitrogen fertilization in the range from 30 to 90 kgN·ha^{-1}, even when combined with sprinkler irrigation, did not result in considerable crop production increase of technical barley. The worst variant as regards cropping of technical barley was W_0N_3 treatment, where 90 kgN·ha^{-1} translated into the lowest crop of technical barley of both tested kinds of barley. The most effective, as regards maximization of technical grain crop for both kinds, turned out to be the cultivation treatment where plants were supplied with nitrogen fertilizer in the classical dose of 30 kgN·ha^{-1}, and effects of droughts were compensated with interventional sprinkler irrigation.

The test results prove that it is possible to cultivate malting barley on sandy soils in the regions, where there are agricultural droughts, which is also confirmed by the tests conducted on the soil of VI quality class near Bydgoszcz (Rzekanowski *et al.* 2011, Żarski and Dudek 2005, Żarski 2006). Irrespective of economic circumstances, which require some additional elaboration, the production effects obtained as a result of three year tests indicate that it is purposeful to introduce sprinkler irrigation into the process of cultivating malting barley as a process increasing crops of technical grain in the periods of vegetation that are characterized by the occurrence of agricultural droughts.



Source: own results and elaboration

Figure 1. Impact of nitrogen fertilization and sprinkler irrigation of malting barley plants on the content of protein (a) and malt extractivity (b) (average for vegetation seasons 2010–2012)

The argument in favour of applying malting barley in a crop rotation on irrigated arable land is also a distinct advantageous change in grain quality (Figure 1). Sprinkler irrigation (W_1 treatment) contributed to limiting protein increase in malt which is unfavourable from the technological point of view and results from rainfall shortages. The emergence of drought during the increased water needs of malting barley contributes to the deterioration of yields, both quantitatively and qualitatively. According to Bertholdsson (1999), this is due to its detrimental effect on the uptake of nitrogen compounds from the soil and the protein content of the grain. Drought in the vegetative growth phase causes limited nitrogen uptake and reduces the potential yield of grain. If it occurs in the generative development phase, it limits the synthesis of carbohydrates and the accumulation of dry matter in the cassava. Pre-maturation of the grain then reduces yield and increases protein content. It concerns, however, only the rate of nitrogen fertilization of 30 kg·ha^{-1}. Sprinkler irrigation only slightly limits increase of protein content in grain but does not eliminate the negative effect of increased amount of nitrogen fertilization. Therefore, sprinkler irrigation cannot be treated as a counteraction for typical effects of excessive nitrogen fertilization of the malting barley plant.

The increase of protein content in malt almost automatically translates into decreased malt extractivity. It is illustrated by the results in Figure 1, which prove that the relation between protein content in malt and its extractivity is shaped similarly both in the treatments with sprinkler irrigation of barley plants and in the not irrigated ones. According to opinions of Pecio (2002) and Liszewski *et al.* (2011), protein content in barley grain constitutes the most important quality indicator, showing the usefulness of raw material for brewing purposes. It shows important correlation with many technological features of malt and wort that make up together a synthetic evaluation of malting usefulness of barley grain.

Simplified mashing efficiency is a forecasting factor of the brewing capacity on the basis of the volume of the wort and the wort extract content (Szwed *et al.* 2014). Mashing efficiency is a basic parameter of practical evaluation of processing value of Pilsen type malt (Kunze 1999). It is calculated from the following formulae:

$$uW = B \cdot 10 \cdot (V_k / V_{max})$$

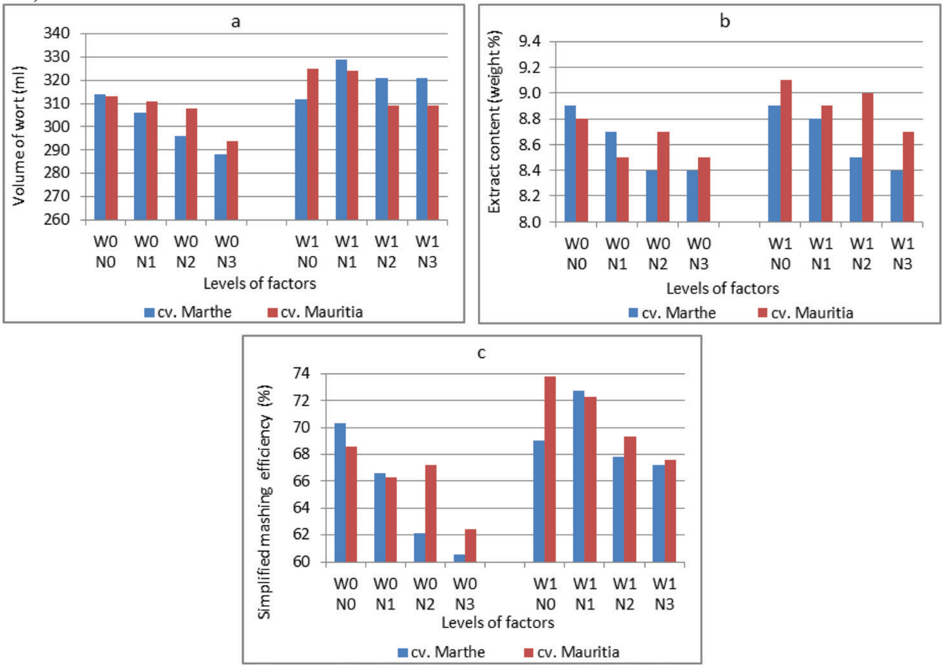
where:

uW – simplified mashing efficiency,

B – extract content of wort [% w/w],

V_k – final volume of wort,

V_{max} – maximal volume of wort – for congress method set to 400 ml (Szwed *et al.* 2014).



Source: own results and elaboration

Figure 2. Impact of nitrogen fertilization and sprinkler irrigation of malting barley plants on the volume of wort V_k (a), extract content B (b) and simplified mashing efficiency uW (c) (average for vegetation seasons 2010–2012)

Among many indicators used to assess the technological suitability of malt the Pilsen type, in this paper the simplified mashing efficiency was chosen that clearly allows for indication in what way lack of irrigation of malting barley plants (W_0 treatments) and sprinkler irrigation (W_1) influence the size of this parameter (Figure 2).

In the plan of the experiment four levels of nitrogen fertilization were tested: N_0, N_1, N_2 and N_3. They show clearly, that the application of limited fertilization to the plants of barley (N_0) (using natural soil richness in nitrogenous elements), and fertilization at N_1 level (dose of 30 kgN·ha^{-1}) in connection with sprinkler irrigation of barley cultivations ensure maximum values of simplified mashing efficiency exceeding 70% (Figure 2). Application of nitrogen fertilization at the rates N_2 (60 kgN·ha^{-1}) and N_3 (60 kgN·ha^{-1}pre-sowing and 30 kgN·ha^{-1} as main one) decreases the simplified brewhouse efficiency by at least 3–5% in the processing of malts obtained both from grains of irrigated and non-irrigated plants.

CONCLUSIONS

The results of the experiment carried out in the years 2010–2012 confirmed the hypothesis that as regards shaping of production and quality indicators, introduction of sprinkler irrigation into the process of malting barley cultivation is a desirable aim. It was found that nitrogen fertilization at the rate of 30 kg·ha^{-1} of irrigated cultivations of malting barley ensures (in relation to control non-irrigated treatments) best values as regards weight of crop of useful grain, protein content, extractivity of Pilsen type malt, amount of obtained wort and simplified mashing efficiency .

As the result of the conducted research, it was found that the effectiveness of obtaining higher crop of technical barley depends mainly on sprinkler irrigation of cultivations fertilized with nitrogen at the N_1 rate (30 kg·ha^{-1}). Application of nitrogen fertilization at the rates N_2 (60 kgN·ha^{-1}) and N_3 (60 kgN·ha^{-1} pre-sowing and 30 kgN·ha^{-1} as main one) reduces yield of non-irrigated technical barley (W_0) in a considerable way and to a lesser extent also of irrigated barley (W_1). Favourable impact of sprinkler irrigation on some selected features of grain of Pilsen type malt and wort was revealed in each analysed case – at all analysed levels of nitrogen fertilization, in each vegetation season and for both tested kinds. Evaluation of malting usefulness of barley grains showed that the quality of the raw material improved under the influence of the application of sprinkler irrigation and considerably deteriorated under the influence of nitrogen fertilization at the rates N_2 (60 kg·ha^{-1}) and N_3 (60 kg·ha^{-1} pre-sowing and 30 kg·ha^{-1} as principal one).

Potential application of sprinkler irrigation in the cultivation of quality kinds of malting barley will depend mostly on economic effectiveness of such enterprising, shaped by the crop value (price of good quality raw material), and on infrastructural circumstances, mainly on availability of water source for irrigations.

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