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ORIGINAL PAPER

Evaluation of yield and content of selected nutrients and minerals in spring wheat grain*

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Abstract

The aim of the study was to compare the volume and quality of yield of selected wheat species: common (*Triticum aestivum* subsp. *aestivum*), hard (*T. turgidum* L. subsp. *durum*), spelt (*T. aestivum* subsp. *spelta*), emmer (*Triticum turgidum* subsp. *dicoccum*) and einkorn (*T. monococcum* subsp. *monoccocum*). The field experiment was established at the Podkarpackie Agricultural Advisory Center in Boguchwała, Podkarpackie Voivodeship, Poland. It was carried out in 2019, 2020 and 2021. It was a one-factor experiment in a randomized block design with four replicates. The experiment was set up on Luvisol soil with slightly acidic pH and medium humus and mineral nitrogen content. Common wheat was characterized by the shortest straw, long ear and the highest number of grains per ear and TSW. Hard wheat and spelt had similar or slightly lower biometric parameters. Emmer and einkorn developed the longest culm and were susceptible to lodging. In addition, they had short ears with a low number of grains and TSW. The yield of common wheat ranged from 5.88 to 6.66 t ha^{-1}, durum wheat yielded lower, from 5.06 to 5.81 t ha^{-1}, and spelt from 3.44 to 4.05 t ha^{-1}; the lowest yield was obtained from emmer and einkorn wheats, from 1.72 to 2.31 t ha^{-1} and 1.45 to 2.23 t ha^{-1}, respectively. However, einkorn and emmer grains contained the most nutrients and minerals, while grains of spelt and durum wheats had less of these components. A high content of protein, fat, calcium, manganese and copper was determined in the grain of these species. In addition, emmer grain contained high ash content and einkorn grain possessed high magnesium content. In general, the lowest amount of nutrients and minerals components was determined in naked wheat grains, especially in common wheat.

Keywords: common wheat, durum wheat, spelt wheat, emmer wheat, einkorn wheat, minerals components

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INTRODUCTION

Most cultivated varieties of common and hard wheat have been genetically altered through breeding programs. This has resulted in high grain yields with good characteristics for the food industry (Alvarez, Guzmán 2018). Čurná, Lacko-Bartošová (2017) have reported that food products from naked wheat are commonly consumed as a source of protein and carbohydrates. However, consumer interest in hulled wheat has increased in recent years owing to their favorable chemical grain composition. Such relict species include spelt, emmer and einkorn (Zaharieva, Monneveux 2014, Picascia et al. 2020). Arzani and Ashraf (2017) reported that ancient wheats were cultivated in the Middle East, from where they spread to other parts of the world. Subsequently, these species were replaced by more efficient wheat, i.e. common and durum wheats (Zaharieva, Monneveux 2014, Volante et al. 2021, Fundurulic et al. 2022). Currently, common wheat is one of the most important crops in the world, and its grain is used in food (de Sousa et al. 2021) or fodder production. In this aspect, it should be noted that wheat foods contain gluten, and therefore are not recommended for people with celiac disease (Picascia et al. 2020, Brouns et al. 2022). Overall, it is estimated that 10% of the population in Western countries suffer from gastrointestinal symptoms that have no apparent cause. In the case of such diseases, correct diagnosis and diet selection are important, which especially applies to cereal products. Comparison of the nutritional value of various wheats showed that hulled grains contained more protein and other valuable ingredients than naked wheat grains. It should be noted, however, that the chemical composition of the grain can also be modified by habitat conditions and the agricultural practices used (Brouns et al. 2022). Ancient wheats are most often grown on organic farms (Zaharieva, Monneveux 2014), but they can also be useful in conventional systems, e.g. low-input farms (Lacolla et al. 2021). Ancient wheats are much more resistant to fungal diseases than common wheat.

Bouchareb and Guendouz (2022) concluded that wheat species and varieties should be adapted to the local conditions of the habitat, which would allow obtaining stable crops of good grain quality. Yang et al. (2022) indicated that many varieties of common wheat are susceptible to biotic and abiotic stresses. Therefore, ancient species, i.e. spelt, einkorn or emmer, are used in the breeding of new varieties to improve their resistance to environmental stresses (de Sousa et al. 2021, Volante et al. 2021, Gong et al. 2022).

Variation in the yield of individual wheat species is high. Troccoli and Codianni (2005) obtained on average 1.42 t ha^{-1} einkorn grain, 2.80 t ha^{-1} spelt and 3.54 t ha^{-1} emmer. In the study of Biel et al. (2021), the average grain yield was 4.8 t ha^{-1} common wheat, 3.2 t ha^{-1} spelt, 2.5 t ha^{-1} of emmer and 2.0 t ha^{-1} einkorn. In contrast, Marino et al. (2009) showed similar yields of emmer wheat to durum wheat, but it was susceptible to lodging. Moreover, the yield of emmer (Marino et al. 2009) or spelt (Zečević et al. 2022) can be increased with nitrogen fertilization. However, a nitrogen dose must be adapted to the species and even the variety. Ali et al. (2021) showed that wheat yields depended on many factors, including species or variety. The spelt yields obtained by the authors ranged from 2.97 t ha^{-1} for the variety Polonicum to 7.71 t ha^{-1} for the variety Ofanto. In this aspect, Csákvári et al. (2021) reported that winter forms yielded higher than spring forms, but contained less protein in grain. A study by Keçeli et al. (2021) showed that einkorn grain was high in protein and macro- and micronutrients. Therefore, flour from ancient wheat is a good addition to common wheat flour. Rachoń et al. (2015) confirmed that einkorn wheat had a good chemical grain composition compared to other wheat species. With respect to common wheat, they showed that the grain contained primarily carbohydrates. Longin et al. (2016) also demonstrated that einkorn, emmer and spelt had a good chemical composition of grain, but lower yields compared to common wheat. In addition, they develop long culms susceptible to lodging. Therefore, it should be expected that breeding programs will be aimed at improving the unfavorable features of ancient wheats, which would allow for their popularization in cultivation. Consumer interest in products from ancient wheats is already resulting in an increase in their acreage and availability of food products. Fadida-Myers et al. (2022) have pointed out, however, that hulled wheats require post-harvest grain processing. Therefore, it is necessary to purchase special machines for dehulling and cleaning the grain, which increases the costs of grain production. Therefore, conducting experiments with different wheat species should be considered cognitively important, especially in terms of changing food trends.

The aim of the study was to compare the yield and quality of five spring wheat species. The research hypothesis assumed that hulled wheats would yield lower than naked wheats, but they would have a more favorable grain chemical composition, especially of mineral components.

MATERIALS AND METHODS

The field experiment was established at the Podkarpackie Agricultural Advisory Center in Boguchwała (21°57′E 49°59′N), Podkarpackie Voivodeship, Poland. It was carried out in 2019, 2020 and 2021. It was a one-factor experiment in a randomized block design with four replicates. The following spring wheat species were included in the study:

- common wheat (*Triticum aestivum* L. subsp. *aestivum*), variety Mandaryna;
- hard wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.), variety SMH87;

– spelt wheat (*Triticum aestivum* L. subsp. *spelta* (L.) Thell.), variety Wirtas;
– emmer wheat (*Triticum turgidum* subsp. *dicoccum* (Schrank ex Schübl.) Thell.), variety Bondka;
– einkorn wheat (*Triticum monococcum* L. subsp. *monoccocum*), variety Pagatula.

The experiment was set up on Luvisol soil (IUSS Working Group WRB 2015) with slightly acidic pH and medium humus and mineral nitrogen content. The content of available phosphorus and potassium was high, while that of magnesium was medium (Table 1). Micronutrient content was medium and only boron was low. Soil samples were collected in spring, to a depth of 30 cm, and their analysis was conducted by an accredited laboratory of the Regional Chemical and Agricultural Station in Rzeszów, according to Polish standards.

Table 1

Chemical analysis of soil

Parameter	Unit	2019	2020	2021
pH in KCl	–	6.3	6.4	5.9
Humus	%	1.6	1.3	1.2
Nmin	(kg ha^{-1})	77	72	74
P_2O_5	(mg 100 g^{-1} soil)	19.8	18.6	17.9
K_2O		22.6	21.3	20.9
Mg		6.2	6.6	5.8
Fe	(mg kg^{-1} soil)	2677.6	2092.1	2337.5
Zn		14.6	11.8	12.4
Mn		379.2	221.6	308.8

After harvesting the preceding crop (field bean), a disc harrow and harrowing were applied, as well as plowing to a depth of 25 cm before winter. Harrowing was conducted in the spring and a combined cultivator was used before sowing.

The weather conditions were given according to the records of the Meteorological Station of the Subcarpathian Agricultural Advisory Center in Boguchwała. The weather conditions varied during the study years, and modified the yield and seed quality parameters. Low precipitation was recorded in June 2019 and April, July and August 2020. On the other hand, rainfall in June 2020 was more than twice as high compared to the long-term average. In 2021, April and August were cold, and July was a hot month. High temperatures were recorded in June 2019, and low in May 2020 (Figure 1).

In autumn, superphosphate (19% P_2O_5) and potassium salt (60% K_2O) were used for fertilization. The P and K doses were 20 and 50 kg ha^{-1},

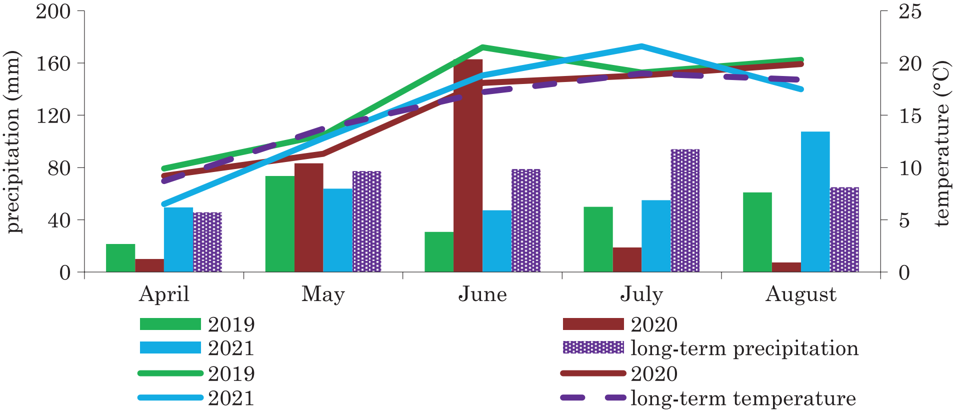

Fig. 1. Weather conditions

respectively. Nitrogen fertilization (34% ammonium nitrate) was applied at a dose of 60 N kg ha^{-1} before sowing. Fertilizer (Basfoliar 2.0 36 Extra) was sprayed at a dose of 4 L ha^{-1} during the stem shooting stage.

The seed material was treated with the Gizmo 060 FS preparation (50 mL 100 kg^{-1} of grain). Sowing was carried out on: April 10, 2019, April 8, 2020 and April 7, 2021. The sowing amount for common wheat and hard wheat was 450 grains m^{-2}, while 350 spikelets m^{-2} were sown for spelt, emmer and einkorn wheats.

The row spacing was 15 cm and sowing depth was 4 cm. The area of a single plot was 15 m^2. The preparation GF-2573 (halauxifen methyl – Arylex) at a dose of 0.6 L ha^{-1} was used to control weeds. No other chemical plant protection treatments were applied.

The number of spikes before harvest was counted on an area of 1 m^2. Subsequently, 40 plants were collected for biometric measurements: plant height, spike length, number of grains per spike and thousand grain weight. Harvesting was carried out using a plot harvester on the following days: August 12, 2019, August 10, 2020 and August 13, 2021. The yield was converted to 1 ha, at 14% grain moisture. The yield amounts reported are referred to the hulled kernel for the wheat species: Spelt, Emmer, Einkorn.

Chemical grain composition (protein, fat, starch, ash) was determined using the near-infrared method and a FT-LSD MPA spectrometer (Bruker, Germany). To determine the nutrient content, grain samples were mineralized in HNO_3:$HClO_4$:H_2SO_4 in a 20:5:1 ratio using an open system and a Tecator heating block. The content of macro- and micronutrients was determined in the samples by atomic absorption spectroscopy (FAAS) using a Hitachi Z-2000 apparatus (Konica Minolta, Inc., Tokyo, Japan). In a typical FAAS instrument, the sample is atomized, thereby transiting from a ground state to higher energy levels. In the excited state, each element has a unique spectrum that distinguishes it from other elements. The spectral lines are very sharp, so that they rarely overlap. A UV-VIS Shimadzu spectrophotometer (Konica Minolta, Inc. Tokyo, Japan) was used for the determination of phosphorus (P) using the vanadate-molybdate method.

The results were statistically analyzed using the Statistica 13.3.0 software (TIBCO Software Inc., Palo Alto, CA, USA). Two-way ANOVA was applied, and the Tukey's HSD post-hoc test ($p \leq 0.05$) was used to determine the differences between the mean values of the analyzed parameters.

RESULTS

The height of the plants depended on the interaction of the species with the years of research. In 2019 and 2020, the height of emmer plants was 84.6 cm and 100.3 cm, respectively. Common wheat developed significantly lower plants, less by 9.0 and 9.4 cm, respectively. In 2021, einkorn wheat developed the highest plants, while bread wheat and spelt significantly lower plants. Plant lodging did not depend on the interaction of the species with the years of the study. It was shown that einkorn and emmer were the most affected subspecies. Spelt wheat showed less lodging, and bread and hard wheat were the least susceptible to lodging. In 2020, plant lodging was significantly higher compared to 2019 and 2021. Spelt and bread wheat developed the longest ears, durum wheat had significantly shorter ears, and einkorn and emmer wheats grew the shortest ears. The ears were significantly longer in 2020 than in 2019 and 2021 (Table 2).

The number of ears per 1 m^{-2} depended on the interaction of the species with the study years. It was shown that the smallest number of ears per unit area was found in emmer wheat in 2020 and 2021, and in einkorn wheat in 2019 and 2020. The number of grains per ear varied between wheat species. In order from the largest, these were: bread wheat, hard wheat, spelt, emmer and einkorn. In 2019, the number of grains per ear was significantly higher compared to 2020. Thousand grain weight was the highest in bread wheat, lower in hard wheat and spelt, and the lowest in emmer and einkorn subspecies. In 2019 and 2021, thousand grain weight was higher than in 2020 (Table 3).

The height of the plants depended on the interaction of the species with the study years. Bread wheat yielded the highest, from 5.88 to 6.66 t ha^{-1}. Durum wheat yielded similarly or slightly lower, from 5.06 to 5.81 t ha^{-1}. On average, spelt wheat produced lower grain yields. It should be noted, however, that the yield of spelt wheat in 2019 and 2021 was similar to the yield of durum wheat obtained in 2020. Emmer and einkorn yielded the lowest (Figure 2). In 2020, the yield of einkorn was 1.45 t ha^{-1}. It was therefore more than four times lower in relation to bread wheat.

The basic chemical composition of the grain did not depend on the interaction of the species with the years of study. The lowest protein content

Table 2

Plant measurements and ear length

Species	Years	Plant height (cm)	Lodging (1-9°)	Ear length (cm)
Common wheat	2019	75.6[e]	8.57	9.10
	2020	90.9[bcd]	7.53	9.90
	2021	74.7[e]	8.60	9.17
Durum wheat	2019	80.7[cde]	8.77	6.40
	2020	97.7[ab]	7.67	7.13
	2021	80.6[cde]	8.73	6.43
Spelt wheat	2019	77.9[de]	7.93	9.17
	2020	95.4[ab]	6.93	9.97
	2021	76.7[e]	8.00	9.20
Emmer wheat	2019	84.6[bcd]	7.50	5.30
	2020	100.3[a]	6.43	6.10
	2021	79.9[cde]	7.53	5.27
Einkorn wheat	2019	80.6[cde]	7.36	5.77
	2020	94.2[abc]	6.37	6.57
	2021	83.5[bcd]	7.37	5.50
Species x years		*	n.s.	n.s.
Common wheat		81.5[b]	8.23[a]	9.39[a]
Durum wheat		86.4[ab]	8.39[a]	6.66[b]
Spelt wheat		83.3[ab]	7.62[b]	9.44[a]
Emmer wheat		89.5[a]	7.16[c]	5.56[c]
Einkorn wheat		84.1[ab]	7.03[c]	5.94[bc]
Species		*	***	***
2019		79.9[b]	8.03[a]	7.15[b]
2020		95.9[a]	6.99[b]	7.93[a]
2021		79.1[b]	8.05[a]	7.11[b]
Year		***	***	**

***, **, * indicate significant differences at $p<0.001$, $p<0.01$ and $p<0.05$;
n.s. – non-significant, according to the Tukey's honestly significant difference (HSD) test. Mean values with different letters (*a–e*) in columns are statistically different for foliar fertilization.

in the grain was determined in bread wheat and significantly higher in the hulled species. Emmer and einkorn wheats were characterized by the high fat content. In addition, einkorn wheat contained more ash in grain compared to common wheat. A similar relationship was shown for fiber. The content of the discussed components varied over the years, with the exception of starch (Table 4).

Table 3

Yield component measurements

Species	Years	Ears per m^{-2}	Number of grains per ear	Mass of 1000 grains (g)
Common wheat	2019	491.9^{a}	33.5	40.3
	2020	475.8^{ab}	31.3	39.4
	2021	491.2^{a}	32.5	41.3
Durum wheat	2019	487.0^{ab}	30.8	38.6
	2020	470.7^{abc}	29.0	37.0
	2021	486.2^{ab}	29.8	39.5
Spelt wheat	2019	483.3^{ab}	25.6	32.6
	2020	468.5^{abc}	23.5	31.2
	2021	482.4^{ab}	24.6	32.7
Emmer wheat	2019	448.5^{abcd}	20.8	24.7
	2020	435.7^{bcd}	19.0	22.4
	2021	421.5^{cd}	16.8	24.2
Einkorn wheat	2019	421.9^{cd}	17.6	23.5
	2020	409.5^{d}	15.8	22.4
	2021	453.9^{abcd}	19.8	24.8
Species x years		*	n.s.	n.s.
Common wheat		486.3^{a}	32.4^{a}	40.3^{a}
Durum wheat		481.3^{a}	29.9^{b}	38.4^{b}
Spelt wheat		478.1^{a}	24.6^{c}	32.2^{c}
Emmer wheat		446.0^{b}	19.9^{d}	23.9^{d}
Einkorn wheat		417.6^{c}	16.7^{e}	23.4^{d}
Species		***	***	***
2019		466.5	25.6^{a}	31.9^{a}
2020		452.1	23.7^{b}	30.5^{b}
2021		467.1	24.7^{ab}	32.5^{a}
Year		n.s.	**	***

***, **, * indicate significant differences at $p<0.001$, $p<0.01$ and $p<0.05$;
n.s. – non-significant, according to the Tukey's honestly significant difference (HSD) test. Mean values with different letters (*a–e*) in columns are statistically different for foliar fertilization.

The content of phosphorus and potassium did not differ significantly between the wheat species or in the individual study years. It was found, however, that the magnesium content was high in einkorn grain and significantly lower in bread and hard wheat. Emmer and einkorn contained more calcium in grain than hard wheat. Only the calcium content in the grain was significantly modified during the study years (Table 5).

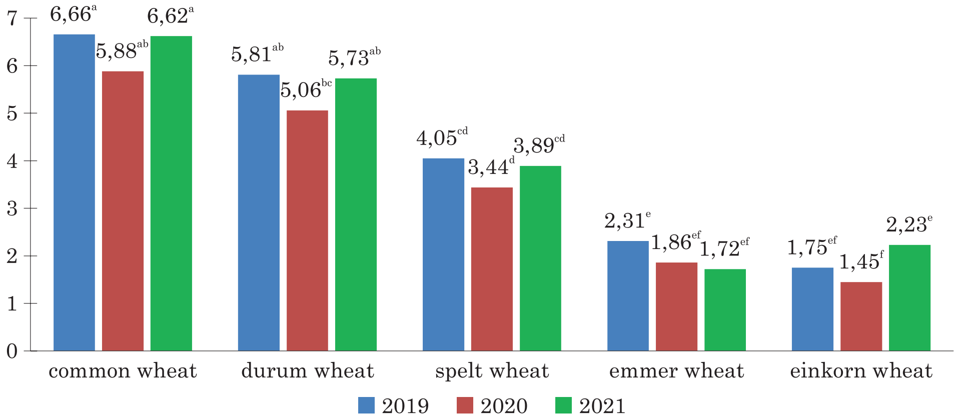

Fig. 2. Grain yield (t ha^{-1})

The micronutrient content of the grain did not depend on the interaction of the species with the study years. Hard wheat had the lowest concentration of iron compared to the hulled species. The highest levels of manganese and copper were found in the grains of emmer and eikorn wheats. A high content of copper was also determined in spelt grain. The content of copper varied over the years, which was not confirmed for other micronutrients (Table 6).

DISCUSSION

Wheat (*Triticum* L.) is one of the oldest cultivated plants. Among many species of this cereal, common and durum wheats are of the greatest economic importance. Since the 20th century, there has been a significant increase in their yield and harvest, which is a result of the progress in breeding and intense use of mineral fertilizers and pesticides. Cereal cultivation technologies, including field irrigation systems, have also changed. Velimirovic et al. (2021) reported that common wheat yields have trebled in the last 50 years. According to Wang et al. (2022), it is possible to obtain more than 7 t ha^{-1} of grain from a spring form, but only under the conditions of intensive agricultural technology. Lacko-Bartošova and Otepka (2001) have shown that new varieties of spelt already yield similarly to common wheat. In addition, they are characterized by a favorable proportion of hulls (26.1%), high TSW (49.29 g) and ear length (11.2 cm). However, Zhang et al. (2022) concluded that the yields of wheat, especially spring forms, may decrease despite the breeding progress due to climate warming. For this reason, they considered it important to study the adaptation of different wheat species to changing habitat conditions and human food requirements.

Table 4

Basic chemical composition of grain in % DM

Species	Years	Protein	Fat	Starch	Ash	Fiber
Common wheat	2019	14.3	1.24	62.3	1.74	1.69
	2020	13.4	1.92	64.5	2.42	2.35
	2021	15.2	1.25	63.1	1.66	1.79
Durum wheat	2019	15.4	1.43	60.6	1.80	1.82
	2020	14.5	2.11	61.6	2.45	2.39
	2021	16.1	1.44	60.2	1.71	1.84
Spelt wheat	2019	16.2	1.62	61.9	1.81	1.95
	2020	15.0	2.31	61.8	2.46	2.43
	2021	16.6	1.64	60.7	1.74	1.85
Emmer wheat	2019	16.5	2.15	64.4	1.99	2.52
	2020	15.7	2.84	63.9	2.67	2.65
	2021	17.2	2.16	63.1	1.92	2.00
Einkorn wheat	2019	16.7	2.32	63.4	2.09	2.60
	2020	15.9	3.01	64.1	2.72	2.72
	2021	17.5	2.32	62.6	2.05	2.08
Species x years		n.s.	n.s.	n.s.	n.s.	n.s.
Common wheat		14.3^{b}	1.47^{b}	63.3	1.94^{b}	1.94^{c}
Durum wheat		15.3^{ab}	1.66^{b}	60.8	1.99^{ab}	2.02^{bc}
Spelt wheat		15.9^{a}	1.86^{b}	61.5	2.00^{ab}	2.08^{abc}
Emmer wheat		16.5^{a}	2.38^{a}	63.8	2.19^{ab}	2.39^{ab}
Einkorn wheat		16.7^{a}	2.55^{a}	63.4	2.29^{a}	2.46^{a}
Species		***	***	n.s.	*	**
2019		15.8^{ab}	1.75^{b}	62.5	1.88^{b}	2.12^{b}
2020		14.9^{b}	2.44^{a}	63.2	2.54^{a}	2.51^{a}
2021		16.5^{a}	1.76^{b}	61.9	1.82^{b}	1.91^{b}
Year		***	***	n.s.	***	***

***, **, * indicate significant differences at $p<0.001$, $p<0.01$ and $p<0.05$;
n.s. – non-significant, according to the Tukey's honestly significant difference (HSD) test. Mean values with different letters (*a–c*) in columns are statistically different for foliar fertilization.

In the present study, spring wheat yields depended on the interaction of species with the study years. Common wheat yielded the highest, from 5.88 to 6.66 t ha^{-1}, followed by hard wheat and spelt. The lowest yields were obtained from the cultivation of ancient wheats, i.e. emmer and einkorn. It should be noted that wheat was grown in low-input technology. In 2020, the yield of einkorn was only 1.45 t ha^{-1}. It was therefore more than four times lower in relation to common wheat.

Table 5

The content of macronutrients in grain (mg kg-1)

Species	Years	P	Mg	K	Ca
Common wheat	2019	2686.7	969.7	848.5	523.2
	2020	2883.1	859.9	843.7	654.6
	2021	2686.4	993.4	739.9	524.4
Durum wheat	2019	2816.1	1119.1	803.7	450.0
	2020	2978.1	1005.5	802.9	579.1
	2021	2836.2	1136.7	771.3	452.1
Spelt wheat	2019	2844.4	1293.6	808.1	525.3
	2020	3005.3	1182.9	809.4	660.7
	2021	2880.5	1315.5	734.6	526.5
Emmer wheat	2019	2914.8	1369.8	818.3	579.1
	2020	3068.5	1252.2	817.6	714.7
	2021	2954.6	1382.7	757.9	579.8
Einkorn wheat	2019	2946.1	1461.9	799.8	609.3
	2020	3081.7	1317.5	782.6	706.3
	2021	2990.5	1451.0	769.7	609.7
Species x years		n.s.	n.s.	n.s.	n.s.
Common wheat		2752.1	941.0^{c}	2973.7	567.4^{ab}
Durum wheat		2876.8	1087.1^{bc}	3450.2	493.9^{b}
Spelt wheat		2910.1	1264.0^{ab}	3341.4	570.8^{ab}
Emmer wheat		2979.3	1334.9^{ab}	3579.8	624.5^{a}
Einkorn wheat		3036.1	1410.1^{a}	3762.4	641.7^{a}
Species		n.s.	***	n.s.	***
2019		2841.6	1242.8	3382.6	537.4^{b}
2020		3003.4	1123.6	3525.9	663.2^{a}
2021		2869.6	1255.9	3355.9	538.5^{b}
Year		n.s.	n.s.	n.s.	***

***, indicate significant differences at $p<0.001$;
n.s. – non-significant, according to the Tukey's honestly significant difference (HSD) test. Mean values with different letters (*a–c*) in columns are statistically different for foliar fertilization.

Rachoń et al. (2020) confirmed that ancient wheat species generated lower yields compared to common and durum wheats. According to the above authors, the yields of ancient wheats were lower by 30 to 56%. However, they indicated stable yields, even in poorer habitat conditions, as an advantage of ancient wheats. Troccoli and Codianni (2005) demonstrated that low yields of spelt and einkorn resulted from late heading, and also from high lodging in the case of einkorn. Morgounov et al. (2013) reported that high yields of common wheat could be attributed to the improved yield compo-

Table 6

The content of micronutrients in grain (mg kg^{-1})

Species	Years	Fe	Zn	Mn	Cu
Common wheat	2019	51.1	35.9	35.5	1.87
	2020	46.8	32.1	38.6	2.53
	2021	50.1	34.7	35.9	1.48
Durum wheat	2019	39.5	34.7	35.3	1.59
	2020	36.8	31.0	37.8	2.38
	2021	39.3	34.0	35.8	1.42
Spelt wheat	2019	60.9	36.3	37.2	2.64
	2020	58.3	33.1	39.9	2.39
	2021	59.8	35.7	37.8	2.29
Emmer wheat	2019	68.0	40.6	42.3	2.63
	2020	65.8	37.3	45.2	2.41
	2021	67.6	40.3	42.6	2.28
Einkorn wheat	2019	65.9	41.7	42.0	2.84
	2020	64.1	38.1	45.2	3.51
	2021	65.9	41.1	42.3	2.35
Species x years		n.s.	n.s.	n.s.	n.s.
Common wheat		49.3^{ab}	34.2	36.7^{b}	1.96^{b}
Durum wheat		38.5^{b}	33.3	36.3^{b}	1.80^{b}
Spelt wheat		59.7^{a}	35.0	38.3^{ab}	2.77^{a}
Emmer wheat		67.2^{a}	39.4	43.4^{a}	2.78^{a}
Einkorn wheat		65.3^{a}	40.3	43.2^{a}	2.90^{a}
Species		**	n.s.	*	***
2019		57.1	37.8	38.5	2.31^{b}
2020		54.4	34.3	41.3	3.05^{a}
2021		56.5	37.2	38.9	1.96^{c}
Year		n.s.	n.s.	n.s.	***

***, **, * indicate significant differences at $p<0.001$, $p<0.01$ and $p<0.05$;
n.s. – non-significant, according to the Tukey's honestly significant difference (HSD) test. Mean values with different letters (*a–c*) in columns are statistically different for foliar fertilization.

nents, but the grain had a lower protein concentration. A study by Fan et al. (2008) found that common wheat grain had an overall lower content of nutrients, including macro- and micronutrients. Murphy et al. (2008) also confirmed that common wheat grain had lower concentrations of minerals, with the exception of calcium. Therefore, they postulated a higher consumption of wholegrain bread or bread made from ancient wheats. Hellemans et al. (2018) concluded that the growing interest in functional food requires changes in wheat breeding in order to improve not only its yield but also the nutritional value of the grain. Bradauskiene et al. (2023) added that due to celiac disease, there has already been an increased demand for foods free of gluten, which is found in most grain products, including wheat grain.

The results of the present study showed that common wheat was characterized by the lowest content of protein in grain, and significantly higher content of other tested species. Moreover, emmer and einkorn had a high fat content, and einkorn additionally also had high ash and fiber content. The content of the discussed components varied over the years, with the exception of starch.

Lacko-Bartošova and Otepka (2021) showed that the number of ears per m^2 was lower in spelt wheat compared to common wheat. In the current study, the smallest number of ears per unit area was recorded for emmer and eikorn. This could be due to the applied lower rate of spikelet sowing in comparison to grains of naked wheats.

Konvalina et al. (2010) reported that einkorn and emmer had long and weak culms, and as a result, they were prone to lodging. In turn, Marino et al. (2009) showed that emmer lodging was low, especially of the spring form. However, the ears of this species are short and the grain has a low TSW. Gong et al. (2022) confirmed that emmer had low biometric parameters of the ear, but the grain showed favorable qualitative characteristics. Kulathunga et al. (2021) proved that einkorn grain was smaller compared to other wheat species, but its chemical composition was one of the most optimal ones. A study by Han and Hendek Ertop (2022) showed that the TSW of einkorn was on average 30.93 g. Marino et al. (2009) emphasized the advantages of spelt wheat, which was characterized by long and loose ears and larger grain. However, Tóth et al. (2022) concluded that the TSW of spelt varied significantly from 23.2 to 49.7 g, which was dependent on the variety. Zečević et al. (2022) showed that the yielding of spelt depended on yield components, i.e. the number of ears per m^2, number of grains per ear and TSW.

Our study indicated that the height of plants depended on the interaction of individual species with the study years. Emmer plants were higher, while bread wheat plants were lower. As a result, high lodging of emmer plants, but also of eikorn, was recorded. Spelt lodging was lower, and that of bread and durum wheats was the lowest. Of the species studied, spelt and bread wheat developed the longest ears, durum wheat grew shorter ears, while ears of einkorn and emmer wheats were the shortest. The highest number of grains per ear was found in the following descending order: bread wheat, durum wheat, spelt, emmer and einkorn. Thousand grain weight was the highest in bread wheat, lower in hard and spelt wheats, and the lowest in emmer and einkorn wheats.

Previous studies (Rachoń et al. 2015, Biel et al. 2016, Hendek Ertop, Atasoy 2019, Kulathunga et al. 2021, Tóth et al. 2022) have shown that ancient wheat grain has a more favorable chemical composition compared to commonly cultivated bread wheat. Biel et al. (2021) found the highest protein content in einkorn wheat – 18.1%, followed by emmer (15.4%), spelt (12.8%) and common wheat (11.0%). Einkorn wheat grain contained the highest proportion of crude ash – 2.65%, followed by emmer (2.16%), spelt (1.86%) and common wheat (1.52%). Fiber concentration also varied significantly, ranging from 1.78% in common wheat to 5.19% in eikorn. Suchowilska et al. (2009) reported that the average protein content in einkorn grain was 20.8%, emmer – 19.7%, and spelt – 17.0%. The crude fat content in einkorn grain (2.7%) was significantly higher than in spelt (2.4%) and emmer (2.3%). Han and Hendek Ertop (2022) showed that einkorn wheat grain contained 2.35% ash, 2.88% fat, 14.22% protein and 69.48% carbohydrates. Kulathunga and Simsek (2022) proved that the fiber content in wheat grain varied and depended on the species and even the variety. They showed that ancient wheats contained more fiber compared to common wheat.

In the present study, chemical grain composition varied significantly between the studied species. The lowest protein content in the grain was determined in bread wheat, and significantly higher was in the hulled species. Emmer and einkorn wheat were characterized by a high fat content. Einkorn wheat contained more ash and fiber in grain than bread wheat grain did. The content of the discussed components varied over the years, with the exception of starch.

Rachoń et al. (2015) determined a high content of protein, fat, ash, phosphorus, potassium, magnesium, calcium, copper, zinc, iron and manganese in einkorn wheat grain. Çığ et al. (2021) showed that einkorn wheat grain contained high levels of potassium and trace elements, such as iron, manganese and zinc. Abdel-Aal et al. (1995) reported that einkorn grain was of better quality, as it contained more protein, phosphorus and potassium. According to these authors, spelt grain was also rich in protein, and some varieties contained high starch and fat content. Biel et al. (2021) reported that among the analyzed macronutrients, potassium, phosphorus, magnesium and calcium had the highest concentration in wheat grain. This decreasing order (K > P > Mg > Ca) was confirmed in all wheat species. With the exception of phosphorus, all ancient wheats showed significantly higher macronutrient levels than common wheat. Ostrowska and Porębska (2017) showed that common wheat grain contained more magnesium than calcium.

These results were consistent with our work. In addition, the content of phosphorus and potassium did not differ significantly between wheats or the study years. It was found, however, that the magnesium content was high in einkorn grain and significantly lower in bread and hard wheat grains. Emmer and einkorn contained more calcium in grain than hard wheat. Only the calcium content in the grain was significantly modified during the study years.

Biel et al. (2021) proved that the content of micronutrients in wheat grain was in the following order: Fe > Mn > Zn > Cu. In turn, Zhao et al. (2009) found that the content of micronutrients in wheat grain varied as follows: Fe from 28.9 to 50.8 mg kg^{-1}, Zn from 13.5 to 34.5 mg kg^{-1}, and Se from 33 to 238 µg kg^{-1}. Melese et al. (2022) reported that the mineral composition of emmer grain depended on the growing season and variety. For the analyzed elements, the latter authors obtained the following results (mg kg^{-1}): phosphorus (2072 to 5639), potassium (3956 to 5437), iron (35.2 to 68.1), manganese (28.3 to 46.5), copper (3.4 to 46.5) 4.4), zinc (41.5 to 119.5), magnesium (1019 to 1517), sulfur (13.2 to 184.0) and calcium (290.2 to 653.5). Hussain et al. (2010) recorded high content of copper (5.62 mg kg^{-1}) and zinc (41.2 mg ha^{-1}), but low of manganese (22.6 mg kg^{-1}) in spring wheat grain. Genc and MacDonald (2008) showed that emmer wheat contained more zinc (Zn) in grain than common wheat and durum wheat. Krochmal-Marczak and Sawicka (2016) showed that the content of macronutrients in spelt was in the following order: potassium > phosphorus > magnesium > calcium. Magallanes-López et al. (2017) reported that durum wheat grain contained 25.7-40.5 mg kg^{-1} iron and 24.8-48.8 mg kg^{-1} zinc.

The present study found that durum wheat had the lowest iron content, while the highest levels of manganese and copper were found in the grains of emmer and eikorn wheats. A high content of copper was also determined in spelt grain. The content of copper varied over the years, which was not confirmed for other micronutrients.

CONCLUSIONS

1. Yields of spring wheat depended on the species and years of research. Common wheat yielded the highest (5.88-6.66 t ha^{-1}), followed by hard wheat (5.06-5.81 t ha^{-1}) and spelt (3.444.05 t ha^{-1}). The lowest yields were obtained from the cultivation of emmer (1.72-2.31 t ha^{-1}) and einkorn (1.45-2.23 t ha^{-1}).

2. Biometric measurements of plants showed that emmer and einkorn culms were long and therefore more susceptible to lodging. In addition, einkorn and emmer developed short ears with a low number of grains per ear and a low TSW.

3. The chemical composition of the grain was more favorable in ancient wheats, especially in emmer and einkorn. A high content of protein, fat, calcium, manganese and copper was determined in the grain of these species. In addition, emmer grain had a high ash content and einkorn grain had a high magnesium content. Spelt grain contained high copper levels, but the concentration of other nutrients was satisfactory. In general, the lowest amount of nutrients and minerals components was determined in naked wheat grains, especially in common wheat.

4. The results of our research showed that the volume and quality

of wheat grain depends on the species grown and weather conditions. In the case of hulled wheat, it is necessary to improve its varieties and agrotechnology.

SUPPLEMENTARY MATERIALS

The data presented in this study are available on request from the corresponding author.

AUTHOR CONTRIBUTIONS

R. T-S., W.J. A. A-P. – conceptualization; W.J. – data curation; W.J. – formal analysis; R. T-S., W.J. A. A-P. – funding acquisition; R. T-S., W.J. – methodology; W.J. – resources; W.J. – supervision; R. T-S., W.J., A. A-P. – writing – original draft preparation; R. T-S., W.J. – writing – review & editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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