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TECHNOLOGICAL ASSESSMENT OF WINTER CULTIVAR OF COMMON WHEAT (*TRITICUM AESTIVUM* L.) AND WINTER BARLEY (*HORDEUM VULGARE* L.) FOR PALE MALT PRODUCTION

– Research paper –

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Abstract: The study was designed to assess technological quality of grains from two wheat cultivars (*Elixer* and *Rockefeller*), as well as one cultivar of winter (*Joy*) and one cultivar of spring barley (*Irina*), and to carry out the malting process at temperature of 15°C for 5 days. Malt analyses were carried out in accordance with the ECB Methods. The wheat malts were found with lower *Kolbach* index, and high viscosity was identified in wort obtained from wheat. The findings related to the wheat malts showed better quality parameters in *Elixer* variety compared to *Rockefeller* variety.*Elixer* wheat malt had higher diastatic power (427.03 WK) and lower extractivity (81.85%) compared to *Joy* barley malt (376.12 WK and 85.79%). Laboratory tests assessing the malts and wort showed that winter barley grain has high malting quality and can be used without modifications in the malting and mashing processes in brewing industry. It is necessary to conduct further research focusing on cultivation, agricultural techniques and technologies applied in wheat farming, in order to obtain cultivars which can be used to produce high quality malts.

Keywords: winter barley, wheat malt, malting loss, *Kolbach* index, extract potential, diastatic power

INTRODUCTION

In recent years there has been growing interest in production of beer from other raw materials than spring barley. In order to obtain high quality malt, it is necessary to select appropriate variety and cultivar of the raw material and to modify the technological process of malting, in order to obtain good physicochemical and sensory properties of the beer produced (Szwed et al., 2009).

Common wheat *(Triticum aestivum L.),* after maize, is the second most commonly grown cereal crop worldwide (FAOSTAT 2017). Wheat grain is mainly processed for the needs of milling and baking industries. It is generally characterized by higher total contents of protein compared to barley grain. Progress in wheat cultivation leads to production of high-protein varieties intended mainly for production of flour; these, however, are not used in production of wheat malt. Grain of winter wheat has lower contents of total proteins, hence the malt made from it is characterised by higher extract potential and can be used to obtain a product meeting high requirement of consumers (Boros et al., 2014). During the malting process, wheat grain proteins are partly or completely hydrolysed by proteolytic enzymes (Xie et al., 2014). Nitrogen compounds contained in wheat and barley grain significantly influence the processes of mashing and fermentation. They determine the quality and stability of beer foam, as well as the contents of higher alcohols and other substances which are responsible for the flavour and taste of beer (Szwed et al., 2009). The content of wheat malt used in production of wheat beer ranges from 50 to 60% (Kunze, 2010). By extending the duration of wheat grain germination it is possible to obtain good quality malts from wheat grains with high contents of protein (Jin et al., 2012). Wheat malt has higher content of non-starch polysaccharides, mainly arabinoxylans, contrary to barley malt in which β-glucans are the main non-starch polysaccharide (Boros et al., 2014).

Winter malting barley, particularly its two-row forms, in Poland is gaining attention of researchers, as well as malt and beer producers. As an advantage, the grain can be used immediately following the harvest (seed dormancy is not

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required), therefore malt-houses can work continuously even if seeds of spring barley have not achieved the optimum germination energy. Compared to spring varieties of malting barley, the winter varieties produce higher yield from 1 ha. Additionally, they can be harvested earlier, as a result of which it is possible to apply optimum schedules for field works (sowing of catch crops, soil cultivation prior to the sowing of winter cultivars, e.g. of rapeseed) (Hłasko-Nasalska et al., 2012; Leszczyńska and Patkowski, 2016; Leszczyńska and Noworolnik, 2017).The drawbacks of winter barley include its relatively poor frost tolerance and high sensitivity to soil conditions (Leszczyńska and Patkowski, 2016; Leszczyńska and Noworolnik, 2017).

The quality of malting barley depends on the cultivar used, and on the weather and soil conditions throughout the vegetation period. By applying adequate doses of soil amendments, particularly nitrogen fertilizers, plant growth regulators as well as fungicidal protection, and by providing the plants with micro-elements and macro-elements, it is possible to achieve high yield of good quality (Chrzanowska-Drożdż and Kaczmarek, 2007). Adequate dose of potassium and phosphorus beneficially affects the plants and their resistance to diseases, as well as the structure and size of winter barley caryopsis (Shala et al., 2013).

Spring varieties of barley are preferred by malt-houses because of their higher extract potential, and greater grain density and weight per 1,000 grains (Hłasko-Nasalska et al., 2012). The seeds are larger, and they absorb water and germinate in a uniform manner. The processes of major importance in beer making include malting of grains, and mashing of malted grains. Seed germination is to activate hydrolytic enzymes, mainly α-amylase, β-amylase and α-glucosidase, which during the mashing process convert starch into reducing sugars (Farzeneh et al., 2017; Yu et al., 2019). The economics of beer making, as well as the flavour, taste and quality of the beer, largely depend on the choice of adequate raw material and on the conditions in which the above processes are conducted.

The purpose of the study is to subject two winter varieties of wheat and one winter variety of barley to a malting process, and then to assess the quality of the obtained malts and wort, and to compare their parameters to those of the malt obtained from spring barley, and finally to calculate malting loss naturally occurring during grain malting process.

MATERIAL AND METHODS

Material

The study investigated samples of winter barley grains of *Joy* variety, and spring barley of *Irina* variety, as well as winter wheat of *Elixer* variety, supplied to *Farming Cooperative SAN* in Głuchów in 2019. The measurements also took into account grain of winter wheat of *Rockefeller* variety, from *KWS SAAT SE & Co*.

Technological analyses of wheat and barley grain

The technological assessment of the grains was performed in the laboratories at the Farming Cooperative SAN in Głuchów, in accordance with the recommendations of the *European Beer Convention (EBC)* and *Polish Standards (PKN).* The barley and wheat grains were subjected to organoleptic assessment and were examined for moisture contents, protein and starch contents, as well as grain size uniformity, germinative energy, germination rate as well as weight per 1,000 grains.

Sensory evaluation involved visual examination of the grain appearance, and colour and odour of the grains selected for analyses. Moisture was measured with GAC 2500–INTL grain moisture tester from DICKEY-john. Protein content (nitrogen content in the grain multiplied by the coefficient 5.7 for wheat and 6.25 for barley) was examined by spectrometry using Omega – Omeg Analyzer Grain. Grain size uniformity was determined using SŻK series mechanical sorting device manufactured by Sadkiewicz Company. Subsequently, representative samples were selected from the entire batches of winter and spring barley and two winter wheat varieties, and these were subjected to further examinations.

In order to determine germinative energy and germination rate of the grains, 100 seeds were picked from each sample (3 x 100 seeds), and subjected to germination process, following Aubry Method (3.6.1. EBC Method).

Malt preparation

Further measurements were carried out in the laboratory of the Department of Agricultural and Food Engineering at the University of Rzeszow. Representative samples of the material were purified using *Vögel* sieve, subsequently grain fraction >2.5 mm (samples 700 g each) was selected for the experiment.

Barley grains
The grains were spread on metal germination plates covered with filter paper, and they were soaked to achieve moisture level of 45% (by spraying tap water at 15ºC±1°C, from atomizer, twice a day with 12-hour intervals). Plates with the samples were placed in climate cabinet, at relative air humidity of 90% and temperature of 15°C±1°C. Following the defined germination time, the material was dried in a laboratory dryer for the duration of: 15h – 40°C, 3h – 50°C, 3h – 65°C, and 2h – 80°C, and subsequently the rootlets were removed.

Wheat grains
The grains were spread on metal germination plates covered with filter paper, and they were soaked to achieve moisture level of 45% (by spraying tap water at 15ºC±1°C, from atomizer, twice a day with 12-hour intervals). Plates with the samples were placed in climate cabinet, at relative air humidity of 90% and temperature of 15°C±1°C. Following the defined germination time, the material was dried in a laboratory dryer for the duration of: 15h – 40°C, 3h – 50°C, 3h – 65°C, and 2h – 80°C, and subsequently the rootlets were removed.

Analysis of the malts and worts
The malts were ground into flour (2 mm) in a Cemotec disc mill from FOSS and analysed for: protein content *Kjeldahl* Method (4.3.1 EBC Method), moisture (4.2 EBC Method), and then the material was subjected to mashing in accordance with 4.5.1 EBC Method (Analytica EBC, 2004).
The laboratory wort, obtained as a result of mashing, was examined for the content of extract in the dry malt mass, runoff time, viscosity of the wort, and its pH according to 4.6.1 EBC Method. The content of soluble protein was measured (EBC Method 4.9.1) and based on that, *Kolbach* index was calculated. Diastatic power of the malt was measured in accordance with 4.12.1 EBC Method. The degree of final fermentation was determined in accordance with 4.11.1 EBC Method and the contents of β-glucans were examined using enzymatic method (*Megazyme* Test, K-BGLU; 8.13.1. EBC Method).
The polarimetric method was applied to measure the contents of starch in the barley and wheat grains, and the malts produced from them, while *Luff-Schoorl* method was used to determine the contents of reducing sugars in the wort.

Statistical analysis
All the described analyses were carried out in three parallel replications. The results were computed using Statistica 13.3 software. To interpret the results, Pearson's linear correlation coefficients were used, at a significance level $\alpha = 0.05$, in order to identify the relationship between the selected malting process features, and the specific qualitative components of the malt and wort.

RESULTS AND DISCUSSION

Quality of material subjected to malting
Water contents in the grains designated for the malting process were consistent with the norms (PN-A-79083-5:1998) and ranged from 11.9±0.10% (winter barley of *Joy* variety) to 13.9±0,10% (winter wheat of *Elixer* variety, Table 1). Low water contents in grains subjected to malting are adverse because soaking of very dry grains leads to greater stress, which then is increased during the drying process, resulting in transversal cracking of endosperm, and that adversely affects the quality of the material (Woźniak, 2004; Woźniak and Grundas, 2006).
Fine quality malt is obtained from barley grains with total protein contents in the range of 9.5 – 11.5% d.m. (Liszewski et al., 2011). Low protein content in the grain subjected to malting results in insufficient quantity of nitrogen compounds required for brewing yeast metabolism. Due to the impaired metabolic process, sugars contained in the grain are not processed by yeast optimally into ethyl alcohol, which leads to losses in the yield of beer obtained and a decrease in its quality. In the case of protein contents exceeding the norms, the malting process is associated with more difficult ‘loosening’ of the grains, which leads to lower extract yield and subsequently to haze formation and sediments occurring in beer held in storage. Barley grains of *Irina* and *Joy* varieties were found with normative total protein contents, while grains of winter wheat of *Elixer* and *Reckefeller* varieties had slightly higher contents.
Grain size uniformity is one of the most important technological characteristics of raw material designated for malting. Brewing barley should be characterised by grain size uniformity of 90% or more (Liszewski et al., 2011). Such grain is healthy, has good contents of reserve substances and it uniformly absorbs water with its entire bulk, as a result of which it germinates evenly and uniformly dehydrates during a drying process; this leads to optimum loss of caryopsis weight and to

high quality of the malt obtained. Grain size uniformity in winter barley was at the level of 84.0±0.27%, and in spring barley was slightly higher, amounting to 88.5±0.33%. The decrease in this parameter in the barley varieties was associated with unskilfully performed threshing as a result of which some grains were damaged (crushed grains) and disregarded. The requirements of the Polish malt-house related to wheat grain size uniformity are slightly lower, compared to barley grain, amounting to 85.0%. The measurements of wheat grains showed lower size uniformity, more specifically 81.0±0.21% in *Elixer* and 77.2±0.12% in *Rockefeller* variety (Table 1). The material delivered to a malt-house is purified, whereby the fraction of contaminants is discarded which leads to increased size uniformity of the caryopses designated for malting.

Germinative energy in the case of material subjected to malting should not be lower than 95%. Low value of this parameter may result in lack of uniform germination of the seeds, which is linked with poorer extract yield and diastatic power of the malt, leading to longer duration of mashing. Seed germination is a highly complex process where chemical composition of the grain is modified by the action of hydrolytic, proteolytic and other enzymes, leading to changes desirable from the viewpoint of beer-making (Schmitt et al., 2013; Kleiwächter et al., 2014). The findings showed germinative energy of spring barley of *Irina* variety and winter barley of *Joy* variety amounting to 94%, and 95%, respectively. Germinative energy of winter wheat seeds was similar to that observed in the barley, and amounted to 94% and 93% for *Elixer* and *Rockefeller* varieties, respectively (Table 1). Mechanical damage, which occurs during threshing, leads to decrease in germination rates, resulting from damage to embryos. During storage, there is greater likelihood of microbial growth in damaged material, leading to further qualitative deterioration of the grains (Szmigiel et al., 2014).

Malting loss

As a result of the malting process conducted, the wheat and barley grains achieved final moisture level of 45% in 5 days. The optimum moisture was monitored through measuring water absorption by the caryopsis in the processes of soaking and germination. By applying an adequate drying program, it was possible to obtain final moisture of the wheat and barley malts in the range of 3.4 – 4.5% (Table 2), which enables longer storage of the malt. The recommended water contents in wheat and barley malts should be in the range of 4.5 – 5.0% (Faltermaier et al., 2014).

Total malting loss is defined as a decrease in the weight of grain subjected to malting. Mean loss naturally occurring in wheat grain amounted to 3.57±0.10% d.m. in *Elixer* variety, where 60% of the total loss was accounted for root weight. In the malting process, grain of *Rockefeller* variety was found with slightly lower total loss amounting to 3.3±0.11% d.m., whereby weight loss due to changes occurring in the caryopsis accounted for 37.6% of the total loss. In winter and spring barley grains the total loss was much higher, amounting to 10.87±0.22% d.m. and 12.80±0.17% in *Joy* and *Irina* varieties, respectively (Table 2). A study (Błażewicz et al., 2010) reported findings related to 5-day barley malt, with a total loss amounting to 8.71% d.m. in a planting experiment and to 11.24% d.m. in a fertilizer experiment. According to the same team of researchers, overall loss of weight in the process of barley malting should be in the range of 12 - 14%, loss of root weight 3 - 4%, and loss of caryopsis weight should range from 4 to 8%. Root weight in the obtained barley malts was over one per cent higher than the recommended norms. The remaining percent losses were in line with the norms. A study investigating spring barley of *Irina* variety (Gorzelany et al. 2019) showed mean total loss at a similar level (12.62% d.m.), mean root weight loss in line with the norm (3.39% d.m.), and mean loss of grain weight slightly higher (9.16% d.m.). A decrease in the temperature of the malting process (from 20±1°C to 15±1°C) affected the changes in the weight of spring barley grain subjected to malting. Review of the related literature showed no evidence pertaining to the effects of malting process in loss of wheat grain weight. .Quality determinants in the obtained malts and wort are presented in Table 3.

Changes in protein content resulting from malting process

The physicochemical and technological parameters of malt characterization include total protein content, soluble protein content, *Kolbach* index, starch content, diastatic power of the malt, extract potential, viscosity, pH, saccharification time and wort runoff time. Additionally, the wort was examined for the contents of reducing sugars equivalent to glucose and contents of β-glucans.

Table 1. Mean values of quality parameters in the grains of winter and spring barley as well as winter wheat

	Winter wheat *Elixer* variety	Winter wheat *Rockefeller* variety	Winter barley *Joy* variety	Spring barley *Irina* variety
Moisture [%]±SD	13.9±0.10	12.4±0.14	11.9±0.10	12.4±0.10
Total protein[% d.m.]±SD	11.9±0.20	11.6±0.30	11.3±0.10	11.2±0.20
Starch content[% d.m.]±SD	61.4±0.40	62.2±0.30	56.2±0.22	57.1±0.32
Grain size uniformity [%]±SD	81.0±0.21	77.2±0.12	84.0±0.27	88.5±0.33
Germinative energy after 72 hours [%]±SD	94.0±0.00	93.0±1.00	95.0±0.60	94.0±0.40
Germination rate after 120 hours [%]±SD	95.0±1.00	94.0±0.20	96.0±0.10	95.0±0.80

Table 2. The effect of the malting process in 1000-grain weight (TGW), moisture and natural loss in the malts

	Winter wheat *Elixer* variety	Winter wheat *Rockefeller* variety	Winter barley *Joy* variety	Spring barley *Irina* variety
Mean TGW for grain[g d.m.]±SD	39.10±0.26	38.60±0.33	41.60±0.13	46.20±0.37
Mean TGW for malt[g d.m.]±SD	37.80±0.15	36.00±0.11	39.80±0.26	41.70±0.10
Total loss [% d.m.]±SD	3.57±0.10	3.30±0.11	10.87±0.22	12.80±0.17
Weight loss - roots [% d.m.]±SD	2.14±0.22	2.06±0.27	5.31±0.35	5.20±0.44
Weight loss – grains[% d.m.]±SD	1.43±0.37	1.24±0.50	5.56±0.66	7.60±0.54
Grain moisture before drying [%]±SD	45.00±0.10	45.00±0.10	45.00±0.10	45.00±0.10
Grain moisture after drying [%]±SD	3.40±0.10	4.10±0.20	4.50±0.13	4.20±0.08

Table 3. Mean values of quality parameters in the malts and wort from grains of winter and spring barley as well as winter wheat

Malt samples	Winter wheat *Elixer* variety	Winter wheat *Rockefeller* variety	Winter barley *Joy* variety	Spring barley *Irina* variety
Moisture [%]	3.40±0.10	4.10±0.20	4.50±0.13	4.20±0.08
Total protein in malt [% d.m.]	11.60±0.21	11.20±0.18	10.70±0.25	10.90±0.11
Soluble protein in malt [% d.m.]	3.83±0.54	3.72±0.24	3.91±0.38	3.97±0.32
Kolbach Index [%]	33.01±1.22	33.21±0.89	35.87±0.76	37.10±1.02
Diastatic power in WK	427.03±4.21	422.34±4.02	376.12±2.87	357.41±3.73
Starch content in malt [% d.m.]	55.70±0.32	55.20±0.19	55.10±0.38	55.10±0.21
Extract potential of malt (2mm) [% d.m.]	81.85±0.17	81.71±0.21	85.79±0.33	86.38±0.14
pH	5.75±0.10	5.87±0.10	5.60±0.10	5.56±0.10
Saccharification time [min.]	10-15±1.00	10-15±1.00	10-15±1.00	10-15±1.00
Wort runoff [min.]	45±1.00	75±1.00	45±1.00	60±1.00
Wort viscosity[mPa*s]	2.65±0.58	2.71±0.76	1.73±0.61	1.68±0.42
Contents of β-glucans[mg*dm^{-3}]	86±1.00	68±1.00	513±1.00	456±1.00
Reduction sugars (glucose) [%]	1.10±0.39	1.34±0.21	1.73±0.33	1.55±0.16
Final attenuation [%]	82.24±0.89	79.79±0.72	81.76±0.45	82.80±0.67

Total protein content in grains designated for malting is strictly defined because it is necessary to provide beer yeast with adequate amount of nitrogen compounds required for metabolism, to enable optimum production of ethyl alcohol. Excessively high protein content in malt leads to decreased extract potential – reduced effectiveness of the brewing process and possible haze formation and sediments occurring in beer held in storage. During the malting process, storage proteins with high molecular mass, mainly glutenin and gliadin, are subjected to proteolysis in order to obtain low-molecular-mass proteins and amino acids (Guo et. al., 2019). The optimum recommended total protein content in wheat malts is in the range of 11.0-13.0% d.m. and in barley malts is 9.50-10.50% d.m.(Falternaier et al., 2014). The current findings related to wheat malts show total protein content amounting to 11.60±0.21% d.m. in *Elixer* and 11.20±0.18% d.m. (Table 3) in *Rockefeller* varieties. Another study (Boros et al., 2014) reported malts from winter wheat amounting to 14.80% d.m., while study (Weiner et al., 2008) showed mean total protein contents at the level of 13.28% d.m. The present findings related to barley malts showed total protein content of 10.90±0.11% d.m. in the malt produced from spring barley *Irina* and 10.70±0.25% d.m.in malt from winter barley *Joy*. Another study (Gorzelany et al., 2019), carried out one year earlier, assessed malts from *Irina* barley and showed total protein content of 10.87% d.m. – the mean protein content in the malts did not differ in the relevant years. Fine quality malt is characterised by total protein contents up to 10.8% and protein loss up to 0.5% relative to its amount in barley grains (Kunze, 2010). Sensory properties of beer are impacted by soluble proteins, which in the mashing process pass into the wort. The contents of soluble proteins in the malts in question were in the range of 3.72 – 3.97% d.m. (Table 3). The malts obtained met the requirements related to soluble protein contents, which should be in the range of 3.4 – 4.7% d.m.(Michałowska, 2017).

Protein content losses during malting process are unavoidable due to the modifications mediated by proteolytic enzymes and connected with stimulation of the embryo to develop into a new plant, and to produce radicles accounting for approximately 3-4% of the dry mass content (Błażewicz et al., 2013). The wheat malts investigated in the study were found with protein loss of 0.30% and 0.40% in *Elixer* and *Rockefeller* varieties, respectively. Studies (Boros et al., 2014) assessing malts from winter wheat reported mean loss of 0.59%, and 1.22% (Weiner et al., 2008). The findings related to barley malts showed protein loss in *Joy* variety amounting to 0.50%, and in *Irina* variety to 0.30%. It is recommended that protein loss during barley malting should not be higher than 0.3 – 0.5% (Szwed et al., 2009). The parameter of *Kolbach* index is applied to determine the quantity of protein substances contained in malt and extracted into wort during the mashing process, which reflects high degree of proteolytic modification. *Kolbach* index depends on the contents of proteins in cereal grains subjected to malting as well as on the amount of soluble protein. Malts delivered to breweries most commonly have *Kolbach* index in the range of 38 – 45% (Michałowska, 2017). Studies investigating wheat malts reported *Kolbach* index of 33% (Li et al., 2017) as well as 31.4 – 45.5% (Jin et al., 2012). The current findings show *Kolbach* index for wheat malts amounting to 33.01±1.22% in the case of *Elixer*, and 33.21±0.89% (Table 3) in *Rockefeller* varieties. The relevant parameter was found to assume higher values in the barley malts; *Kolbach* index in *Joy* variety amounted to 35.87±0.76% while the malt from spring barley *Irina* was characterised by *Kolbach* index of 37.10±1,02% (Table 3). Excessively low value of *Kolbach* index reflects poor activity of proteolytic enzymes. Malts recommended for use in production of Pilsner and lager type beer should have *Kolbach* index in the range of 33-37%, while infusion mashing requires malts with slightly higher *Kolbach* index (38 – 42%). Excessive degree of proteolytic modification of the malt (over 45%) may be beneficial only in production of low-alcohol beer but it may also be associated with deterioration of sensory properties of the beer produced (poor stability of beer foam) (Szwed et al., 2009).

Extract potential of the obtained malts

Extract potential of malt is one of the most important quality parameters reflecting effectiveness of the malting process as it represents the amount of substances which in the mashing process pass into the wort. Based on that brewers select parameters of the process, the amount of row material in order to achieve adequate effectiveness of the brewhouse (Gorzelany et al., 2019). Extract yield depends on the chemical composition of the grain and on the hydrolysing activity of the enzymes (Boros et al., 2014). The higher the extract potential of malt the richer the flavour of the beer produced. Fine quality wheat and barley malts should be characterised by extract potential exceeding 83%, and 81%, respectively (Faltermaier et al., 2014). Mean extract yield of wheat malts was reported to total at 83.4% (Boros et al., 2014), 79.3 – 82.3% (Jin et al., 2012), or range from 75% to 86.9% (Depraetere et al., 2004); and in the case of barley malt was found at a level of 81.0% and 80.9% (Li et al., 2017). The current findings showed extract content in the wheat malts to amount to 81.85±0.17% in *Elixer* variety and to 81.71±0.21% in *Rockefeller* variety. Extract potential of barley was slightly higher, amounting to 85.79±0.33% and 86.38±0.14% in *Joy* and *Irina* variety, respectively (Table 3). The study carried out during the previous year showed mean extract potential of malt from *Irina* variety amounting to 81.15% (Gorzelany et al., 2019). The results obtained in the case of wheat malts showed slightly lower extract potential, compared to both the barley malts and brewing industry recommendations. The degree of final fermentation in the relevant wheat wort was found at 82.24±0.89% in *Elixer* and 79.79±0.72% in *Rockefeller* varieties, while the corresponding value for the barley wort was identified at 81.76±0.45% in *Joy* and 82.80±0.67% in *Irina* variety (Table 3). Final attenuation in the case of malts from winter varieties of wheat were reported at the level of 82.90% (Boros et al., 2014).

Activity of hydrolytic enzymes

Diastatic power is a parameter describing activity of hydrolytic enzymes which decompose starch into various glucose oligomers. This activity is expressed in Windlich-Kolbach degrees (Boros et al., 2014). Malts with low activity are characterised with high contents of non-hydrolysed starch and beer obtained from it is found with low degree of final fermentation (Gorzelany et al., 2019). The present study showed high diastatic power in the wheat malts, amounting to 427.03±4.21WK in *Elixer* and 422.34±4.20WK in *Rockefeller* variety. The barley malts showed slightly lower enzymatic activity, i.e. 376.12±2.87WK in *Joy* and 357.41±3.73WK in *Irina* variety (Table 3). Other researchers obtained wheat malts with diastatic power of 369 WK (Li et al., 2017), in the range of 384 – 496 WK (Jin et al., 2012) and 286 WK (Weiner et al., 2008), while barley malts were reported to show activity of 339 WK (Li et al., 2017) and 242 WK (Weiner et al., 2008). Barley malt from *Irina* variety, obtained in 2018, was characterised by mean diastatic power of 236 WK (Gorzelany et al., 2019). Saccharification time for all the malts investigated amounted to10-15 min.

Activity of enzymes converting the substances contained in malt depends on pH value. The wheat malts examined were found with higher pH (5.75±0.10 in *Elixer* and 5.87±0.10 in *Rockefeller* variety) compared to the barley malts (5.60±0.10 in the winter variety *Joy* and 5.56±0.10 in the spring variety *Irina*, Table 3). Decrease in pH to a level below 5.6 (preferably 5.2 – 5.3), owing to the optimum conditions for activity of amylolytic and proteolytic enzymes, results in higher extract potential, lower viscosity of the wort, and ultimately better quality of the beer (Pater et al., 2019; Nowak et al., 2009). Increase in pH of the wort occurs with a decrease in the diameter of particles used in mashing of malt, which simultaneously leads to increase in extract potential of the malt (Natoniewski et al., 2018). The method of mashing applied in this case did not include correction of pH.

Factors affecting wort viscosity

Wort viscosity is associated with effectiveness of amylolytic and cytolytic enzyme activity. Increase in viscosity is related to non-starch polysaccharides contained in wheat or barley malt, mainly arabinoxylans and β-glucans in soluble forms, which pass into wort during mashing and as a result adversely affect the processes of wort filtration and runoff, and ultimately negatively impact extract potential of the malt. High viscosity of wort used in production of beer may result in sediment appearing in such beer during storage. Emergence of aggregates of long arabinoxylan chains (complexes) is largely related to the process of mashing – the use of high temperature in the process, followed by rapid cooling of the wort (Szwajgier and Targoński, 2005). The current findings related to the wheat malts show viscosity of 2.65±0.58 mPa*s in the wort produced from *Elixer* wheat and 2.71±0.76 mPa*s in the wort from *Rockefeller* wheat (Table 3). Mean viscosity reported for wort from winter wheat amounted to 1.79 mPa*s (Boros et al., 2014). Higher viscosity of wheat malts may suggest insufficient cytolysis of the malt. The parameter of viscosity in the investigated barley wort was slightly lower, and in *Joy* and *Irina* varieties amounted to 1.73±0.61 mPa*s, and 1.68±0.42 mPa*s, respectively (Table 3). In 2018 barley wort from *Irina* variety was found with mean viscosity of 1.76 mPa*s (Gorzelany et al. 2019). The value of viscosity in wheat wort should be lower than 1.80 mPa*s, and in barley wort should be higher than 1.56 mPa*s (Faltermaier et al., 2014).

Wort runoff time reflects the rate with which a specific amount of wort is filtered. The wort produced from the winter wheat variety *Elixer* and the winter barley variety *Joy* was found with the fastest runoff rate of 45 min. The wort from the spring barley variety *Irina* was filtered in 60 min. The longest runoff time was identified in the case of the wort from *Rockefeller* wheat. Wort runoff time is correlated to the parameter of wort viscosity. This is associated with the non-starch polysaccharides (arabinoxylans, β-glucans and other) occurring in congress wort. In wheat wort the contents of β-glucans were low (86±1.00 mg*dm^{-3}in wheat wort of *Elixer* variety, and 68±1.00 mg*dm^{-3} in wheat wort of *Rockefeller* variety). This is linked with the chemical composition of wheat grains, and much lower contents of β-glucans, while the non-starch polysaccharides responsible for increase in wort viscosity are arabinoxylans. The barley wort examined in the present study was found with much higher contents of β-glucans, amounting to 513±1.00 mg*dm^{-3} and 456±1.00 mg*dm^{-3} in *Joy* and *Irina* varieties, respectively (Table 3). These values were more than twice as high as the norms of up to 200 mg*dm^{-3} recommended by breweries. Each stage in beer making (from production of grain, through malting, mashing, brewing and storage) may affect the content of β-glucans (Czarnecki et al., 2004).

Changes in starch content in the malting process

The content of starch in grain designated for malting, as well as the ratio of amylopectin and amylose contents, are important for obtaining high extract yield in the malt. There were no significant differences in starch contents in the malts investigated. The highest loss of starch weight was found in the wheat malt of *Rockefeller* variety, and amounted to 7%. The lowest loss of starch content (1.1%) was identified in barley malt of *Joy* variety. Loss in starch weight is associated with activity of hydrolytic enzymes converting starch into simple sugars, which in the fermentation process are transformed into ethanol by beer yeast (Jin et al., 2011). The contents of reducing sugars equivalent to glucose were identified as follows: in *Elixer* variety – 1.10±0.39%, in *Rockefeller* – 1.34±0.21%, and slightly higher in barley malts, i.e. *Joy* variety – 1.73±0.33% and *Irina* variety – 1.55±0.16% (Table 3). In another study, the contents of reducing sugars in wort from wheat malt amounted to 4.13%, and in barley malt was found at the level of 5.47% (Weiner et al., 2008).

Relationships between the quality characteristics of the malts

The computed Pearson's linear correlation coefficient (Table 4) show very high, statistically significant relationship between total protein and soluble protein contents in the *Elixer* wheat malt. There is a high, negative correlation between the degree of final fermentation in wheat wort and wort viscosity, which means that higher viscosity will adversely affect the process of fermentation by beer yeast. *Kolbach* index in both wheat malts and barley malts is negatively correlated to viscosity of the obtained wort. A study (Jin et al., 2012) reported significant, positive correlation between *Kolbach* index and extract yield of malts. It was also shown (Xie et al., 2014) that soluble protein content in malts was significantly positively correlated to diastatic power, extract potential of malt, and *Kolbach* index and negatively correlated to viscosity of the wort produced.

The current findings related to *Joy* barley malt (Table 5) show very high, positive correlation between the content of soluble protein and extract potential of the malt. There were also statistically significant relationships of extract potential of malt and *Kolbach* index to degree of final fermentation, as well as negative relationships between total protein content in malt and viscosity of barley wort.

Table 4. Correlation coefficients for the variables in the *Elixer* wheat malt and wort at a significance level of $p < 0.05$

Variable	Total protein	Soluble protein	*Kolbach* index	Diastatic power	Extract potential	Viscosity
Soluble protein	**0.999703***					
Kolbach index	0.975158	0.980270				
Diastatic power	0.986241	0.989980	**-0.998359***			
Extract potential	0.917663	0.907699	0.806847	0.839349		
Viscosity	-0.960769	-0.967247	**-0.998337***	-0.993399	-0.771454	
Final attenuation	0.944350	0.952092	0.993755	0.985735	0.735887	**-0.998534***

* - statistically significant relationship (Pearson coefficient)

Table 5. Correlation coefficients for the variables in the *Joy* barley malt and wort at a significance level of $p<0.05$

Variable	Total protein	Soluble protein	Kolbach index	Diastatic power	Extract potential	Viscosity
Soluble protein	0.981981					
Kolbach index	0.910105	0.972015				
Diastatic power	0.930062	-0.843871	-0.694211			
Extract potential	0.986444	**0.999680***	0.965766	0.857164		
Viscosity	-0.993399	-0.953821	-0.856565	0.966067	-0.961109	
Final attenuation	0.954919	0.993814	0.992091	0.779065	0.990690	-0.914563

* - statistically significant relationship (Pearson coefficient)

CONCLUSION

Choice of appropriate variety of wheat and barley is every important to ensure fine quality of the malt produced. An experimental study taking into account varieties of spring barley (*Irina*) and winter barley (*Joy*) allowed to obtain good quality malts which can widely be used in brewing industry. Pilsner malt from the winter barley variety was characterised by slightly lower *Kolbach* index (35.87%), which may be associated with the specific variety-related properties, as the remaining quality parameters were good. The contents of β-glucans were at a very high level (513 mg*dm^{-3}), while viscosity and runoff time of the wort were acceptable. Winter barley grain of *Joy* variety is of good malting quality and may be used in the malting and mashing processes in brew houses.

The findings related to the wheat malts showed better quality parameters in *Elixer* variety compared to *Rockefeller* variety. The relatively long runoff time combined with high viscosity of the wort shows that grain of *Rockefeller* wheat contains high quantities of substances (the content of β-glucans is relatively low – 68 mg*dm^{-3}), which contribute to poorer quality of the malt produced. Wheat malts with *Kolbach* index of approximately 33% may be used in production of lager. It is possible to increase the value of *Kolbach* index in the relevant wheat varieties by modifying the technology of the malting process (increasing the temperature of the malting process from 15°C to 16°C). Congress wort from malt obtained from *Elixer* wheat was found with high level of viscosity (2.65 mPa*s), that however did not negatively affect the speed with which the mash was filtered. Although the process applied in wheat grain malting (5 days, temperature of 15°C) met the expectations related to both total malting loss and good quality of the malt obtained, it would be justifiable to continue research in plant breeding and farming, focusing on cultivation technology, to enable production of winter wheat varieties which can be used in production of wheat malts and beers.

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