

## IMPACT OF NITROGEN FERTILISER APPLICATION ON THE GRAIN QUALITY OF SELECTED WINTER WHEAT CULTIVARS USED FOR MALT PRODUCTION

– Research paper –

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**Abstract:** The nitrogen fertilisation used and the wheat cultivar significantly affect grain quality, determining its suitability for use in malting and brewing. Nitrogen fertilisation at a dose of 60 and 80 kg N·ha<sup>-1</sup> used in 3-year field experiments had a positive effect on total protein content (10.6% dry matter and 11.2% dry matter, respectively), grain uniformity (84.8% and 85.9%, respectively) and germination capacity (94.8% and 95.1%, respectively). The average grain moisture content at harvest was 13.8%, while the bulk density of the grain was 68.4 kg·hl<sup>-1</sup>. In canopy experiments, the average total protein content in wheat grain was 12.18% dry matter, germination capacity was 92.75%, and average grain uniformity was 75.45%. Based on the results obtained in field and canopy experiments, a nitrogen fertiliser dose of 60 and 80 kg N·ha<sup>-1</sup> and the Elixer, Gimantis and Rockefeller varieties are recommended for the production of winter wheat for malting and brewing purposes.

**Keywords:** nitrogen, wheat cultivar, grain quality, uniformity, protein content, malt, wheat beer

### INTRODUCTION

Unlike malting barley, whose quality requirements for grain and malt have already been extensively researched and described in the literature, wheat grain and the malt obtained from it do not have developed and approved analytical methods for determining their brewing value (Faltermaier et al., 2014; Depaetere et al., 2004). In order to determine the technological properties of wheat grain and malt, the methodology adopted for barley is most often used, with reference to the few scientific studies available and the quality requirements (specifications) developed in malt houses and breweries.

Winter forms of common wheat are most often selected for the production of wheat malt because they have a higher extract and lower total protein content in the grain compared to spring forms, and the beers produced are characterised by a lighter colour (Boros et al., 2014). Maltsters are generally more interested in soft wheat varieties with a mealy endosperm and a protein content of 11.0-11.5%

(Mascia et al., 2014; Depaetere et al. 2004). However, some brewers believe that hard wheat cultivars with a higher protein content in the grain (e.g. durum wheat) can also be successfully used for the production of malt and wheat beer. This is due to the increased turbidity (cloudiness) of beer associated with the high content of high molecular weight wheat proteins, e.g. glycoproteins, which also affect the stability of beer foam (Faltenmaier et al., 2014; Mascia et al., 2014; Depaetere et al., 2004). In Poland, malt houses generally require wheat grain to have a total protein content of 9.5-11.5% dry matter. Above-standard total protein content may reduce the extractivity of the malt obtained due to insufficient protein loosening (Jin et al., 2008). In addition, during the ageing of beer prepared from malt with an increased protein content, there may be an increased risk of excessive sedimentation and cloudiness (wheat beers are characterised by natural opalescence). On the other hand, too low a protein content in the grain intended for malting results in an insufficient amount of nitrogen compounds used for yeast metabolism, which will inefficiently convert the available sugars

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into ethyl alcohol, reducing the efficiency of the fermentation process (Boros et al., 2014).

Wheat grain uniformity is a parameter determining the quality and size of grains that undergo the malting process. Malting plants in Poland require wheat grains to have a minimum grain uniformity of 85%. This is related to the even absorption of water during malting, simultaneous germination (obtaining sprouts of the same size after a specified time), which results in optimal grain weight loss and even water release during the drying of high-quality malt. It is also important to clean the grain before malting, during which broken and damaged grains, grains of other cereals, or undersized grains (bran) are removed. In addition, useless impurities such as sand, soil, stones, parts of straw and other plants, and weed seeds are also separated, which at the same time increases the cost of malt production.

Energy and germination capacity indicate the vitality and physiological condition of the grain intended for malting. The determination is carried out at least six weeks after harvest, and the value should not be lower than 95% (Boros et al., 2014). Disturbances in energy and germination capacity may result from damage to the grain, e.g. during mechanical harvesting or as a result of microbial activity.

Other parameters determined for wheat grain are bulk density and thousand-grain weight (TGW). These parameters do not significantly affect the brewing value of wheat grain, but they can supplement the commodity assessment. Grain

density and TGW allow the size and quality of the grain to be determined, as well as the degree to which it is filled with reserve substances. The higher the value of these parameters, the more effective and uniform the processes of soaking, germination and drying of the malt (Gorzelany et al., 2019). It is important to remember to conduct an organoleptic assessment of the grain and determine its moisture content. Wheat grain, like other cereals, should be clean and ripe, of appropriate size and shape, and uniform in colour. The smell should be distinctive, typical and fresh. The water content in cereal grains determines how long the grain can be stored without changing its quality. Both excessively dry and wet wheat grains are undesirable as raw material for malting, as they hinder the malting process. When soaking excessively dry grain, there is an increased risk of transverse cracks in the endosperm due to the increase in tension generated during grain moistening, which is further reinforced during the drying process, leading to a reduction in the quality of the raw material (Woźniak and Grundas, 2006; Woźniak, 2004). Malting grain that is too moist (above 16%) results in malt of poorer quality and increased susceptibility to the growth of microorganisms.

The aim of the study was to determine the technological value of selected wheat cultivars obtained from three years of field experiments and two years of canopy experiments, depending on the level of nitrogen fertilisation used, in terms of their potential for use in the malting industry.

## MATERIAL i METHODS

### Research material and location

The research material used in the field experiments was certified seed of four winter wheat cultivars – Elixer, Lawina, Gimantis and Rockefeller. The field experiments were conducted during the 2020/2021, 2021/2022 and 2022/2023 growing seasons in Jelcz-Laskowice (51°21' N; 17°35' W), belonging to the Department of Herbology and Soil Cultivation Techniques of the IUNG-PIB, Wrocław. The canopy experiments were conducted on seven commercial farms during the 2020/2021 and 2021/2022 growing seasons in the districts of Rzeszów, Łańcut and Przeworsk in the Podkarpackie Province [location of farms in Belcar and Gorzelany (2024)].

### Field experiments conditions

Certified winter wheat seed was sown on 23 October 2020, 29 October 2021 and 28 October 2022 at a rate of 300 seeds·m<sup>-2</sup>. The area of each experimental plot was 11 m<sup>2</sup>. The soil pH and

content of basic chemical components before fertilisation are presented in Belcar and Gorzelany (2024). Experiments with selected wheat cultivars were conducted for four nitrogen fertilisation variants: no fertilisation (control), 40 kg N·ha<sup>-1</sup> (20 kg N·ha<sup>-1</sup> + 20 kg N·ha<sup>-1</sup>, variant I), 60 kg N·ha<sup>-1</sup> (30 kg N·ha<sup>-1</sup> + 20 kg N·ha<sup>-1</sup> + 10 kg N·ha<sup>-1</sup>, variant II) and 80 kg N·ha<sup>-1</sup> (40 kg N·ha<sup>-1</sup> + 20 kg N·ha<sup>-1</sup> + 10 kg N·ha<sup>-1</sup>, variant III). The nitrogen fertilisation variants were determined on the basis of preliminary studies conducted during the 2019/2020 growing season, the results of which were published in Belcar et al. (2021a). Mineral nitrogen fertilisation (ammonium nitrate 34% N Pulan) of winter wheat was carried out twice (for nitrogen fertilisation at a dose of 40 kg N·ha<sup>-1</sup>) in the BBCH 25–26 phase (beginning of spring vegetation) and the BBCH 32–34 phase (shooting), while for the remaining nitrogen fertilisation levels, it was carried out three times, including, in addition to the above development stages, nitrogen

fertilisation in the BBCH 28–30 stage, at the end of tillering. Wheat grain harvesting in subsequent years of the study was carried out at full harvest maturity (29.07.2021, 25.07.2022 and 16.08.2023).

#### **Conditions for conducting canopy experiments**

Certified seeds of selected winter wheat cultivars were sown in canopy experiments on 10 October 2020 and 9 October 2021 at a rate of 300 seeds·m<sup>-2</sup>. The area of each experimental plot averaged 1 hectare (class III soil). The soil pH and content of basic chemical components before fertilisation are presented in Belcar and Gorzelany (2024). One nitrogen fertilisation variant was used in the experiments: 60 kg N·ha<sup>-1</sup> (20 kg N·ha<sup>-1</sup> + 40 kg N·ha<sup>-1</sup>). Mineral nitrogen fertilisation (ammonium nitrate 34% N Pulan) of winter wheat was carried out twice in the BBCH 25–26 phase (beginning of spring vegetation) and the BBCH 32–34 phase (stem elongation). In subsequent years of the study, wheat was harvested at full grain maturity (13.08.2021 and 27.07. 2022).

#### **Determination of grain technological parameters**

The wheat grain obtained was subjected to a commodity assessment, which included the determination of:

- grain moisture content using the drying method based on the Polish Standard PN-EN ISO 712:2012,

- grain density in bulk using a manual grain densimeter in accordance with Polish Standard PN-EN ISO 7971-3:2019-03,
- grain uniformity (accuracy) using Stainecker-Vögle sieves, assuming as uniformity the percentage of the sample weight of grains remaining on sieves with a mesh size of 2.5 and 2.8 mm combined,
- energy and germination capacity in accordance with method 3.6.1 EBC (Aubry method; EBC – European Brewing Convention) by taking 100 grains from each batch and subjecting them to germination,
- total protein content using the Kjeldahl method (nitrogen content multiplied by a factor of 5.7 for wheat).

#### **Statistical analysis**

All analyses described were performed in three parallel replicates. The results were collected using Statistica 13.3 statistical software. To interpret the results, a one-way ANOVA (Tukey's test) was used with a significance level of  $\alpha = 0.05$  for individual grain commodity parameters determined depending on the wheat cultivar. To examine the effect of wheat cultivar and nitrogen fertilisation level on the commodity parameters of wheat grain, a multivariate analysis of variance (Tukey's HSD test) was used with a significance level of  $\alpha = 0.05$ .

## **RESULTS AND DISCUSSION**

#### **Commodity analysis of grain obtained from field experiments**

After harvesting, the water content in the grain of the analysed winter wheat cultivars was measured (Figure 1). The water content in winter wheat grain in the years 2021–2023 averaged 13.8%. The moisture content of wheat grain depended on the growing season, but was not dependent on the cultivar used or the level of nitrogen fertilisation. The winter wheat grains of the Gimantis and Rockefeller cultivars had the lowest average water content, while the Elixer and Lawina cultivars had the highest, with no significant differences in water content. During the analysed period, the lowest water content in wheat grain was recorded for the control and averaged 13.5%, while the highest (14.1%) was recorded for nitrogen fertilisation at a dose of 80 kg N·ha<sup>-1</sup> (variant III). The increase in nitrogen fertilisation affected the water content in winter wheat grain, but the differences were not significant. The moisture content of the analysed winter wheat cultivars after harvest varied between growing seasons; the highest average water content

was recorded in the first year of the study, while in subsequent growing seasons the water content in the grain was significantly lower; by 20.75% in the second year of the study and by 19.50% in the last growing season, while no significant differences in the water content of the grain obtained in the second and third years of the study were recorded.

The selected wheat cultivars analysed by Krstanović et al. (2021) as potential raw material for malting had a grain moisture content of 11.28–12.66%. The wheat grain used by Depraetere et al. (2004) for beer production had an average moisture content of 11.98%. Selected wheat varieties used as raw material for malt production had a grain moisture content of 9.6–10.3% (Gonu and Withayagiat, 2023). In pilot canopy experiments conducted during the 2019/20 growing season, the water content in the grains of the Elixer, Rockefeller and Gimantis wheat cultivars ranged from 11.0 to 11.6%, regardless of the nitrogen fertilisation used (Belcar et al., 2021a), while in the studies by Zhuang et al. (2017), the average moisture content of wheat grain for malt production was 12.32%.

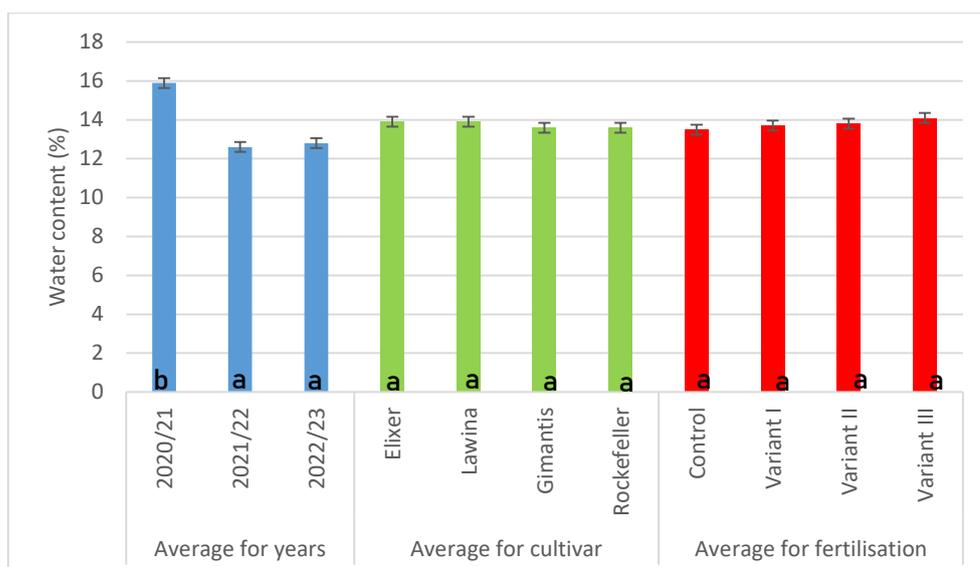


Figure 1. Average water content (%) in winter wheat grain obtained from field experiments immediately after harvest a–b – statistically significant differences at a confidence level of  $p = 0.05$

The bulk density of grain is important and depends on its chemical composition and structure, grain size, as well as the amount and type of impurities. Increased nitrogen fertilisation affects not only the protein content of wheat grain but also its bulk density, and the most important factor is the weather during the growing season, which has a significant impact on this parameter. Moderate air temperature distribution and total precipitation during the grain filling period increase the bulk density of the grain (Harasim and Wesolowski, 2013). After harvesting in the years 2021, 2022 and 2023, measurements of the bulk density of the analysed winter wheat varieties were made (Figure 2). The average bulk density of grain for the analysed winter wheat cultivars in the study years was  $68.4 \text{ kg}\cdot\text{hl}^{-1}$ . The bulk density of grain depended on the variety used, the level of nitrogen fertilisation and the growing season. The grain of the Gimantis winter wheat cultivar had the lowest average bulk density, while the grain of the Elixer wheat cultivar had the highest bulk density (on average 6.24% higher). The highest bulk density ( $71.1 \text{ kg}\cdot\text{hl}^{-1}$ ) of the analysed winter wheat cultivars was obtained as a result of nitrogen fertilisation at a dose of  $80 \text{ kg N}\cdot\text{ha}^{-1}$ . The grain density of the analysed winter wheat cultivars varied in individual growing seasons; the highest average value of the tested parameter was obtained in the second year of the study and was 9.60% higher than in the first growing season, while the results of the parameter in question obtained in the

second and third years of the study did not vary. The selected wheat cultivars used as raw material for malt production were characterised by a bulk density of  $83.9\text{--}84.6 \text{ kg}\cdot\text{hl}^{-1}$  (Gonu and Withayagiat, 2023). In pilot canopy experiments conducted in the 2019/20 growing season, the bulk density of Elixer wheat ranged from  $70.4$  to  $72.7 \text{ kg}\cdot\text{hl}^{-1}$ , while that of the bulk density of Lawina wheat was in the range of  $69.0$  to  $70.0 \text{ kg}\cdot\text{hl}^{-1}$ , the Rockefeller cultivar ranged from  $67.0$  to  $68.8 \text{ kg}\cdot\text{hl}^{-1}$ , while the grain density of the Gimantis wheat cultivar was in the range of  $69.2\text{--}71.8 \text{ kg}\cdot\text{hl}^{-1}$  (Belcar et al., 2021a). The use of wheat as a preceding crop for wheat (sown in monoculture) did not reduce the bulk density of the grain, which at a dose of  $140 \text{ kg N}\cdot\text{ha}^{-1}$  averaged  $79.1 \text{ kg}\cdot\text{hl}^{-1}$  (Woźniak, 2006). The bulk density of winter wheat in the studies by Jańczak – Pieniążek et al. (2020) using medium-intensity technology ( $111 \text{ kg N}\cdot\text{ha}^{-1}$ ) averaged  $73.9 \text{ kg}\cdot\text{hl}^{-1}$ , while for population varieties it ranged from  $74.2$  to  $75.1 \text{ kg}\cdot\text{hl}^{-1}$ . The grain density of winter wheat when fertilised with  $80 \text{ kg N}\cdot\text{ha}^{-1}$  in three doses ( $40+30+10 \text{ kg N}\cdot\text{ha}^{-1}$ ) was  $80.7 \text{ kg}\cdot\text{hl}^{-1}$  (Stankowski et al., 2004), and after fertilisation with  $100 \text{ kg N}\cdot\text{ha}^{-1}$ , it ranged from  $73.6$  to  $78.2 \text{ kg}\cdot\text{hl}^{-1}$  in the analysed years of the study (Harasim and Wesolowski, 2013). In the study by Podolska et al. (2004), the grain density of winter wheat with fertilisation of  $80 \text{ kg N}\cdot\text{ha}^{-1}$  averaged  $76.9 \text{ kg}\cdot\text{hl}^{-1}$  (depending on the cultivar used) and  $74.3\text{--}78.9 \text{ kg}\cdot\text{hl}^{-1}$  (depending on the method of protection).

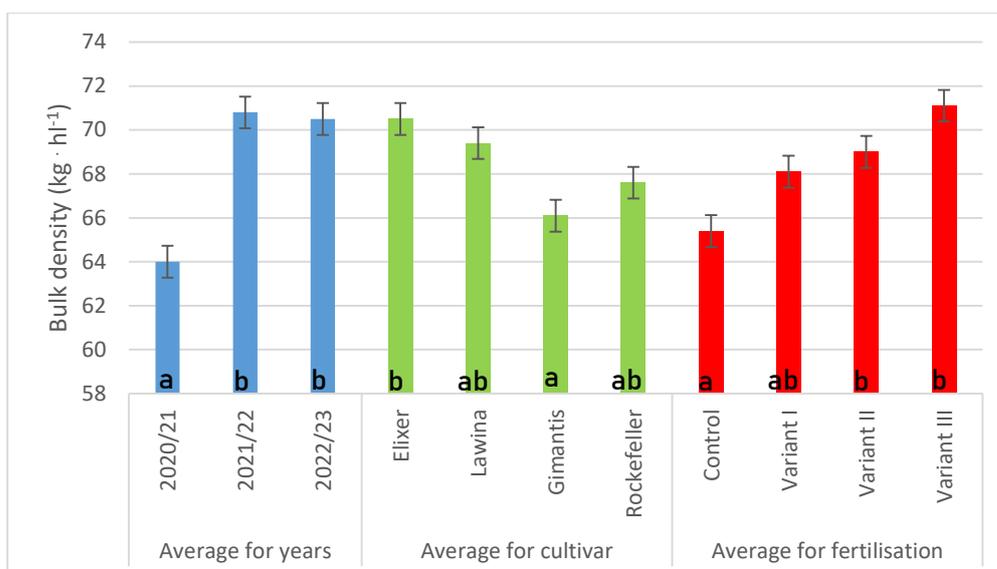


Figure 2. Average bulk density (kg·hl<sup>-1</sup>) of wheat grain from field experiments in 2021–2023  
a–b – statistically significant differences at a confidence level of  $p = 0.05$

A deficiency of any of the macronutrients during the growing season of winter wheat affects grain size, reducing the fraction >2.5 mm (Jaskulska et al., 2015). After harvesting, the grain size uniformity of the analysed winter wheat cultivars was determined (Figure 3). The average grain uniformity for the analysed winter wheat cultivars during the study period was 83.7%. The grain uniformity value depended on the cultivar used, the level of nitrogen fertilisation and the growing season. The grain of the Lawina winter wheat cultivar had the lowest average uniformity, while the grain of the Gimantis wheat cultivar had the highest uniformity, amounting to 87.9%.

An increase in the dose of nitrogen fertilisation used affected grain uniformity; the average value for the control group over the three years of research was 79.7%, and for the highest dose of nitrogen fertilisers used (80 kg N·ha<sup>-1</sup>; variant III) it was 7.22% higher. The grain uniformity of the analysed winter wheat cultivars varied in individual growing seasons; the highest value was obtained in the third year of the study and was on average 15.45% higher than in the first growing season. In the second and third years of the study, no significant differences in grain uniformity were observed. In the study by Boros et al. (2014), which involved the search for winter wheat lines for the production of wheat malt, grain uniformity ranged from 71.0 to 99.7%. In pilot field experiments conducted in the 2019/20 growing

season, grain uniformity of the Elixer wheat cultivar ranged from 70.6 to 75.2%, grain uniformity of the Rockefeller wheat cultivar ranged from 58.4 to 60.4%, while grain uniformity of the Gimantis wheat cultivar ranged from 76.7 to 79.8% (Belcar et al., 2021a). Using only wheat in crop rotation (sowing in monoculture) resulted in a reduction in grain uniformity from 95.0 (forecrop – wheat) to 92.6% (forecrop – 3x wheat; Woźniak, 2006).

After harvesting in the 2021–2023 study years, the germination energy of the analyzed winter wheat cultivars was determined (Figure 4). The average germination energy of the analyzed winter wheat grains during the study years was 93.4%. There was no significant effect of the variety used, nitrogen fertilization level, or growing season on the germination energy of wheat grains. Winter wheat grains of the Lawina and Rockefeller cultivars had the lowest average germination energy (92.9%), while the highest germination energy (94.1%) was observed in the Elixer cultivar, but these differences were insignificant. There was no significant effect of different nitrogen fertilization levels, compared to the control, on the germination energy of the analyzed winter wheat cultivars. The germination energy of the analyzed winter wheat cultivars did not vary across the growing seasons, and the highest average value was obtained in the third year of the study, at 95.2%.

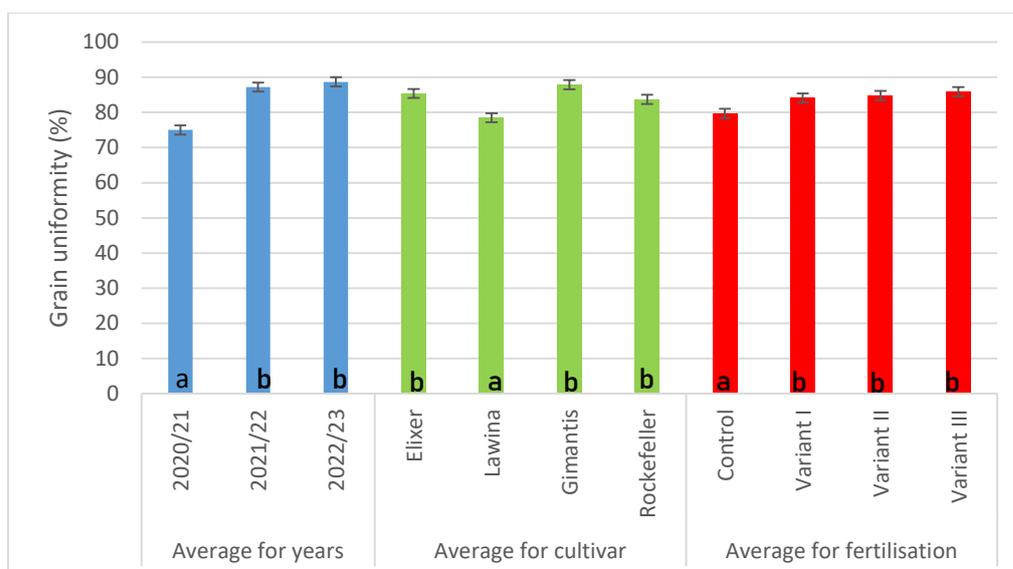


Figure 3. Average uniformity (%) of wheat grain obtained from field experiments in 2021–2023  
a–b – statistically significant differences at a confidence level of  $p = 0.05$

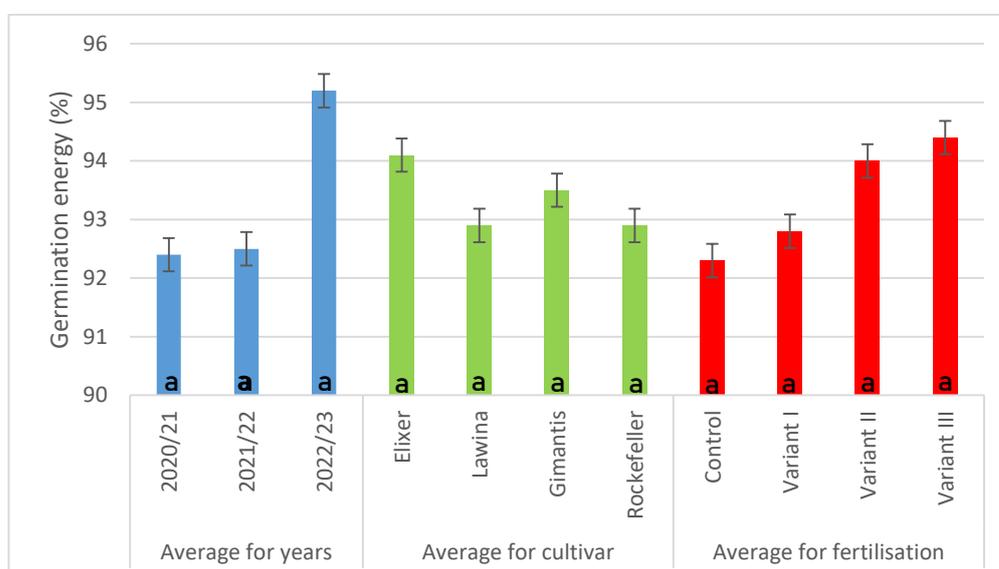


Figure 4. Average germination energy (%) of wheat grain from field experiments in the research years 2021–2023  
a – statistically significant differences at a confidence level of  $p = 0.05$

In a study by Boros et al. (2014) exploring winter wheat lines for malt production, the average germination energy was 95.2%. Wheat cultivars analyzed by Krstanović et al. (2021) as potential malting raw materials had germination energy levels of 95.0–98.0%. Selected wheat cultivars used as raw materials for malt production had grain germination energy levels ranging from 97.0 to 97.5% (Gonu and Withayagiat, 2023). In pilot field experiments conducted during the 2019/20 growing season, the average germination energy of wheat grain cultivars Elixer and Rockefeller was 95.0%, and of the Gimantis cultivar, 96.0% (Belcar et al., 2021b).

The germination capacity of the analyzed winter wheat cultivars in the 2021–2023 study years is presented in Figure 5. The average germination capacity of the harvested winter wheat grain was 94.1%. The germination capacity value did not depend on the cultivar used, the level of nitrogen fertilization, or the growing season. Winter wheat grain of the Lawina and Rockefeller cultivars had the lowest average germination capacity (93.6%), while the highest germination capacity was obtained for the Elixer cultivar (95.0%), but these differences were insignificant. There was also no significant effect of different nitrogen fertilization levels, compared to the control, on this parameter.

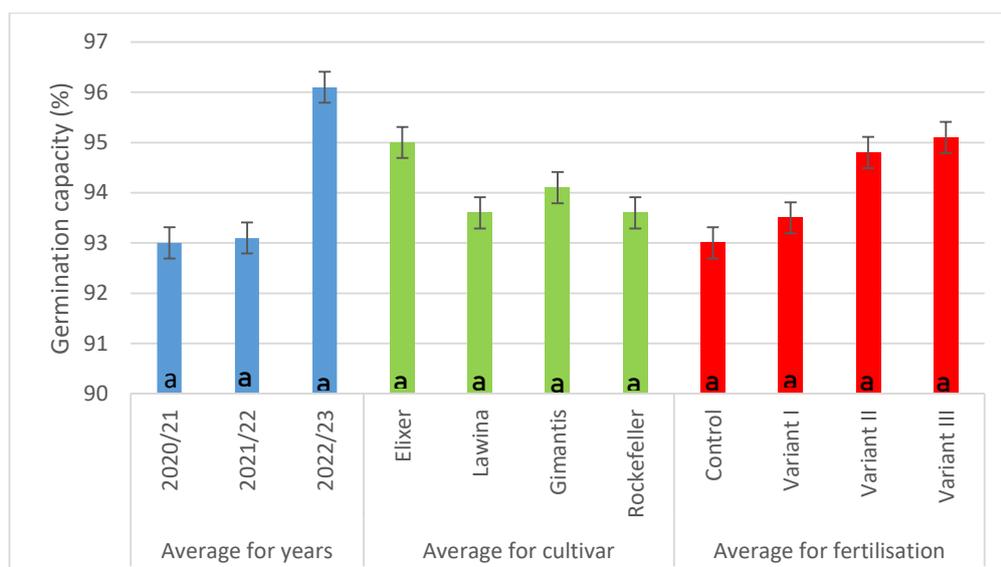


Figure 5. Average germination capacity (%) of wheat grain from field experiments in the research years 2021 – 2023  
a – statistically significant differences at a confidence level of  $p = 0.05$

The germination capacity of the analyzed winter wheat cultivars did not vary across the growing seasons, and the highest value was obtained, similarly to germination energy, in the third year of the study, reaching an average of 96.1%. Selected wheat cultivars analyzed by Krstanović et al. (2021) as a potential raw material for malting were characterized by a germination capacity of 97.5–99.4%. In pilot field experiments conducted in the 2019/20 growing season, the average values of wheat grain germination capacity of selected cultivars were: Elixer - 96.0%, Rockefeller - 95.0%, and Gimantis - 97.0% (Belcar et al., 2021b).

The total protein content in winter wheat grain intended for malting and brewing is one of the key quality parameters of the raw material. Increasing nitrogen fertilization positively affects the total protein content in wheat grain, but using too high a dose of nitrogen not only fails to improve but actually limits the total protein content and negatively impacts its quality (Jankowski et al., 2016). Increased rainfall during the winter wheat growing season over many years reduces the total protein content in wheat grain (Buczek and Bobrecka-Jamro, 2015). Excessive concentrations of this parameter also affect the soluble protein content in the resulting wheat malt, which also negatively impacts its quality. In a study by Jin et al. (2008), however, it was proven that malt obtained from wheat grain with a total protein content of 16.0% d.m. after modifications during malting (e.g., extending the malting time) will also be of adequate quality. Generally, however, recommendations are to use wheat grain with a floury endosperm and a total protein content of up to 11.0% d.m. for the production of wheat malt (Krstanović et al., 2021;

Faltenmaier et al., 2014; Depraetere et al., 2004). Research is also underway on the use of durum wheat grain characterized by a high total protein concentration, especially for the production of beers characterized by significant haze (e.g., Witbier) due to the share of high molecular weight proteins (Krstanović et al., 2021). Wheat grain with a harder endosperm and typically high total protein content absorbs water less readily, thus delaying enzymatic activity and modification in the malted grain (Krstanović et al., 2023). High protein content (and therefore high nitrogen content) in wheat grain intended for malting reduces the extractivity and attenuation of the wort due to the lower starch content in the wheat grain, thus causing problems with mashing, filtration, and fermentation of wheat beer, often impairing the flavor of the final product (Psota et al., 2018).

In 2021–2023, the total protein content in the grain of the analyzed winter wheat cultivars was determined after harvest (Figure 6). The average total protein content in the analyzed winter wheat grain during the study years was 10.4% d.m. Total protein content depended only on the applied nitrogen fertilization level, with no effect of the variety or growing season. Winter wheat grain of the Gimantis cultivar had the lowest average total protein content (10.2% d.m.), while the highest total protein content was found in the Lawina cultivar (10.5% d.m.); these differences were insignificant. Total protein content in winter wheat grain was influenced by different nitrogen fertilization rates. The increase in total protein content was 8.74% for the 40 kg N·ha<sup>-1</sup> dose, 11.32% for the 60 kg N·ha<sup>-1</sup> dose, and 16.07% for the 80 kg N·ha<sup>-1</sup> dose, respectively, compared to the parameter discussed

in the control. The total protein content in the grain of the analyzed winter wheat cultivars did not vary between growing seasons, and the highest average value was obtained in the second year of the study and was 10.6% d.m. In the study by Buczek and Bobrecka-Jamro (2015), the average total protein content in winter wheat grain grown in the Podkarpackie Voivodeship was 11.7% d.m. (low-input cultivation; nitrogen fertilization 60 kg N·ha<sup>-1</sup>). Wheat cultivars analyzed by Krstanović et al. (2021) as a potential raw material for malting were characterized by a total protein content of 12.16–13.55% d.m. The grain of wheat used by Depraetere et al. (2004) for the production of beers was characterized by a total protein content ranging from 8.7 to 14.4% of dry matter. In the research by Boros et al. (2014) involving the search for winter wheat lines for the production of wheat malt, the total protein content was at the level of 14.5–17.0% of dry matter. In pilot field experiments conducted in the 2019/20 growing season, the total protein

content in the wheat grain of the Elixer cultivar ranged from 11.6 to 12.1% of dry matter, for the wheat grain of the Rockefeller cultivar this value was from 11.9 to 12.1% of dry matter, while for the Gimantis cultivar it was in the range of 10.9–11.2% of dry matter (Belcar et al., 2021a). The total protein content in winter wheat grain in the study by Jańczak-Pieniżek et al. (2020) in the medium-intensive technology (111 kg N·ha<sup>-1</sup>) was on average 11.99%, while for population varieties it ranged from 11.73 to 12.87%. The total protein content in winter wheat grain with fertilization of 80 kg N·ha<sup>-1</sup> was at the level of 10.05% (Knapowski et al., 2010), and with the applied fertilization of 100 kg N·ha<sup>-1</sup> it ranged on average from 9.8 to 13.8% in the analyzed years of the study (Harasim and Wesołowski, 2013). In the study by Podolska et al. (2004), the content of total protein in wheat grain with fertilization of 80 kg N·ha<sup>-1</sup> was 12.4% (depending on the cultivar used) and 12.1 – 12.3% (depending on the protection method).

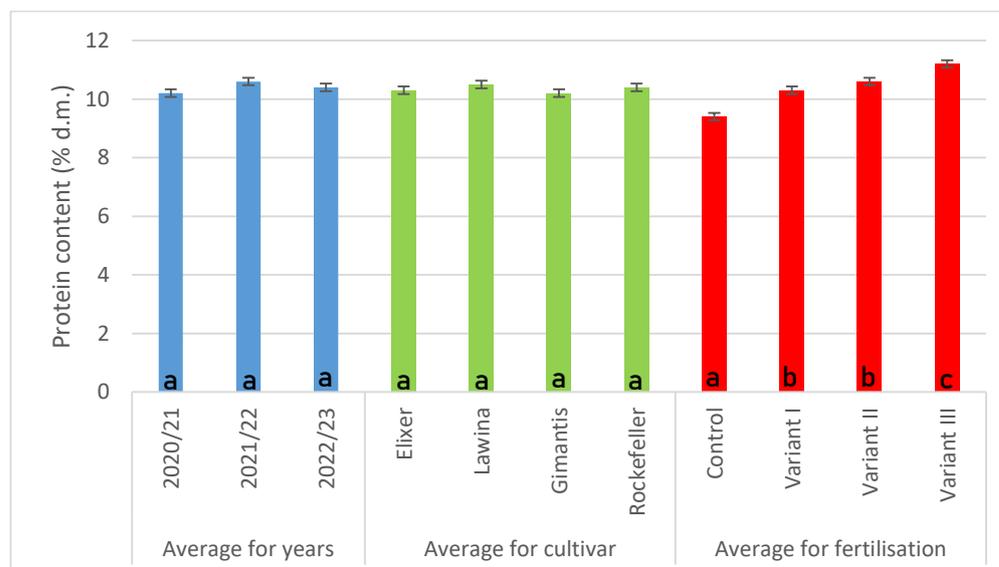


Figure 6. Average total protein content (% d.m.) in wheat grain from field experiments in the research years 2021–2023 a–c – statistically significant differences at a confidence level of  $p = 0.05$

### Commodity Analysis of Wheat Grain Obtained from Field Experiments

Grain yield and quality, including chemical, physical, and technological properties, depend significantly on the cultivar genotype, soil conditions, and fertilization intensity during the growing season of winter wheat (Psota and Musilová, 2020; Jaskulska et al., 2015). The results of the commodity evaluation of the analyzed winter wheat cultivars obtained in canopy experiments are presented in Tables 1–4.

Table 1 presents the results of the commodity evaluation of wheat grain of the Elixer cultivar obtained from canopy experiments in 2020–2022.

The water content in the analyzed wheat grain of the Elixer cultivar ranged from 11.9% to 15.1%. Grain bulk density in the first year of the study averaged 70.63 kg·hl<sup>-1</sup>, while in the following year it reached 75.9 kg·hl<sup>-1</sup> (an increase of 6.94%), which contributed to its uniformity. Comparing the average water content and bulk density of winter wheat of the Elixer cultivar obtained in field experiments in the Lower Silesian Voivodeship and in canopy experiments in the Podkarpackie Voivodeship, it was observed that water content was at the same level, while bulk density was 3.03% higher compared to the parameter discussed in the field experiments.

Table 1. Results of commodity analysis of wheat grain of the Elixer cultivar in 2020–2022 – canopy experiments

Parameter	Farm B		Farm E	Farm G	Farm D	Average
	I year of research	II year of research	I year of research	I year of research	II year of research	
Water content (%)	11.9 <sup>a</sup> ±0.7	15.1 <sup>d</sup> ±0.5	13.2 <sup>b</sup> ±0.0	14.8 <sup>d</sup> ±0.1	14.0 <sup>c</sup> ±0.2	13.8±1.3
Bulk density (kg·hl <sup>-1</sup> )	74.0 <sup>b</sup> ±0.8	75.3 <sup>b</sup> ±0.7	69.0 <sup>a</sup> ±0.2	68.9 <sup>a</sup> ±1.2	76.5 <sup>b</sup> ±0.3	72.7±3.6
Grain uniformity (%)	81.2 <sup>bc</sup> ±1.5	87.0 <sup>d</sup> ±0.6	57.8 <sup>a</sup> ±0.2	77.9 <sup>b</sup> ±0.7	82.7 <sup>cd</sup> ±0.9	77.3±11.4
Germination energy (%)	92.3 <sup>a</sup> ±0.6	92.7 <sup>a</sup> ±1.5	91.0 <sup>a</sup> ±0.0	93.0 <sup>a</sup> ±2.0	91.7 <sup>a</sup> ±1.5	92.1±0.8
Germination capacity (%)	93.3 <sup>a</sup> ±1.2	93.0 <sup>a</sup> ±2.6	92.0 <sup>a</sup> ±1.0	93.0 <sup>a</sup> ±1.0	93.0 <sup>a</sup> ±2.6	92.9±0.5
Total protein content (% d. m.)	13.3 <sup>c</sup> ±0.4	11.4 <sup>b</sup> ±0.3	12.7 <sup>c</sup> ±0.1	10.8 <sup>a</sup> ±0.0	11.6 <sup>b</sup> ±0.1	12.0±1.0

a-d – statistically significant differences at a confidence level of  $p = 0.05$

Grain uniformity and total protein content are the most important quality parameters of grain grown for malting and brewing purposes. Malting plants in Poland require the first of these parameters to be no lower than 85%, while the second should be in the range of 9.5–11.5% d.m. In the case of the Elixer cultivar, the requirements for the analyzed parameters were met in the second year of the study on farm B (grain uniformity 87.0% and total protein content 11.4% d.m.). Regardless of the year of the field study conducted on three farms: B, G, and D, wheat grain of the Elixer cultivar was characterized by a reduced grain uniformity parameter, averaging 82.2%. In the absence of raw material, after grain cleaning (removal of damaged and undeveloped grain), this parameter can be used for malt production; however, the process used will increase the production costs of the final raw material. Elixer wheat grain obtained in the first year of field testing on farm E, characterized by a uniformity of 57.8% and an additional above-standard total protein content (12.7% d.m.), did not meet quality requirements and should be used for feed. Raw material obtained from farm B in the 2020/2021 growing season was characterized by an increased total protein content (13.3% d.m.) and, depending on the maltster's needs, may be used for malt production with a price deduction or rejected and designated as raw material for consumption (if it meets quality requirements, e.g., has a standard gluten content or falling number parameter) or as feed material. Comparing the average grain uniformity and total protein content of winter wheat grain of the Elixer cultivar obtained in field and canopy experiments, it was observed that grain uniformity from the field experiments was 9.48% lower, and total protein content was 14.17% higher, compared to the parameters discussed in the canopy experiments. In pilot studies conducted in the 2019/2020 season on selected farms in the Podkarpackie Voivodeship, the total protein content

of Elixer wheat grain was 11.9% d.m., and grain uniformity was 81.0% (Belcar et al., 2020).

The energy and germination parameters of wheat grain intended for malting should not be lower than 95%. For wheat grain of the Elixer cultivar obtained in canopy experiments, the germination energy parameter averaged 92.14%, while germination capacity was 92.86%. Comparing the average energy and germination capacity of winter wheat grain of the Elixer cultivar in field and canopy experiments, the values of these parameters were found to be lower by 2.13% and 2.20%, respectively, than those obtained in field experiments. In pilot studies conducted in the 2019/2020 season on selected farms in the Podkarpackie Voivodeship, the energy and germination capacity of winter wheat grain of the Elixer cultivar were 94.0% and 95.0%, respectively (Belcar et al., 2020). Mechanical damage during combine harvesting (embryo damage; Szmigiel et al., 2014) has a significant impact on reducing energy and germination capacity. The grain cleaning process (to improve grain uniformity) removes grains that do not germinate, which also increases the energy and germination parameters of the cleaned wheat grain.

Table 2 presents the results of qualitative analysis of Lawina wheat grain obtained in canopy experiments conducted between 2020 and 2022 in the Podkarpackie Voivodeship. Lawina wheat grain moisture ranged from 11.2% to 15.0%. Grain bulk density in the first growing season of the canopy experiments was relatively low, averaging 68.83 kg·hl<sup>-1</sup>, and was 9.26% higher in the second year. Comparing the average water content and bulk density of Lawina winter wheat grain obtained in field and canopy experiments, it was observed that the water content in the field experiments was 4.32% lower, and the bulk density was 3.07% higher, compared to the parameter discussed in the canopy experiments.

Table 2. Results of commodity analysis of wheat grain of the Lawina cultivar in the research years 2020–2022 - canopy experiments

Parameter	Farm E		Farm C	Farm F	Farm A	Average
	I year of research	II year of research	I year of research	I year of research	II year of research	
Water content (%)	13.7 <sup>c</sup> ±0.9	11.2 <sup>a</sup> ±0.2	13.7 <sup>c</sup> ±0.6	15.0 <sup>d</sup> ±0.3	13.0 <sup>b</sup> ±0.4	13.3±1.4
Bulk density (kg·hl <sup>-1</sup> )	69.1 <sup>a</sup> ±0.8	73.3 <sup>b</sup> ±0.6	69.7 <sup>ab</sup> ±0.5	67.7 <sup>a</sup> ±0.5	78.4 <sup>c</sup> ±0.1	71.6±4.3
Grain uniformity (%)	69.8 <sup>b</sup> ±1.3	61.1 <sup>a</sup> ±1.0	67.5 <sup>b</sup> ±0.5	74.2 <sup>c</sup> ±0.9	89.7 <sup>d</sup> ±0.7	72.5±10.7
Germination energy (%)	89.7 <sup>a</sup> ±1.5	91.3 <sup>a</sup> ±1.2	90.7 <sup>a</sup> ±1.2	89.3 <sup>a</sup> ±1.5	92.7 <sup>a</sup> ±1.5	90.7±1.4
Germination capacity (%)	91.3 <sup>a</sup> ±1.5	93.0 <sup>a</sup> ±1.0	91.7 <sup>a</sup> ±2.1	90.7 <sup>a</sup> ±1.2	93.0 <sup>a</sup> ±1.7	91.9±1.0
Total protein content (% d. m.)	12.5 <sup>c</sup> ±0.1	11.9 <sup>b</sup> ±0.5	12.9 <sup>c</sup> ±0.1	12.5 <sup>c</sup> ±0.0	8.2 <sup>a</sup> ±0.3	11.6±1.9

a-d –statistically significant differences at a confidence level of  $p = 0.05$

Grain uniformity of the Lawina cultivar wheat, with the exception of the raw material obtained on farm A in the second growing season (89.7%), averaged 68.15%, mainly due to the very high proportion of unformed grain, which disqualified the Lawina cultivar wheat for malting and brewing already at the commodity analysis stage. This fact was also confirmed by the above-average total protein content, which averaged 12.45% d.m. The exception was the raw material obtained on farm A, which was characterized by a very low content of this parameter (8.2% d.m.), which is also undesirable in brewing, as total protein losses during the malting process average 0.4% (Szwed et al., 2009). Wort obtained from malt produced in this way will contain too little nitrogen, which is used by yeast for their metabolism during the fermentation process, significantly affecting the ethyl alcohol content in wheat beer (Boros et al., 2014). However, in the malting industry, such raw material is used because grain is purchased in batches, e.g., 200 tons each, with average parameters for both total protein content and grain uniformity. Comparing the uniformity and total protein content of winter wheat grain of the Lawina cultivar obtained in field and canopy experiments, it was found that the average grain uniformity in the field experiments was 7.64% lower, and the total protein content was 9.48% higher.

The average germination energy of Lawina wheat grain obtained in canopy experiments was 90.70%, while germination capacity was 1.20% higher. Comparing the average energy and germination capacity of Lawina winter wheat grain obtained in field and canopy experiments, it was observed that germination energy and germination capacity in field experiments were lower by 2.37% and 1.82%, respectively.

The results of the commodity evaluation of Gimantis wheat grain are presented in Table 3. The water content in Gimantis wheat grain ranged from 13.7 to 14.3%. The average bulk density was 74.9 kg·hl<sup>-1</sup> and was the highest among the analyzed wheat cultivars, which also significantly influenced

the grain MTZ, which averaged 39.02 g d.m. Comparing the average water content and bulk density of winter wheat Gimantis obtained in field experiments in the Lower Silesian Voivodeship and in canopy experiments conducted on selected farms in the Podkarpackie Voivodeship, it was observed that the water content and bulk density of grain obtained in the field experiments were higher by 2.86% and 11.75%, respectively, compared to the parameter discussed in the canopy experiments. The total protein content in Gimantis wheat grain obtained in the second year of canopy experiments was within the norm, while in the first year, the grain had a very high protein content, which disqualifies this raw material for the malting industry due to difficulties in loosening it, resulting in reduced extractability and often cloudiness and sediment formation in the beer during aging (Jin et al., 2008). Comparing the average grain uniformity and total protein content of winter wheat grain of the Gimantis cultivar obtained in field and canopy experiments, it was observed that grain uniformity in the field experiments was 3.64% lower, while the total protein content in winter wheat grain was 17.74% higher compared to the parameter discussed in the canopy experiments. The average grain uniformity, regardless of the growing season, was 84.67% and was the highest among the wheat cultivars analyzed grown during the two-year canopy experiments (an average of 8.68% compared to the Elixer cultivar, 14.42% compared to the Lawina cultivar, and 20.51% compared to the Rockefeller cultivar).

The average germination energy of wheat grain of the Gimantis cultivar was 92.9%, while germination capacity was higher, averaging 93.7%. Comparing the energy and germination capacity of winter wheat grain of the Gimantis cultivar in field and canopy experiments, it was found that these parameters were similar. Among the analyzed wheat cultivars grown for malting purposes, the Gimantis cultivar had the highest values of these parameters.

Table 3. Results of commodity analysis of wheat grain of the Gimantis cultivar in 2020–2022 – canopy experiments

Parameter	Farm D		Farm E	Average
	I year of research	II year of research	II year of research	
Water content (%)	14.3 <sup>a</sup> ±0.2	13.7 <sup>a</sup> ±0.3	13.9 <sup>a</sup> ±0.1	14.0±0.3
Bulk density (kg·hl <sup>-1</sup> )	71.6 <sup>a</sup> ±0.1	76.5 <sup>b</sup> ±0.5	76.5 <sup>b</sup> ±0.3	74.9±2.8
Grain uniformity (%)	81.8 <sup>a</sup> ±0.3	85.8 <sup>ab</sup> ±0.4	86.4 <sup>b</sup> ±0.1	84.7±2.5
Germination energy (%)	93.3 <sup>a</sup> ±1.2	92.7 <sup>a</sup> ±1.5	92.7 <sup>a</sup> ±2.3	92.9±0.3
Germination capacity (%)	94.3 <sup>a</sup> ±1.5	93.0 <sup>a</sup> ±1.0	93.7 <sup>a</sup> ±2.5	93.7±0.7
Total protein content (% d. m.)	14.1 <sup>b</sup> ±0.1	11.8 <sup>a</sup> ±0.1	11.4 <sup>a</sup> ±0.0	12.4±1.5

a-b– statistically significant differences at a confidence level of  $p = 0.05$

Table 4 presents the results of qualitative analysis of Rockefeller wheat grain grown in canopy experiments in the Podkarpackie Voivodeship between 2020 and 2022. The moisture content of Rockefeller wheat grain ranged from 10.9 to 15.7%. The average bulk density was 69.0 kg·hl<sup>-1</sup>. Comparing the average water content and bulk density of Rockefeller winter wheat grain grown in field experiments in the Lower Silesian Voivodeship and in canopy experiments in the Podkarpackie Voivodeship, it was observed that the water content in harvested grain from the field experiments was similar, and the bulk density was 2.03% higher than the parameter discussed in the canopy experiments.

The average grain uniformity parameter for Rockefeller wheat obtained over the two growing seasons was 67.3%, a result that, at this stage of the research, disqualifies the obtained raw material as a substrate for malting; this grain should be used as feed material. This fact is further confirmed by the significantly above-standard total protein content in the grain in question obtained in the first year of the canopy experiments (average 14.23% d.m.), while in the second year of the study it was significantly lower at 10.45% d.m. Comparing the average grain

uniformity and total protein content in Rockefeller winter wheat grain in the field and canopy experiments, it was found that grain uniformity from the field experiments was 19.59% lower, and the total protein content in winter wheat grain was 18.11% higher compared to the parameters discussed in the canopy experiments. In pilot studies conducted in the 2019/2020 season in the Podkarpackie Voivodeship, the total protein content in Rockefeller wheat grain was 11.6% d.m., and grain uniformity was 77.2% (Belcar et al., 2020). The average germination energy of Rockefeller wheat grain was 91.40%, while germination capacity was 92.54%, which was comparable to the parameters discussed for Elixer and Lawina wheat grain grown in the Podkarpackie Voivodeship between 2020 and 2022. Comparing the average energy and germination capacity of Rockefeller winter wheat grain obtained in field and canopy experiments, it was observed that these parameters were similar. In pilot studies conducted in the 2019/2020 season in the Podkarpackie Voivodeship, the energy and germination capacity of winter wheat grain of the Rockefeller cultivar was 93.0% and 94.0%, respectively (Belcar et al., 2020).

Table 4. Results of commodity analysis of wheat grain of the Rockefeller cultivar in 2020–2022 – canopy experiments

Parameter	Farm E		Farm A	Farm D	Farm C	Average
	I year of research	II year of research	I year of research	I year of research	II year of research	
Water content (%)	15.7 <sup>c</sup> ±0.1	13.2 <sup>b</sup> ±0.2	13.6 <sup>b</sup> ±0.2	13.5 <sup>b</sup> ±0.1	10.9 <sup>a</sup> ±0.4	13.4±1.7
Bulk density (kg·hl <sup>-1</sup> )	66.9 <sup>a</sup> ±0.2	69.2 <sup>a</sup> ±1.2	66.7 <sup>a</sup> ±3.4	67.4 <sup>a</sup> ±0.1	74.6 <sup>b</sup> ±0.4	69.0±3.3
Grain uniformity (%)	62.2 <sup>a</sup> ±2.1	66.6 <sup>b</sup> ±1.0	59.5 <sup>a</sup> ±1.6	59.6 <sup>a</sup> ±1.2	88.6 <sup>c</sup> ±0.3	67.3±12.3
Germination energy (%)	92.3 <sup>a</sup> ±1.2	92.7 <sup>a</sup> ±1.5	90.0 <sup>a</sup> ±1.7	90.3 <sup>a</sup> ±1.5	91.7 <sup>a</sup> ±1.5	91.4±1.2
Germination capacity (%)	93.0 <sup>a</sup> ±1.7	93.3 <sup>a</sup> ±1.2	91.7 <sup>a</sup> ±2.1	91.7 <sup>a</sup> ±1.5	93.0 <sup>a</sup> ±2.0	92.5±0.8
Total protein content (% d. m.)	14.5 <sup>d</sup> ±0.0	13.3 <sup>c</sup> ±0.3	11.1 <sup>b</sup> ±0.1	14.9 <sup>d</sup> ±0.1	9.8 <sup>a</sup> ±0.6	12.7±2.2

a-d– statistically significant differences at a confidence level of  $p = 0.05$

## CONCLUSIONS

Commodity analysis of wheat grain obtained in field experiments from selected winter wheat cultivars grown under different nitrogen fertilization regimes revealed significant variation. A positive effect was noted for the Gimantis and Rockefeller cultivars, as well as for nitrogen fertilizer applications at 60 and 80 kg·ha<sup>-1</sup>, on the

technological value of winter wheat grain, including parameters important for the malting process, such as total protein content and grain uniformity, and, to a lesser extent, energy and germination capacity. In canopy experiments, at nitrogen fertilization rates of 60 kg·ha<sup>-1</sup>, the Gimantis and Elixer cultivars demonstrated the highest wheat grain quality.

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