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[1] Zakład Uprawy Roślin i Jakości Plonu, Instytut Uprawy Nawożenia i Gleboznawstwa – Państwowy Instytut Badawczy, Czartoryskich 8, 24-100 Puławy, Polska
[2] Zakład Agroekologii i Ekonomiki, Instytut Uprawy Nawożenia i Gleboznawstwa – Państwowy Instytut Badawczy, Czartoryskich 8, 24-100 Puławy, Polska
*e-mail: mwyzinska@iung.pulawy.pl

MARTA WYZIŃSKA [1]*, ADAM KLEOFAS BERBEĆ [2]

Impact of sowing date and nitrogen fertilization on two cultivars of *Tritordeum* yield potential – a Polish pilot study

Wpływ terminu siewu i nawożenia azotem na potencjał plonowania dwóch odmian *Tritordeum* – polskie badania pilotażowe

Abstract: Agricultural production diversity is becoming a key to solve challenges of modern agriculture – including those related to climate change. The main cereals cultivated in Europe are wheat, rye and barley. One of the new cereals introduced recently into products is *Tritordeum* – a hybrid of durum wheat and a wild form of barley. It is adapted for cultivation conditions of warm and dry climate of Mediterranean. However, recent shifts in climate make it an interesting alternative also for temperate climates. It is also a response to increasing consumer demands for food of good nutritional value. A pilot study (pot experiment) on *Tritordeum* (two cultivars) yield potential under 3 increasing nitrogen fertilization rates (N1, N2 and N3) have been established in 2019–2021in eastern Poland. *Tritordeum* cv. Bulel and *Tritordeum* cv. Aucan performance have been compared with *Triticum durum* Desf. and *Triticum aestivum* L. performance for two sowing dates – autumn and spring. The results demonstrated that the yield level of *Tritordeum* cv. Bulel was comparable to durum wheat yields. Yields of *T. aestivum* L. were higher (only by 8% for autumn sowing and approximately 43% for spring sowing). Moreover, *Tritordeum* cv. Bulel had lower yield level than *Tritordeum* cv. Aucan (by approximately 1–8%). All tested species showed good performance under medium (N2) or even low (N1) nitrogen fertilization rate. The other traits tested (number of ears, productive tillering, thousand grains weight) placed *Tritordeum* (in particular *Tritordeum* cv. Bulel) closer to *T. durum* Desf. than to *T. aestivum* L. *Triticum aestivum* L. had higher results in terms of particularly tillering rate and number of spikes per pot than other 3 tested species. *Tritordeum* has shown that it can be a promising species for cultivation under Polish conditions as its yielding potential can reach yielding potential of *T. durum* Desf. Further field studies on performance of this crop are needed.

Keywords: *Tritordeum*, *Triticum durum* Desf., *Triticum aestivum* ssp. *vulgare*, yielding, nitrogen fertilization

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INTRODUCTION

Cereal grains are an important part of the human diet. The acreage under cereals reached over 736.0 mln ha in 2020, nearly a half of all worlds croplands (1,561.6 mln ha), indicates the great economic importance of this group of crops [FAO 2022]. The first cultivated cereals can be traced back to ancient times. Broomcorn (*Panicum miliaceum* L.) was cultivated in China at least 10,000 years ago [Hunt et al. 2011]. Quinoa (*Chenopodium quinoa* Willd) was first cultivated in Latin America between 5,000 and 7,000 years ago [Kheto et al. 2022]. In the past also rye (*Secale cereale* L.), einkorn (*Triticum boeoticum* Boiss), emmer wheat (*Triticum dicoccoides* Schweinf.), wild barley (*Hordeum spontaneum* Koch), and wild oats (*Avena sterilis* L.) were the important sources of food for human population [Bar-Yosef 2011]. The most important cereals globally nowadays include wheat, rice, maize, and barley. *Triticum aestivum* L. is cultivated in Europe, east Asia, India, both Americas and in Australia. In 2022, 30% of the world's cereal grain production was wheat grain [FAOSTAT 2024]. Genetically, it is a hexaploid, which was created through hybridization of tetraploid *Triticum turgidum* L. with diploid *Aegilops tauschii* Coss [Wang et al. 2013].

The main cereals cultivated in EU are wheat, rye, barley and spelt. *T. aestivum* L. is main substrate for flour and groats production. It is also widely grown as a basic agricultural feedstuff. Rye (*S. cereale* L.) is another important cereal cultivated in Europe, historically significant and still a key crop in many parts of the region [Hagenblad et al. 2016]. Spelt, a subspecies of wheat widely cultivated in Europe before 20th century, continues to be cultivated in Europe and plays an important role as a high-value niche product [Abrouk et al. 2018]. Barley (*Hordeum vulgare* L.) has been cultivated in Europe for approximately 6,000 years [Lempiäinen-Avci et al. 2018]. This cereal crop is utilized mostly as animal feed and for beer production (malting) [Gashaw 2021]. The genetic diversity present in both wild and cultivated barley offers significant potential for breeding programmes and improving crop quality [Zhang et al. 2014]. Cereal breeding is the most important factor behind the improvement of crop productivity and thus addresses the global food security challenges [Jansone et al. 2022].

Progress in cereal breeding provides new varieties that have high yield potential, are more resistant to diseases and pests. Through breeding programs, significant advancements have been made particularly by utilizing dwarf genes and exploiting heterosis [Akbar et al. 2021]. Most of the breeding programmes are resulting in increased diversity within species and new genotypes within the same species (breeding for new cultivars). It is also possible to carry out plant breeding to create new species (eg. through hybridization process). Triticale (× *Triticosecale* Wittmack) is a cereal crop that originated from the successful hybridization of hexaploid wheat (*T. aestivum* L.) and rye (*S. cereale* L.) in 19th century [Ma and Gustafson 2006, Alvarez et al. 2021]. This novel plant, resembling a cross between wheat and rye but morphologically more similar to wheat, was one of the first successful synthetic amphiploid cereals [McGoverin et al. 2011, Góral et al. 2020]. Breeding efforts for triticale have focused on improving its adaptability to local conditions, increased yield potential, disease resistance and nutritional quality of grain. This resulted in improved importance of this cereal in Europe over the last few decades, with production area almost doubled since 2000 to almost 3.3 million ha in 2010 [Kaltsikes et al. 1984, Alvarez et al. 2021]. Currently, according to FAOSTAT [2024] 86% of *Triticale* is cultivated in Europe (3.1 mln ha), with about 1.2 mln ha under cultivation in Poland solely [GUS 2023].

Certainly a lesser-known hybrid-cereal is *Tritordeum*. The parental forms of this species are durum wheat (*Triticum durum* Desf.) and a wild form of barley (*Hordeum chilense* Roem. and Schult) [Martin and Sanchez-Mongelaguna 1981]. The crop have been developed by Spanish National Research Council in the 70s. In 2013 it was introduced to the market. *Tritordeum*, similarly to Barley, is a drought tolerant with good wateruse efficiency. This makes it a good choice for regions with limited water resources. It is adapted to dry climates, resilient to environmental changes, and have a potential for applications in the food industry, such as breadmaking and pasta production [Landolfi and Blandino 2023, Papadopoulos et al. 2023]. The grain yield of the *Tritordeum* is not as high as *Triticum* yields, however, it has higher protein content than wheat. It contains higher levels of carotenoids, arabinoxylans, and antioxidants, with lower immunotoxic peptides compared to wheat [Visioli et al. 2020, Nitride et al. 2022]. *Tritordeum* might be considered as crop adapted to organic farming conditions, as it is showing increased rhizosphere bacterial diversity and beneficial effects on plant growth. Bread made from *Tritordeum* is of yellow colour, has fewer immunogenic epitopes than wheat, making it a potential alternative for those wishing to reduce gluten intake without compromising gut health [Haro et al. 2022]. *Tritordeum* is one of the plants where both the parental forms and the resulting hybrid are best adapted to the warm and fairly dry Mediterranean climate. It seems that, due to the climate changes taking place, there is also the possibility of cultivating this species in Poland. *Tritordeum* grain has high nutritional value, which is related to the absence of allergenic proteins and its increased lutein content.

To date, there are no scientific results on the possibility of cultivating *Tritordeum* under Polish climate conditions. Therefore, the yield potential of this cereal under Polish conditions is not known. Information on this subject can be gleaned from research results obtained under similar climatic conditions to Poland. Although *Tritordeum* is considered a thermophilic crop and is grown as a spring crop, it can also be cultivated as winter crop (under favourable conditions). In a study carried out by Martinek et al. [2003] *Tritordeum* was cultivated under central European climate conditions. A good winter hardiness and higher grain yields were found for autumn sowing of this species compared to spring sowing. The authors state that this may have been due to a mild winter and favourable staggering conditions, as well as better water supply for plants sown in autumn. The yield of plants sown in spring was 1.4–2.44 t ha^{-1}, with a yield of 2.04–3.92 t ha^{-1} of winter crops. As shown in the study by Vaquero et al. [2018], yielding potential of *Tritordeum* can be higher and range from 4.0 t ha^{-1} to 5.5 t ha^{-1}. Such research results give reason to believe that there is a possibility of growing *Tritordeum* in Poland.

Currently, there are no cultivated varieties of *Tritordeum* listed in the register of the Central Plant Variety Testing Centre, as well as in the Community Catalogue of Agricultural Varieties (CCA). Two cultivars are registered with the Community Plant Variety Office (CPVO): Aucan (in 2010) and Bulel (in 2015). A further 12 genetic lines are candidates for variety registration; and in 2018 they were tested in field trials [Różewicz and Wyzińska 2021].

The aim of the study was to assess the possibility of growing two *Tritordeum* cultivars in Poland under autumn and spring sowing conditions, as well as to evaluate the production potential of this species at different nitrogen fertilization rates with comparison to *T. aestivum* L. and *T. durum* Desf.

MATERIAL AND METHODS

The study was carried out in 2019–2021 with harvest in 2020 and 2021 as two two-factor pot experiments, using the independent series method. Experiments were located in the Vegetation Hall belong to the Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy (51.413, 21.965). Mitscherlich pots were used in four replicates per test object. The first experiment used an autumn sowing date for two *Tritordeum* cultivars and the second a spring sowing date. In both experiments, the first order factor was the nitrogen rate. Three levels of nitrogen fertilization were considered: N1 – 1.2 g N per pot; N2 – 2.4 g N per pot; N3 – 3.6 g N per pot. In both experiments, the second order factor was the cereal species. In the first experiment these were: 1) *T. durum* – Metis (winter form), 2) *Tritordeum* – Aucan cultivar, 3) *Tritordeum* – Bulel cultivar, 4) *T. aestivum* L. – Plejada cultivar (winter form). On the other hand, for the second experiment the following were selected: 1) *T. durum* Desf.– SMH 87 cultivar (spring form), 2) *Tritordeum* – Aucan cultivar, 3) *Tritordeum* – Bulel cultivar, 4) *T. aestivum* L. – Rusalka cultivar (spring form). The pots were filled with 7 kg of pseudo-polylic soil. Nitrogen was given in the form of NH_4NO_3, applying ½ dose before sowing and ½ dose at the stalk shooting stage. Fertilization with other nutrients was: P_2O_5 – 2.52 g per pot in the form of KH_2PO_4, K_2O – 2.04 g per pot in the form of K_2SO_4, Mg – 0.5 g per pot in the form of $MgSO_4$. In addition, iron (50 mg per pot), boron (5 mg per pot), manganese (3 mg per pot) and copper (3 mg per pot) were added to the soil substrate. The moisture content of the substrate was maintained throughout the growing season at 60% of the field water capacity. Moisture was controlled by gravimetric method, with pot weighting prior to watering (irrigation) to calculate the difference between the currnet weight and the target weight. Monthly temperatures during vegetation were, generally higher than average for 1981–2020, which seems to be a new reality in Poland nowadays (Tab. 1). Harvest was done at full maturity. After harvest, grain yield and yield structure elements (spikes per pot, tillering rate, thousand grain weight) were determined.

Table 1. Temperature (°C) in the experiment hall during the growing seasons of the study

Month	2019/2020	2020/2021	1981–2020 average
September	14.4	14.9	13.3
October	10.8	10.4	8.0
November	6.4	5.1	2.7
December	3.1	1.7	–1.4
January	1.7	–1.4	–3.3
February	3.4	–2.7	–2.3
March	4.7	2.8	1.6
April	8.9	6.9	8.7
May	11.9	12.9	14.5
June	19.1	20.0	17.2
July	19.3	22.2	19.5
August	20.3	17.1	17.8

Statistical comparison was done on a basis of analysis of variance ANOVA with post-hoc Tukey test at $p \leq 0.05$. Results were statistically processed with Statistica ver. 13.1 (StatSoft, Inc., Tulsa, OK, USA)

RESULTS AND DISCUSSION

Yields

In 2020, for autumn-sown cereals, *T. aestivum* L. yields (average of the 3 tested fertilization levels) were higher than those of the 3 other tested cereals. As a result of the weather pattern in 2021 (January 2021) *Tritordeum* sown in the autumn (both cultivars) did not survive the winter, and therefore no results are available for this species for 2021. No yield differences were observed between *T. durum* Desf. and *T. aestivum* L. for autumn sowing in 2021, while *T. aestivum* L. was significantly higher yielded when sown in spring (Tab. 2). Gallardo and Fereres [1993] found *Tritordeum* yields in Spain to be at the 23–53% of *T. durum* Desf. and *T. aestivum* L. yields. Suchowilska et al. [2021] found *Tritordeum* yields in Poland at a level of about 50% of *T. durum* Desf. This was not confirmed in the present study, where *Tritordeum* cv. Bulel (B) yielded generally at same level as *T. durum* Desf. and at 57–94% of *T. aestivum* L. yields. *Tritordeum* cv. Aucan (A) yields in the present study were at similar level and reached approximately 55–92% of *T. aestivum* L. yield potential. The reason behind lower levels of yield gap between *Tritordeum* and wheat may be due to scale of experiment (field experiment in Suchowilska et al. [2021] experiment vs. pot experiment in present study) and different set of cultivars tested. Currently, the global share of arable land suitable for durum wheat is 13%. Ongoing climate change could reduce this area by 19% by mid-century, and almost by half (48%) by the end of the century. On the other hand, the ongoing climate change may create favorable climate conditions for durum wheat cultivation in many areas of central and western Europe [Ceglar et al. 2021]. In Poland, such changes are visible and creating increasingly better conditions for the cultivation and breeding of pasta (durum) wheat. Compared to common wheat, yields of durum wheat are relatively resilient for drought occurring during the ripening period [Makowska et al. 2008, Harasim 2018]. In a study by Rachoń et al. [2022], the winter form of durum wheat (cv. Lapidur) yielded significantly lower than common wheat varieties. The same relationship was found for the spring form (cv. Floradur and cv. Haristide) of *T. durum* Desf. Yields of durum wheat were about 1 t ha^{-1} lower than yields of common wheat. However, durum wheat flour has a different quality and its unique qualities make it perfect for pasta production.

Kakabouki et al. [2020] tested same *Tritordeum* cultivars as in present study (Bulel and Aucan) under mediterranean conditions and found yields of both varieties to be at the same level. However, in our own research yields of Bulel and Aucan differed significantly for spring sowing dates. Moreover, authors found yields of *Tritordeum* to be at a level of about 47–79% of yield potential of *T. aestivum* L. (lower yield potential that in present study).

Table 2. Grain yield (g pot^{-1}) of tested crop species in 2020 and 2021 – mean for tested species (all N-levels combined)

Harvest year	Sowing date	*T. durum* Desf.	*Tritordeum* cv. Aucan	*Tritordeum* cv. Bulel	*T. aestivum* L.
2020	autumn	36.137 [b]	35.922 [b]	36.892 [b]	39.163 [a]
	spring	23.528 [b]	17.566 [c]	21.543 [b]	31.602 [a]
2021	autumn	44.438 [a]	n.d.	n.d.	45.22 [a]
	spring	28.00 [b]	20.250 [c]	20.450 [b]	35.720 [a]

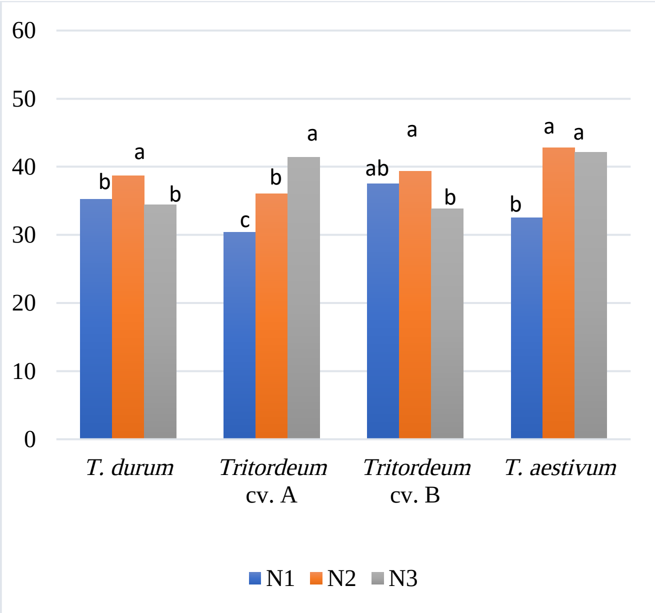
Different lowercase letters indicate significant differences between crop species a $p \leq 0.05$
n.d. – no data

In 2020, the highest yielding *T. aestivum* L., had statistically significan reaction to N fertilization rate. Research has shown that N2 and N3 fertilization resulted in a significant increase in yield to about 41 g pot^{-1} compared to fertilization with N1 (about 32 g pot^{-1}). For *Tritordeum*, the yield response to nitrogen fertilization was different for cultivar A and for cultivar B: *Tritordeum* A yielded the highest for N3 fertilization (41 g pot^{-1}) and *Tritordeum* B yielded highest for N2 fertilization (39 g pot^{-1}). For *T. durum* Desf., the highest yields were observed for N2 fertilization. Among of the tested species, a progressive increase in yield with increasing nitrogen fertilization rate was evident particularly for *Tritordeum* cv. A for which an increase in fertilization from N1 to N3 resulted in a yield increase of about 30%. The results also indicate a general trend of high yields already for N2 fertilization for most of the plants tested, with the exception of *Tritordeum* cv. A (Fig. 1).

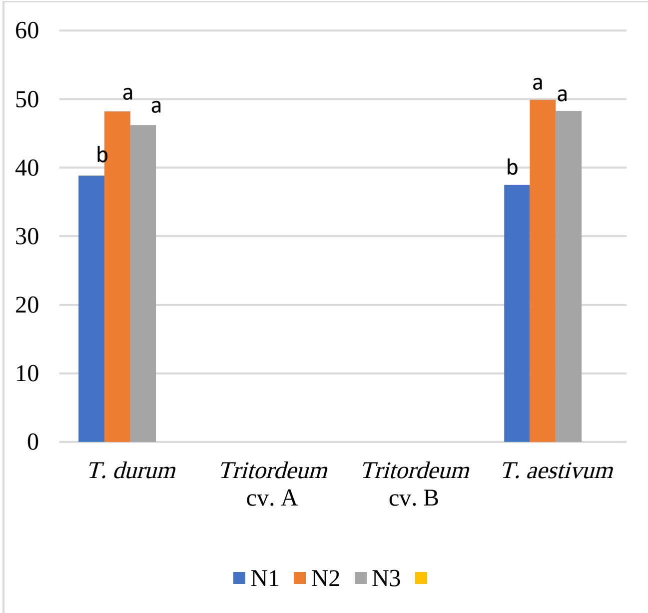
Different nitrogen fertilization rate resulted in different yields of durum wheat and common wheat in 2021: nitrogen fertilization at N2 and N3 levels gave a significant yield increase compared to N1 levels. The results indicate that nitrogen fertilization above the N2 level is not justified, as it did not give a significant yield increase (Fig. 1).

Tested spring sown cereals, in general, had lower levels of yields than autumn-sown cereals. On the other hand, *Tritordeum* sown in autumn 2020 (harvested in 2021) had significant frost damge which resulted in total crop failure. Crop failure was due to drop of temperature to about –20°C for few days. Intestringly, at the same time, same *Tritordeum* cultivars were cultivated in field conditions (unpublished results of Authors studies) and no frost damage was recorded. The risk of frost damage was much higher at pot trials, where crop roots were not protected from frost by snow.

In 2020, similarly to autumn-sown cereals, spring-sown *T. aestivum* L. had the highest yields (average for the 3 tested fertilization levels of about 32 g per pot). The second highest yielded in 2020 was *Tritordeum* cv. B and *T. durum* Desf. (yields level of approximately 22 g pot^{-1}) – Table 2. Interestingly, for spring cereals harvested in 2020, there is a clear trend towards high yields with N1 fertilization rate. The highest yields with N1 fertilization were recorded for *T. aestivum* L., *T. durum* Desf. and *Tritordeum* cv. B. For *Tritordeum* cv. A, the highest yields were recorded for the N2 fertilization level (Fig. 1).



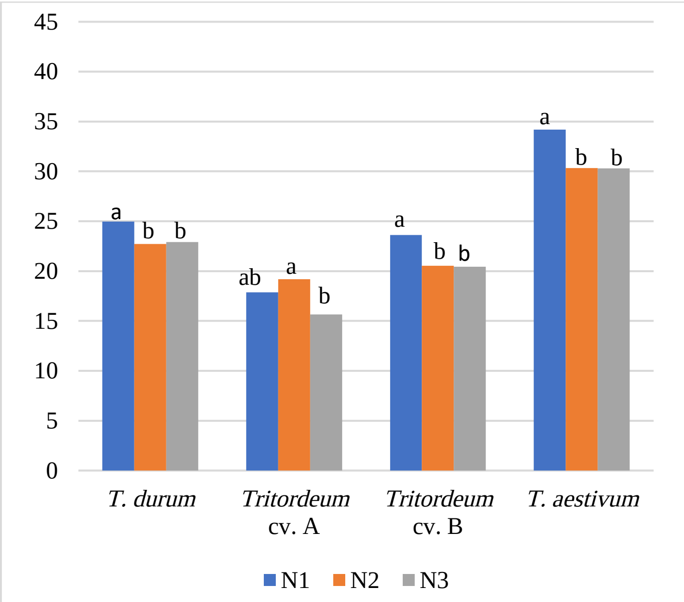
2020



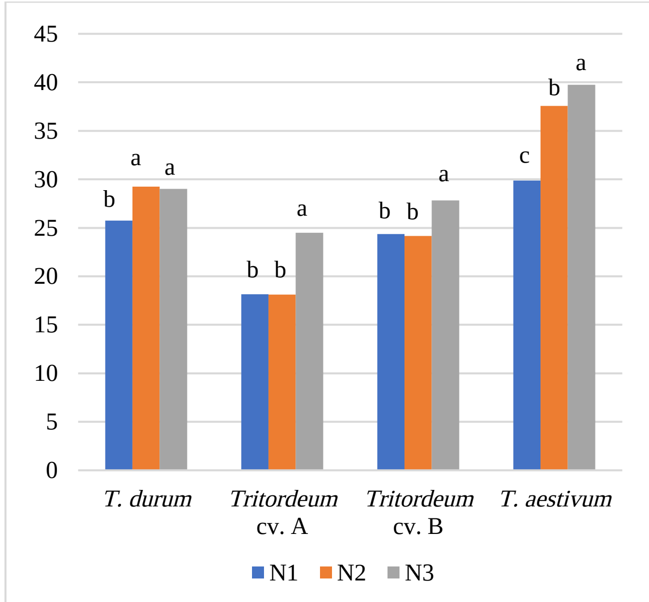
2021

Different lowercase letters indicate significant differences between fertilization levels

Fig. 1. Grain yield (g pot^{-1}) of tested cereal species sown in autumn fertilized with different nitrogen rates



2020



2021

Different lower-case letters indicate significant differences between fertilization levels

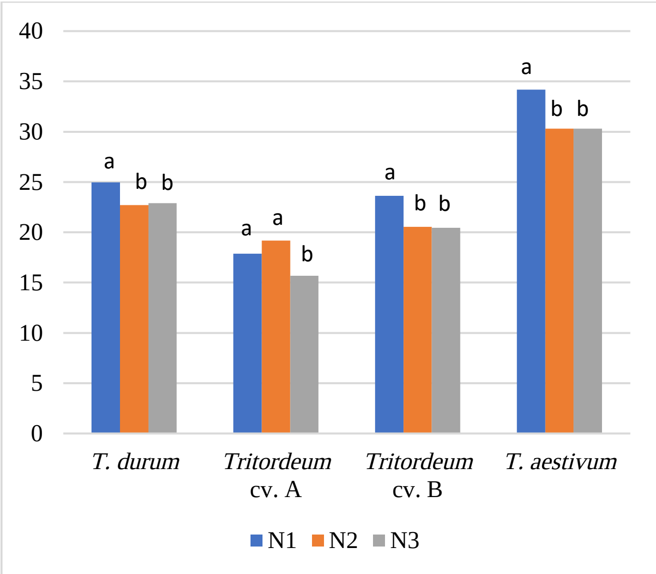
Fig. 2. Grain yield (g pot^{-1}) of tested cereal species sown in spring fertilized with different nitrogen rates

Average performance of tested spring-sown cereals in terms of their yields was similar in 2020 and 2021, – with the highest level of yields recorded for *T. aestivum* L. in both years of the study (approx. 32 g pot^{-1} and 35 g pot^{-1}, respectively), followed by *T. durum* Desf. and *Tritordeum* cv. B while *Tritordeum* cv. A yields were the lowest among all four tested cereals in 2020 and in 2021 (approx. 18 g pot^{-1} and 20 g pot^{-1}, respectively). In 2021, higher doses of nitrogen fertilization resulted in progressive yield increase especially for *T. aestivum* L., with the highest yields obtained for N3 fertilization rate (40 g pot^{-1}). Both tested cultivars of *Tritordeum* reacted positively in terms of yield increase for N3 fertilization, while yield increase for *T. durum* Desf. was the same for N2 and N3 fertilization rate (Fig. 2). In the study of Folina et al. [2020] cv. Bulel *Tritordeum* under NPK mineral fertilization reacted in significant (48%) incerease in yield (compared to control with no fertilization), while natural fertilization with compost and manure resulted in lower yield increase of 14% and 19% respectively. Significance of nitrogen fertilization impact on crop yields is well know, and multiple studies have confirmed higher doses of nitrogen positively impacts yields. This was also confirmed for *T. durum* Desf., species closy related to *Tritordeum* [Tedone et al. 2014, Ayadi et al. 2015, Galieni et al. 2016].

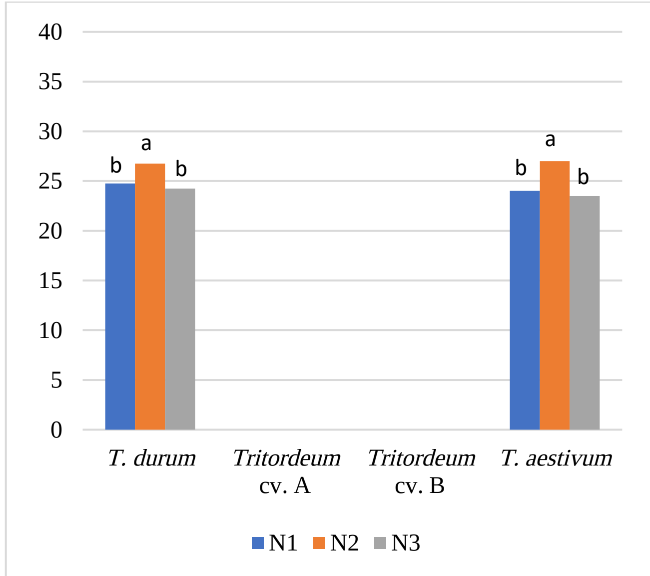
Spikes per pot

Differences in the number of spikes (ears) per pot were evident for the species tested. In general, *T. aestivum* L. had the highest number of spikes in both 2020 and 2021, and for both autumn-sown and for spring sown crops. The only exception was 2021, where for autumn sown cereals there was no differences observed between *T. aestivum* L. and *T. durum* Desf. (both tested *Tritordeu*m cultivars froze). The second highest number of ears were observed for *T. durum* Desf. and *Tritordeum* cv. Bulel for both spring and autumn sowing dates. For cereals sown in spring 2021, the second highest number of ears per pot was recorded for *Tritordeum* cv. B (Tab. 3). Montesano et al. [2021], on a basis of comparison of 5 lines of *Tritordeum* and one *T. durum* Desf. cultivar, found number of spikes of *T. durum* Desf. to be at similar level as of most *Tritordeum* lines. However, study also found one line of *Tritordeum* with significanly lower and one with significantly higher number of spikes than *Tritordeum*, which can indicate number of spikes are strongly dependent on plant genotype.

The nitrogen fertilization rate had a significant effect on the number of ears. For species sown at the autumn sowing date and harvested in 2020, higher fertilization rates resulted in a reduction in the number of ears per pot. On the other hand, autumn-sown cereals harvested in 2021 (*T. aestivum* L. and *T. durum* Desf.) showed a significant increase in the number of ears per pot for the N2 fertilization level (with no data for *Tritordeum*). For cereals sown at the spring sowing date, the fertilization level had different effects on the different species. For *Tritordeum* cv. A and *Tritordeum* cv. B, a decrease in the number of ears per pot for the N3 application rate was observed in 2020 (appropriately 19.5 and 21.5 ears). In 2021, *Tritordeum* cv. A responded with a decrease in the number of ears per pot only for the N2 fertilization rate (23 ears). For *Tritordeum* cv. B, in 2021, no response of this species to nitrogen fertilization (in terms of number of ears) was observed at the spring sowing date. Spring sown *T. aestivum* L. responded with an increase in ear number with increasing fertilization levels in 2021, and the highest number of ears for N2 fertilization in 2020 (Tab. 3, Fig. 3 and 4).



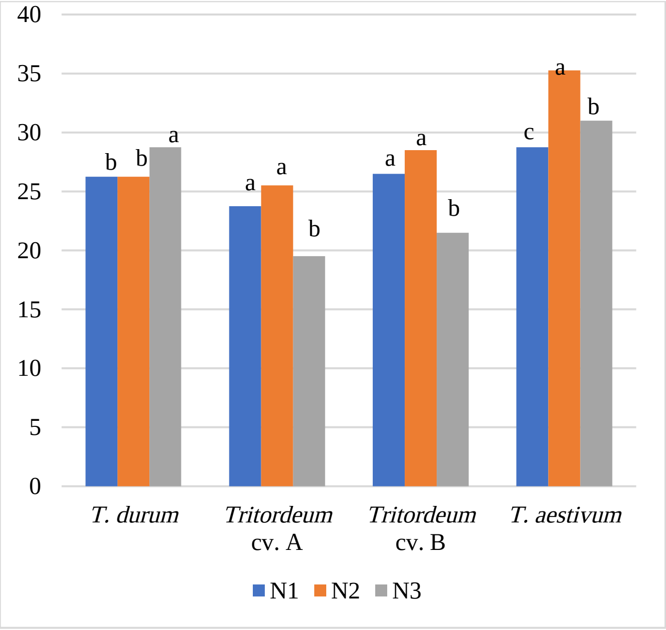
2020



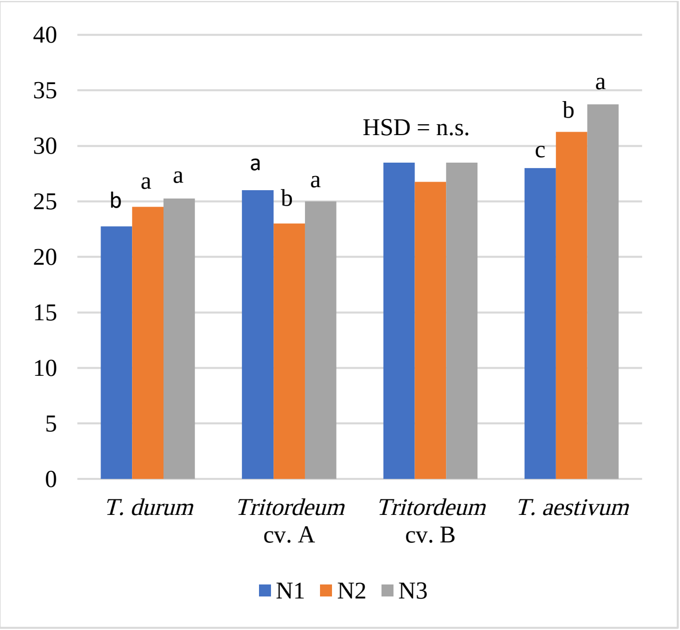
2021

Different lowercase letters indicate significant differences between fertilization levels

Fig. 3. Number of spikes (ears) per pot of tested cereal species sown in autumn fertilized with different nitrogen rates



2020



2021

Different lowercase letters indicate significant differences between fertilization levels.

Fig. 4. Number of spikes (ears) per pot of tested cereal species sown in spring fertilized with different nitrogen rates

Table 3. Number of spikes per pot of tested cereal species depending of sowing date

Harvest year	Sowing date	*T. durum* Desf.	*Tritordeum* cv. Aucan	*Tritordeum* cv. Bulel	*T. aestivum* L.
2020	autumn	23.527 [b]	17.566 [c]	21.543 [b]	31.602 [a]
	spring	27.083 [b]	22.916 [c]	25.500 [bc]	30.666 [a]
2021	autumn	25.25	n.d.	n.d.	24.833
	spring	24.166 [c]	24.666 [c]	27.916 [b]	31.000 [a]

Different lowercase letters indicate significant differences between crop species a $p \leq 0.05$
n.d. – no data

Productive tillering coefficient

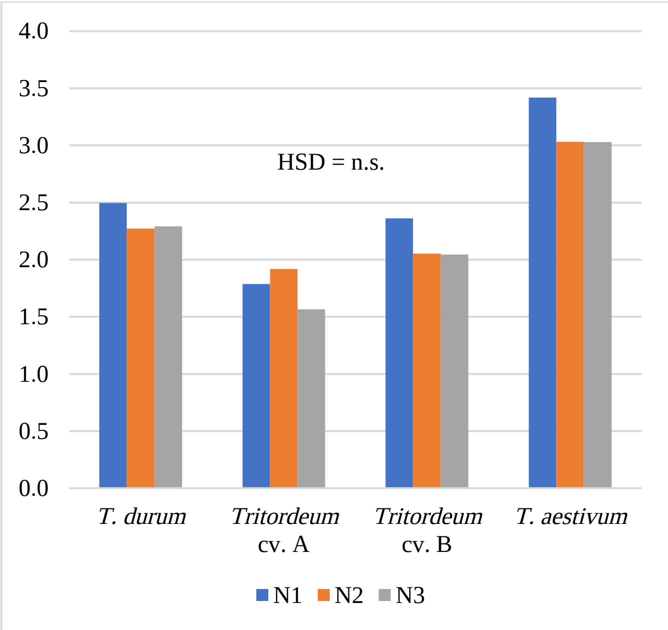
Some differences were observed between the species tested in terms of productive tillering coefficient. It was the highest for *T. aestivum* L. for both sowing dates (autumn and spring) with the exception of the autumn sowing date of 2021, where no differences were observed between *T. aestivum* L. and *T. durum* Desf. (both *Tritordeum* varieties froze). The tillering rate for winter wheat reached a value of approx. 3 (Tab. 4). Kakabouki et al. [2020] found tillering rate of *Tritordeum* cv. Bulel significantly higher than *Tritordeum* cv. Aucan. In the present study, this was only confirmed for 2020 and autumn date of sowing. Authors [Kakabouki et al. 2020], also found *Tritordeum* cv. Bulel to have higher rate of tillering than *T. aestivum* L., which wasn't confirmed in the present study. Studies found, that nitrogen deficiency in winter wheat is associated with a reduced rate of leaf appearance and tiller growth, while an increase in nitrogen application rate increases tiller density and reduces tiller mortality [Yang et al. 2019].

Fertilization rate, in most cases, had no effect on crop tillering rate. The only differences in tillering rate were recorded for spring *T. aestivum* L. In 2020, increasing the fertilization rate to N2 resulted in an increase in productive tillering to a level of 3.5., while in 2021, fertilization at the N3 rate resulted in a similar increase in productive tillering (to about 3.5) – Figures 5 and 6.

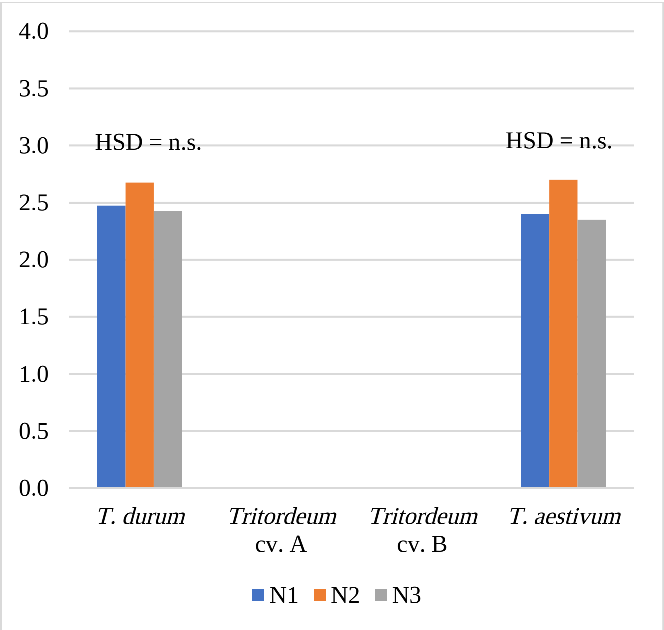
Table 4. Productive tillering coefficient of tested cereal species depending on sowing date

Harvest year	Sowing date	*T. durum* Desf.	*Tritordeum* cv. Aucan	*Tritordeum* cv. Bulel	*T. aestivum* L.
2020	autumn	2.353 [b]	1.756 [c]	2.154 [b]	3.160 [a]
	spring	2.708 [b]	2.291 [b]	2.550 [b]	3.166 [a]
2021	autumn	2.525	n.d.	n.d.	2.483
	spring	2.416 [b]	2.466 [b]	2.791 [b]	3.100 [a]

Different lowercase letters indicate significant differences between crop species a $p \leq 0.05$
n.d. – no data



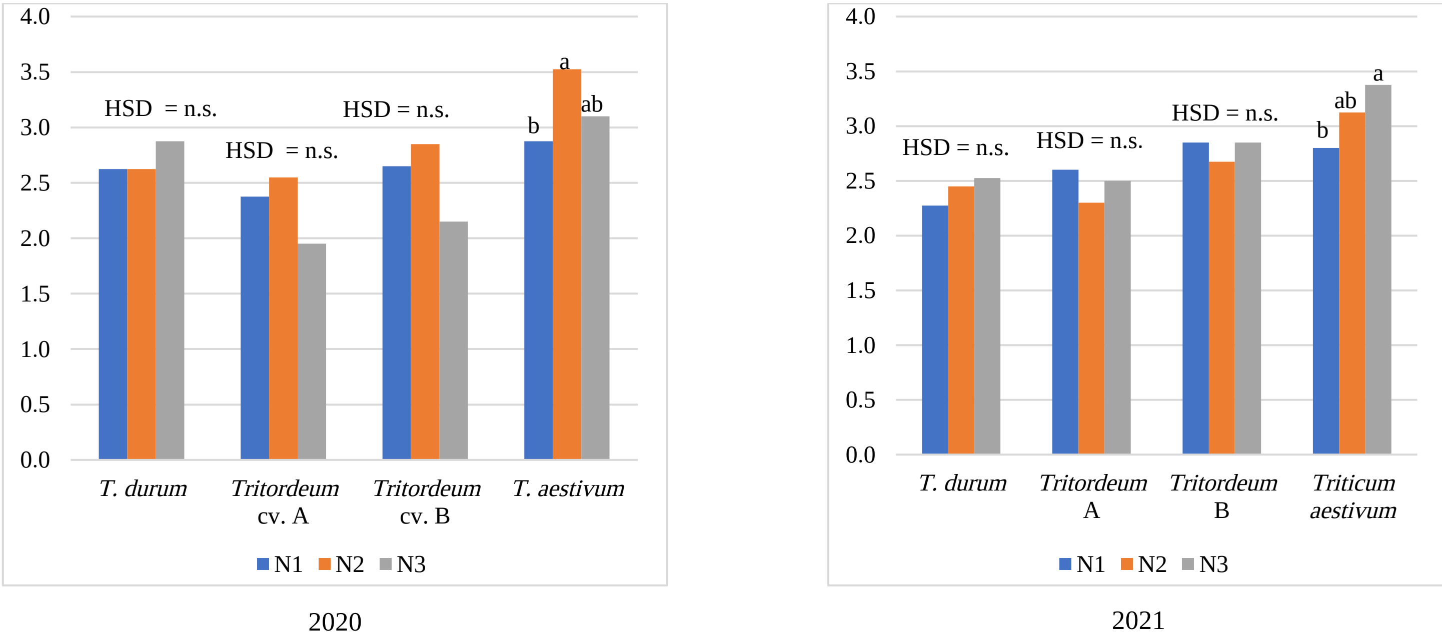
2020



2021

Different lowercase letters indicate significant differences between fertilization levels

Fig. 5. Productive tillering coefficient of tested cereal species sown in autumn fertilized with different nitrogen rates



Different lowercase letters indicate significant differences between fertilization levels

Fig. 6. Productive tillering coefficient of tested cereal species sown in spring fertilized with different nitrogen rates

Thousand grain weight

The thousand grain weight for the tested cereals sown in the autumn was significantly the lowest for *Tritordeum* cv. A in 2020. There was no differences between crop species in 2021. For spring-sown cereals, the lowest thousand-grain weight was recorded for *Tritordeum* cv. B, both in 2020 and 2021 (28.473 g and 29.406 g) – Table 5.

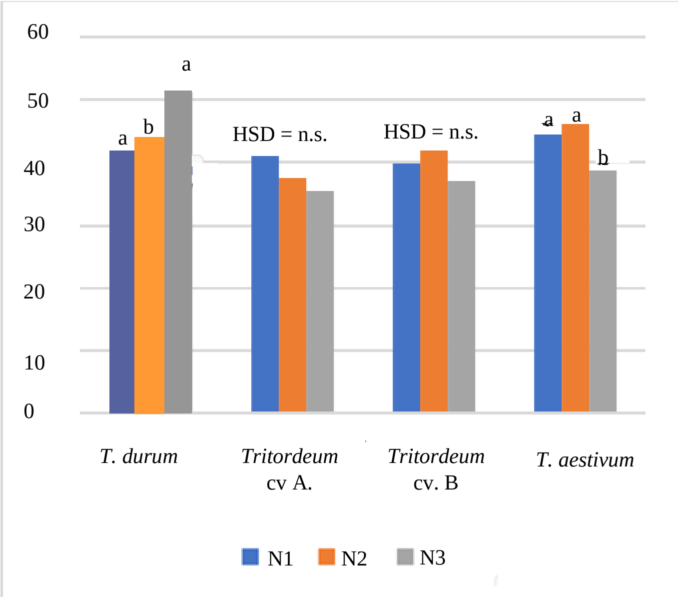
Table 5. Thousand grain weight of tested cereal depending on sowing date

Harvest year	Sowing date	*T. durum* Desf.	*Tritordeum* cv. Aucan	*Tritordeum* cv. Bulel	*T. aestivum* L.
2020	autumn	44.724 [a]	37.965 [b]	39.727 [ab]	43.039 [a]
	spring	30.753 [b]	32.793 [a]	28.473 [c]	31.487 [ab]
2021	autumn	43.648	n.d.	n.d.	44.747
	spring	37.106 [a]	30.911 [bc]	29.406 [c]	33.206 [b]

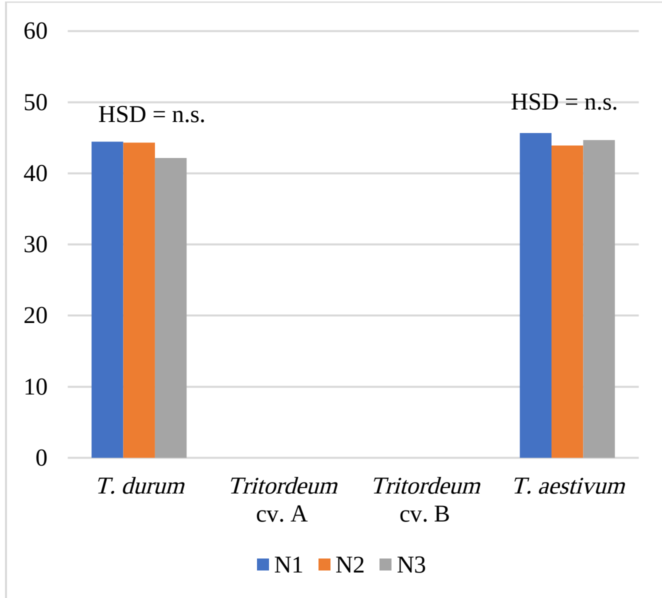
Different lowercase letters indicate significant differences between crop species a $p \leq 0.05$
n.d. – no data

Different levels of fertilization had an effect on some of the species tested. For the autumn sowing date, in 2020, thousand grain weight increased significantly with increasing fertilization for *T. durum* Desf., while fertilization at the N3 level caused a significant reduction in thousand grain weight for *T. aestivum* L. (Fig. 7). For the spring sowing date, in 2020 only *Tritordeum* cv. A showed a decrease in thousand grain weight at increased fertilization level N2. In 2021, the same variety of *Tritordeum* showed an increase in thousand grain weight for fertilization levels of N2 and N3. Spring common wheat harvested in 2021 fertilized with higher doses of nitrogen (N2 fertilization level) had higher thousand grain mass than N1 and N3 nitrogen fertilization rates (Fig. 8). Kakabouki et al. [2020] tested different genotypes of *Tritordeum* for their thousand grain mass. Authors found *Tritordeum* cv. Aucan thousand grain mass to be significantly greater than *Tritordeum* cv. Bulel's in both years of the study (31.4 g and 28.5 g in 2019 and 31.3 and 28.7 in 2020 respectively). Therefore, the level of thousand grain mass for both *Tritordeum* cultivars found by autor was at similar level as in present study. On the other hand, study by Montesano et al. [2021] showed thousand grains mass able to reach 33.8 g–38.2 g depending on *Tritordeum* genotype.

Folina et al. [2020] found *Tritordeum* cv. Bulel 1000 grain weight to significantly increase under mineral fertilization with NPK (increase from 27.5 g to 31.9 g), compost fertilization (increase to 29 g) and manure fertilization (29.8 g). Therefore, mass of thousand grains of *Tritordeum* cv. Bulel fertilized with NPK found by authors was at lower level as *Tritordeum* cv. Bulel sown in autumn thousand grain mass found in present study (39.7 g) and on slightly higher level than for spring *Tritordeum* cv. Bulel (28.5 g in 2020 and 29.4 g in 2021).



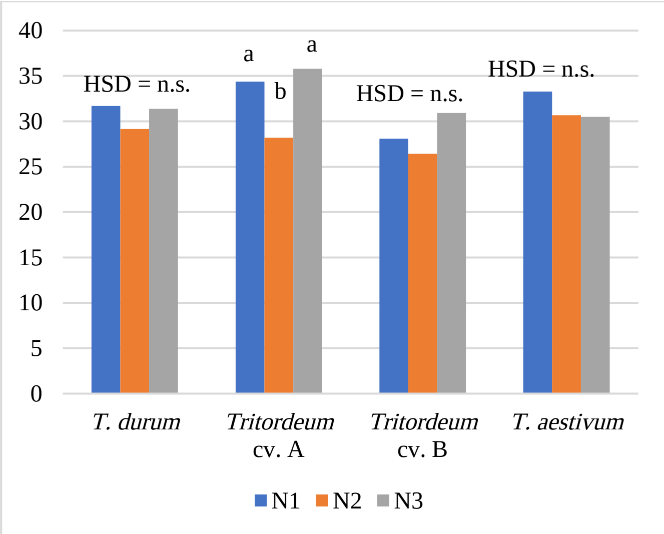
2020



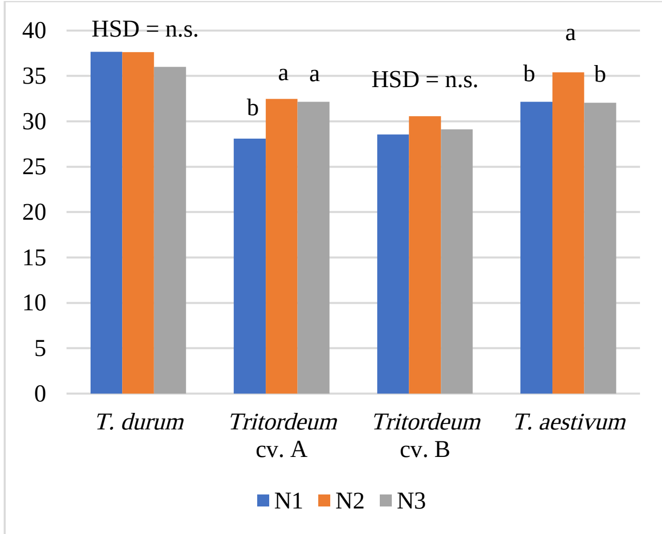
2021

Different lowercase letters indicate significant differences between fertilization levels

Fig. 7. Thousand grain weight of tested cereal species sown in autumn and fertilized with different nitrogen



2020



2021

Different lowercase letters indicate significant differences between fertilization levels

Fig. 8. Thousand grain weight of tested cereal species sown in spring and fertilized with different nitrogen

CONCLUSIONS

The results of the pot experiment on the yield and some traits of the two *Tritordeum* hybrid varieties in relation to the two dominant wheat species in Poland: common wheat (*T. aestivum* L.) and durum wheat (*T. durum* Desf.), showed the yield level of *Tritordeum*, particularly *Tritordeum* cv. Bulel, was similar to that of *T. durum* Desf., while the yields of *T. aestivum* L. were at higher level (8% for autumn sowing and about 43% for spring sowing). Moreover, *Tritordeum* cv. Bulel, showed a slightly lower yield level than cv. Aucan (by about 1–8%).

The other traits tested (number of ears, productive tillering, thousand grains weight) placed *Tritordeum* (in particular *Tritordeum* cv. Bulel) closer to *T. durum* Desf. than to *T. aestivum* L. The latter showed higher results in terms of particularly tillering rate and number of spikes per pot. This shows, that, under Polish clime conditions (moderate climate), yields of *Tritordeum* (sown in autumn) can match-up yields of *T. durum* Desf., and be very close to *T. aestivum* L. performance. Moreover, there is a risk of frost damage to *Tritordeum* sown in autumn – which has occurred in pots. The performance of *Tritordeum* should be further tested, as currently climate of Poland is quickly shifting towards warmer climate zones. Study found, to no surprise, that nitrogen fertilization stimulates yields. However, the optimal level of fertilization depends on the species, cultivar, which also demonstrates the importance of conducting fertiliser trials to optimise the economic effects (applying only as much fertiliser as necessary) of cultivation.

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