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The effect of nitrogen fertilisation, biostimulant application and extra-root phosphorus fertilization on yield and quality of malting barley grain

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Abstract

A series of small-plot field trials were conducted between 2019 and 2021 with the spring barley variety Francin. The impact of Vital Root and YaraVita KOMBIPHOS on the grain quality of malting barley at varying nitrogen fertilization rates (50 kg·ha^{-1} N, 70 kg·ha^{-1} N, 90 kg·ha^{-1} N, and 110 kg·ha^{-1} N) was investigated. The following parameters were evaluated: grain size, thousand grain weight, specific weight, starch content, and protein content. The portion of grain <2.5 mm, weight of thousand grains, and specific weight decreased with increasing nitrogen fertilization. Additionally, a decrease in starch content was observed with an increase in protein content in the grain. The application of Vital Root and YaraVita KOMBIPHOS at lower nitrogen fertilization rates up to 70 kg·ha^{-1} N had a positive effect on grain quality.

Keywords: malting barley; quality; nitrogen; phosphorus; biostimulants

1 Introduction

In the Czech Republic, spring barley (*Hordeum vulgare* convar. *distichon* L.) is the primary raw material utilized in the production of beer. Furthermore, it can be employed in the production of whiskey (Mikołajczak et al., 2020; Pascari et al., 2018; Fox et al., 2003;). The quality and yield of barley grain can be influenced by a number of factors, including drought, heat, nutrition, pests, diseases, and others (Wang et al., 2022; Baillo et al., 2019). Agronomic management, particularly fertilization, influence the mineral composition of the plant. Accordingly, the rate of initiation of growth and stand development is a crucial aspect of barley cultivation, for which sufficient nitrogen is a vital requirement. It is of great importance to provide barley with a balanced amount of individual doses of nitrogen, phosphorus, potassium, magnesium, and sulphur during the sowing and early development stages (Hřivna et al., 2020; Szeuczuk et al., 2018; Kozera et al., 2017). Nitrogen has a significant impact on grain quality, increasing yield and influencing grain protein content. The excessive utilization of nitrogen fertilizers has been identified as a detrimental factor with regard to environmental impact. Furthermore, an excess of nitrogen can have a detrimental impact on the protein content of the grain. The application of excessive quantities of nitrogen fertilizer has been observed to result in an increase in the protein content of the grain. The protein content of the grain should be between 10 and 11%. Furthermore, an increase in nitrogen application has been shown to result in a reduction in grain size and weight (Cozzolino et al., 2021; Stupar et al., 2021; Karunarathne et al., 2020; Hackett, 2019; Knezevic et al., 2016). Phosphorus is typically deficient in soil, necessitating the application

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of phosphorus-containing fertilizers to replenish this essential nutrient. Phosphorus is a vital element for plant growth and development, as well as for the yield and subsequent grain quality of malting barley (Dari et al., 2019; Rogers et al., 2017; Bagyaraj et al., 2015). Furthermore, phosphorus contributes to grain quality, has a positive effect on starch content and, consequently, malt extract, and increases the proportion of fore grain and grain bulk density (Hřivna et al., 2020). Deficiency of sulphur has been shown to have a detrimental impact on plant quality, particularly in terms of reduced yield (Dostálová et al., 2015; Hřivna et al., 2010). Additionally, the sulphur content of grain can influence the sensory quality of beer (Kosař et al., 2000). Potassium plays a significant role in plant nutrition, enhancing plant health and grain quality. Potassium has been demonstrated to enhance drought tolerance (Brodowska et al., 2019), exert a beneficial influence on the starch content of grain, reduce protein content, and augment overflow and weight of thousand grain (Shewangizaw et al., 2022; Hřivna et al., 2020; Mäkelä et al., 2012; Prajapati et al., 2012). Magnesium is a crucial element in photosynthesis, playing a role in chlorophyll synthesis (Tränkner et al., 2018). Magnesium deficiency in plant nutrition impairs root growth and reduces grain yield (Hauer-Jákli et al., 2019).

Extracts derived from marine or freshwater algae are employed as plant biostimulants. The most extensively studied algae is the brown algae *Ascophyllum nodosum* (L.) *Le Jolis*. Other algae utilized in this context include *Fucus* spp., *Laminaria* spp., *Sargassum* spp., and *Turbinaria* spp. (Shukla et al., 2019; Hong et al., 2007). *A. nodosum* has been demonstrated to exert beneficial effects on a range of plant species. These effects encompass enhanced nutrient absorption, augmented root and aboveground plant growth, and heightened resilience to biotic and abiotic stresses (Shukla et al., 2019).

The present study focuses on the applicability of biostimulants in conjunction with phosphate fertilizers and the optimal rates of nitrogen fertilizers, with the objective of achieving the highest quality in spring barley.

2 Materials and methods

2.1 Field trials

The three-year field trials (years 2019–2021) with the Francin variety were established as small plot trials on land belonging to Agrospol Velká Bystřice in the Czech Republic. Francin was bred by Selgen. A description of Francin is given in the study by Psota et al. (2014). The plot is located in a moderately warm and slightly humid region. The soil is moderately heavy, soil type brown earth. Weather conditions are given in Table 1. The pre-crop was sugar beet. The post-harvest residues were always ploughed in the fall with medium tillage. The soil sample was taken from the 0–30 cm profile and analysed to determine the available nutrient content and to prepare the plot before sowing. Table 2 shows the basic agrochemical characteristics of the plot.

Table 1 *Weather conditions during the growing period*

Month	Average temperature [°C]			Precipitation [mm]			Precipitation [%]*		
	2018 – 2019	2019 – 2020	2020 – 2021	2018 – 2019	2019 – 2020	2020 – 2021	2018 – 2019	2019 – 2020	2020 – 2021
September	16.1	15.9	16.2	93.1	61.9	88.5	180	120	171.2
October	11.1	11.1	10.5	46.8	41.4	130.2	144	127	399.4
November	5.4	8.2	4.7	18.8	35.3	20.2	52	98	56.3
December	1.3	2.8	2.8	23.8	43.2	42.1	85	154	149.8
January	-1.7	0.5	-0.1	17	12.9	51.6	78	59	235.6
February	1.7	5.2	-0.4	29.2	28	32.2	161	155	177.9
March	7.2	6.1	3.8	14.9	24	11.7	54	86	42.1
April	12	11.4	7.7	21.8	11.2	33.2	73	38	111.4
May	13.1	13.1	13.1	77.2	65.6	82.6	121	103	129.5
June	22.8	18.9	21.5	88.7	140.9	41.0	130	206	60.0
July	21.1	20.2	22.3	79.9	46.3	99.9	112	65	138.7
August	21.8	21.5	18.8	58.8	69.6	94.0	94	111	149.9

Source: Meteostanice Ditana, spol. s.r.o.
** Precipitation [%] is given as a percentage of the 30-year normal (1980–2010)*

Table 2 *Agrochemical properties of the soil*

Year	pH	Potassium	Phosphorus	Magnesium	Sulphur	Calcium	KVK
		[mg·kg^{-1}]					
2019	5.88	187	72.3	114	12.6	1470	87.5
2020	5.59	200	72.9	106	7.94	1370	82.2
2021	6.00	196	77	119	8.50	1509	90.1

Nutrient content was determined according to Mehlich III; KVK – cation exchange capacity

Before sowing, P, K and N fertilizers were applied. 52 kg·ha^{-1} P_2O_5 in Amofos fertilizer, 50 kg·ha^{-1} K_2O (50% potassium salt) and 185 kg·ha^{-1} LAV 27, i.e. 50 kg·ha^{-1} N were applied. The sowing rate was 3.5 million germinated seeds (MGS) in 2019 and 3.6 MGS in 2020 and 2021. Sowing took place on March 26, 2019, March 18, 2020 and March 31, 2021. The rest of the nitrogen fertilizer was applied at BBCH 25 (tillering). All trials were grown at different nitrogen fertilization rates (50, 70, 90 and 110 kg·ha^{-1} N). The experimental design is presented in Table 3. The Vital Root (UPL – Czech, s.r.o., Czech Republic) formulation with *A. nodosum* L. extract was applied at BBCH 25 (tillering). YaraVita KOMBIPHOS (YARA AGRI Czech Republic s.r.o., Czech Republic) was applied at BBCH 50 (end of tillering). The composition of each product is shown in Table 4. All variants were grown in 4 replications. Grain was harvested at full maturity using a Wintersteiger small plot harvester. Harvesting took place on August 6, 2019, August 14, 2020 and August 15, 2021.

2.2 Characteristics of the grains

Grain sizing was determined using a Steinecker sizer (Stavební strojírenství n.p., Brno, Czechoslovakia). The individual grain proportions were determined. Evenness and fullness were characterized as grain overlap on the 2.5 mm and 2.8 mm sieves, respectively. The remaining grain was characterized as shrinkage. The weight of thousand grains was determined on a Numirex laboratory counter (Mezos, spol. s. r. o., Hradec Králové, Czech Republic). Specific weight was determined according to ČSN EN ISO 7971-2 (461013). The protein content was determined prior to grain fractionalization. The protein content was determined using a Granolyser (Pfeuffer GmbH, Kitzingen, Germany). The instrument operates on the basis of spectroscopic measurement within the wavelength range of 950–1540 (NIR). Starch content was determined by the Ewers method. The principle of the method is the conversion of starch to its soluble form followed by measurement on a polarimeter. The starch content was determined using a conversion factor, the numerical value of which for barley is 1.912 (Basařová, 1992).

Table 3 *Design of the experiment*

Variant		Nitrogen fertilization before sowing [kg·ha^{-1} N]	Nitrogen fertilization BBCH 25 [kg·ha^{-1} N]	Total dose of nitrogen [kg·ha^{-1} N]	BBCH 25 [l·ha^{-1}]	BBCH 50 [l·ha^{-1}]
1	**N50**	50		50	VR 1	
2	**N50**	50		50	VR 1	YVK 3
3	**N70**	50	20	70	VR 1	YVK 3
4	**N90**	50	40	90	VR 1	YVK 3
5	**N110**	50	60	110	VR 1	YVK 3

VR 1 – Vital Root (1 l·ha^{-1}); YVK 3 – YaraVita KOMBIPHOS (3 l·ha^{-1})

Table 4 *Composition of the used preparations*

Fertilizer	Composition
Vital Root	25% extract from algae *Ascophyllum nodosum*;
	P (13% P_2O_5); K (5% K_2O)
Yara Vita KOMBIPHOS	P (456 g·l^{-1} P_2O_5); K (75 g·l^{-1} K_2O); Ca (23 g·l^{-1} CaO);
	Mg (67 g·l^{-1}MgO); Mn 10 g·l^{-1}; Zn 7 g·l^{-1}

2.3 *Statistical evaluation*

The results were processed using Microsoft Excel and Statistica 14 at a significance level of 95% ($p > 0.05$). The homogeneity of the data obtained was tested, followed by the use of multivariate analysis of variance. The data were then tested using Tukey's post-hoc test at the 95% significance level.

3 Results and discussion

In 2019 and 2021, there was no significant difference ($p>0.05$) between the proportions of grains passing through the 2.5 mm sieve (Figure 1). In 2020 the variability of this parameter was higher. Increasing nitrogen fertilization reduced the proportion of large grains. A significant difference ($p>0.05$) was observed compared to the control (variants 2 and 3). Appliction of phosphorus fertilizer in the form of foliar nutrition in later stages of vegetation promotes grain formation. As reported by Hřivna et al. (2010), solid phosphorus fertilizers applied during preplant preparation or in the early stages of vegetation can also have a beneficial effect. The proportions of grains <2.5 mm are shown in Figure 2. The effect of crop year is also evident. Very low values, indicating high grain quality, were observed in 2021. No significant difference between varieties was observed ($p>0.05$). The highest proportion of non-malting grains was found in 2019. In all experimental years there was an increase in values with increasing nitrogen fertilizer rate. High nitrogen fertilizer rates, as reported by Hřivna et al. (2020), can increase the amount of stunted grains. A similar observation was reported by Stupar et al. (2017).

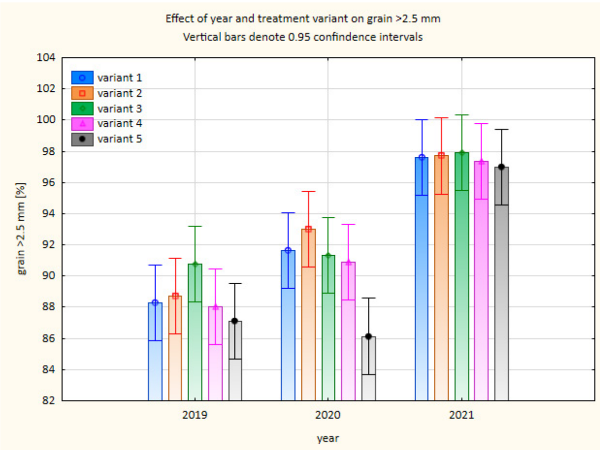

Figure 1 *Effect of year and treatment variant on grain >2.5 mm*

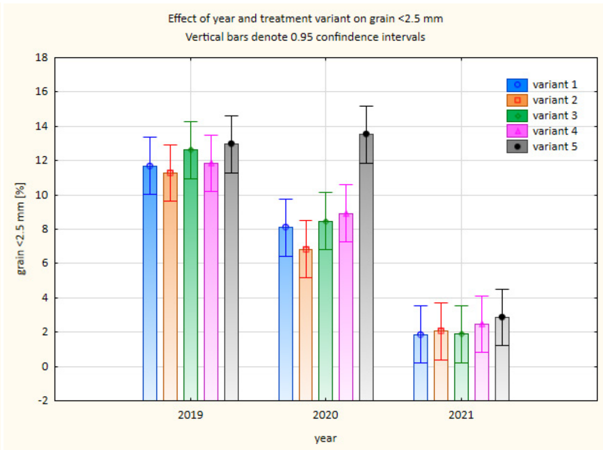

Figure 2 *Effect of year and treatment variant on grain <2.5 mm*

between the nitrogen rate of 110 kg·ha^{-1} N (option 5) and options 1 (N50, VR), 2 (N50, VR, YVK) and 3 (N70, VR, YVK). It has been shown that it is not necessary to apply a high N fertilizer rate after sugar beet preplanting if the post-harvest residue is ploughed. This was confirmed by Cerkal et al. (2011) in their study. Our experiment shows that a dose of 50–70 kg·ha^{-1} is often sufficient. This is in agreement with the results reported by Stupar et al. (2017), who tested the effect of different nitrogen fertilization rates on the grain size of spring barley. They concluded that grain overgrowth values on the 2.5 mm sieve increased up to a nitrogen fertilization level of 75 kg·ha^{-1} N, stagnated at 105 kg·ha^{-1} N and decreased significantly at 135 kg·ha^{-1} N. In our study, the values decreased at a dose of 90 kg·ha^{-1} N. On the contrary, the lower level of nitrogen fertilization in combination with VR and YVK increased the proportion of grains >2.5 mm

The effect of year is also evident in Figure 3, which shows the weight of thousand grain (WTG) results. Neither the application of biostimulant nor the nitrogen fertilization rate nor the application of YVK fertilizer in 2019 or 2021 resulted in significant differences ($p>0.05$) between the variants. In 2020, the highest WTG was recorded for variant 4, while increasing the nitrogen rate by 20 kg·ha^{-1} (variant 5) significantly reduced WTG ($p>0.05$). The application of VR and YVK in 2021 promoted an increase in WTG, while the opposite effect was observed in 2019 and 2020. Cozzolino et al. (2021) also confirmed an increase in WTG after biosimulant application. The specific weight in 2019 was not affected by the different applications, slightly larger but not significant ($p>0.05$) differences were observed in 2021 (Figure 4). A different result was recorded in 2020; despite the low values, a positive effect ($p>0.05$) of the application of VR and YVK was evident for variant 2. On the contrary, the highest nitrogen application had a negative effect for variant 5. In 2019, the application of VR and YVK stabilized the specific weight values even at higher nitrogen fertilization levels. In 2021, the specific weight values at higher N rates were more or less the same as in the control variant, with only a slight decrease in the value for variant 2, where VR and YVK were additionally applied. The application of the biostimulant should contribute to the increase in specific weight as reported by Cozzolino et al. (2021). Similarly, Hřivna et al. (2010) reported that the application of phosphorus fertilizer should increase the specific weight. However, the results observed in our study were probably influenced by non-optimal weather conditions, premature lodging, etc.

As can be seen in Figure 5, the starch content of the grain was characterized by variability between years as well as between variants, but the differences were mostly not statistically significant ($p>0.05$). The largest and even significant ($p>0.05$) differences were observed for variants 4 and 5, which differed markedly with a higher starch content in grain from the 2019 harvest compared to 2020. As nitrogen fertilization increased, starch content in grain generally decreased, but this was not observed in grain harvested in 2019. Phosphorus fertilization should have a positive relationship with starch content in grain, as reported by Hřivna et al. (2020). However, this was not confirmed in our study. The weather at the end of the growing season seems to have played a crucial role. Hartman et al. (2010) show a negative correlation between starch and protein content in grain. As Figure 6 shows, this relationship is not always observed. In our study, the protein content in grain corresponded to the amount of nitrogen fertilizer applied. As can also be seen, the protein content of grain can be significantly influenced by the year. This was evident in 2021, when a significantly ($p>0.05$) lower protein content was determined for all variants compared to grains harvested in the other years. In general, there was an increase in grain protein content with increasing nitrogen fertilization rate. In all years, the highest protein content was found for variant 5.

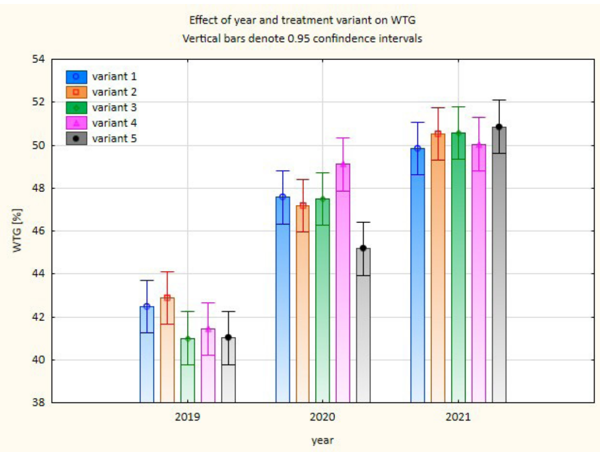

Figure 3 *Effect of year and treatment variant on weight of thousand grains*
Note: WTG – weight of thousand grains; SW – specific weight

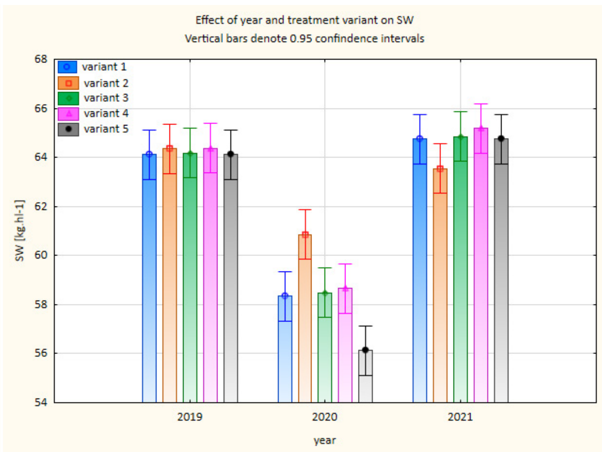

Figure 4 *Effect of year and treatment variant on specific weight*

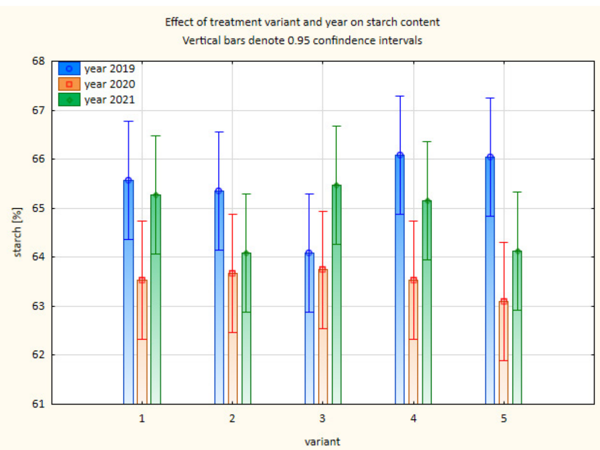

Figure 5 *Effect of treatment variant and year on starch content*

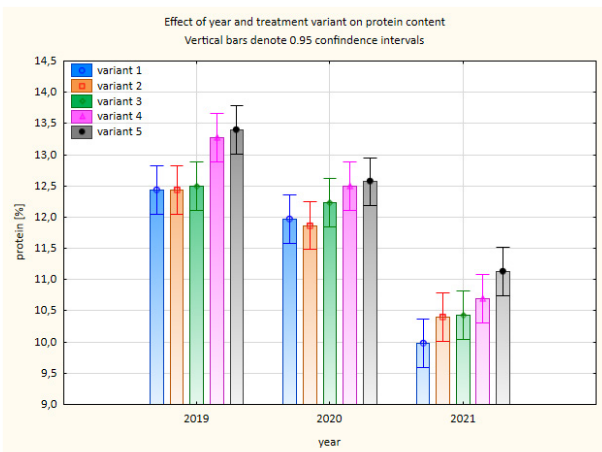

Figure 6 *Effect of treatment variant and year on protein content*

4 Conclusion

It can be concluded that the correct dose of nitrogen fertilizer has a significant effect on the grain quality of malting barley. Higher doses of nitrogen fertilizer usually affect mainly the starch content of the grain and also the protein content. Higher doses of nitrogen fertilizer also reduce the grain overflow values above the 2.5 mm sieve and thus increase the amount of unusable malting grain. It can be concluded that the application of biostimulant in combination with P-fertiliser contributed to an improvement in grain quality, particularly in terms of an increase in grain fraction above the 2.5 mm, an increase in WTG and SW when lower doses of N were applied. Research should focus not only on testing individual biostimulants, but also on their use in combination with nutrition. Testing combinations of different factors on barley grain quality is the aim of our next research.

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