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Sustainable spelt wheat nutrition in extreme weather conditions

A tönkölybúza fenntartható táplálása szélsőséges időjárási körülmények között

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ABSTRACT

In 2020/2021 and 2021/2022, a two-year field trial was carried out in Martonvásár, Hungary to investigate the effects of organic fertilizer (Azoter bacteria, compost, and compost+biophosphate) and various N-fertilizer levels on grain yield, yield components, yield quality parameters, and vitality parameters of three spelt wheat varieties (Mv Martongold, Franckenkorn and Mv Vitalgold) on chernozem soil. There were four replications in the split-plot design of the field experiment. The year had a major impact on grain yield, yield components (spike number, grain number, thousand-kernel weight (TKW) and vitality parameters (LAI, SPAD). Quality parameters (protein content, gluten content and Zeleny sedimentation value) did not change in the control between the two years, but they did in the fertilized plots. Both the 2021 and 2022 early spring seasons were dry, although the 2022 precipitation distribution was better for spelt. For grain yield in 2021 and 2022, the best conventional N-fertilization dosages were 80 kg/ha and 40 kg/ha, respectively. The increased lodging of spelt in 2022 as a result of the higher N-rates (80 and 120 kg/ha) contributed to yield loss. In terms of increasing yield-related features, organic fertilizers at a concentration of 40 kg/ha N appear to be inadequate. On the grain yield and its components, genotype had a significant impact. Franckenkorn produced the highest grain yield, the highest number of spikelets and grains and the highest values for LAI_{max}. In 2021, grain yields of this variety were 17 and 26% higher than those of Mv Martongold and Mv Vitalgold.

Keywords: N-fertilization, organic fertilizer, year effect, genotype

ÖSSZEFOGLALÁS

Kétéves szántóföldi kísérletben vizsgáltuk a szerves trágyázás (Azoter baktérium, komposzt, valamint komposzt+biofoszfát) és a különböző N-műtrágya adagok hatását három tönkölybúza fajta (Mv Martongold, Franckenkorn és Mv Vitalgold) szemtermésére, terméskomponenseire, minőségi paramétereire és vitalitási mutatóira csernozjom talajon 2020/2021-ben és 2021/2022-ben, Martonvásáron (Magyarország). A szántóföldi kísérlet osztott parcellás elrendezésű volt, négy ismétléssel. A szemtermésre, a terméskomponensekre (kalászszám, szemszám, ezermagtömeg) és a vitalitási mutatókra (LAI, SPAD) leginkább az évjárat volt hatással. A minőségi paraméterek (fehérje-, gluténtartalom és Zeleny-szedimentációs érték) a kontroll kezelésben nem, viszont a trágyázott parcellákban szignifikánsan különböztek. Mind 2021-re, mind 2022-re száraz kora tavaszi időszak volt jellemző, de a csapadék eloszlása 2022-ben a tönkölybúza termését tekintve kedvezőbb volt. A hagyományos N-műtrágyázással a szemtermés szempontjából 2021-ben 80 kg/ha, 2022-ben 40 kg/ha N-dózis volt optimális. A magasabb N-adagok (80 és 120 kg/ha) hatására 2022-ben a kg/ha tönkölybúza jelentősen megdőlt, ami terméskiesést okozott. A 40 kg/ha N-tartalmú szerves trágyázás kevésnek bizonyult a termést meghatározó tulajdonságok javításához. A genotípusnak jelentős hatása volt a termésre és a terméskomponensekre. A Franckenkorn fajtát jellemezte a legnagyobb szemtermés, kalászszám, szemszám és LAI_{max}. Termése 2021-ben 17, illetve 26%-kal volt nagyobb, mint az Mv Martongold és az Mv Vitalgold fajtáé.

Kulcsszavak: N-műtrágyázás, szerves trágyázás, évjárat hatás, genotípus

INTRODUCTION

The uncertainties about oil reserves, rising energy prices and the threat of harmful climate change effects have intensified the search for alternative farming systems that reduce negative environmental impacts (Bavec et al., 2012). Organic and biodynamic farming systems present viable alternatives for reducing the impact of agriculture on environmental degradation and climate change. Also because of the development of ecological agriculture and because of the need for sustainable production and the global fertilizer supply problems it can be necessary for low-input crops to be widely involved again in the production. Return to „ancient", high-quality wheat species can enhance biodiversity and the nutritive values of products (Dinu et al., 2018). The oldest cultivated grains are spelt wheat (*Triticum aestivum* ssp. *spelta* L.), Emmer (*Triticum dicoccum*) and Einkorn (*Triticum monococcum*). Starting from the Bronze Age, spelt was one of the more important crop plants in Europe (Andruszczak, 2017). Because of the low yield potential and the need to dehull of grains its production decreased. Nevertheless, numerous scientific reports indicate that spelt contains many valuable nutrients and hence the interest in it has been increasing from year to year. Compared to common wheat, spelt contains more protein and gluten, moreover, it contains substances with antioxidant properties (Jablonskytè-Raščė et al., 2013, Kraska et al., 2013). Recent interest in the use of spelt for ecologically grown foods has led to a resurgence in its cultivation (Zielinski et al., 2008).

Spelt is suitable for ecological production because of its higher tolerance to diseases (Longin et al., 2015) and outstanding stress resistance. By Moudry and Dvoracek (1999) spelt production is recommendable for extensive production systems (low-input systems) because of better nutrient utilization and higher mineral content of grain. Divers information can be found in the literature about grain yield of spelt in reduced tillage systems. Bonafaccia et al. (2000) found spelt wheat to be a low-input plant suitable for growing without the use of pesticides, in harsh ecological conditions and marginal areas of cultivation. Although spelt is considered to be a model crop for the needs of organic farming, the research of some authors reveals that it responds well to the intensification of cultivation. The reason for that can be given by the different agronomic and weather circumstances and the variety. Andruszczak (2017) found spelt grain yield under the conditions of a reduced tillage system lower than under the conventional tillage, but he stated too, that evaluated cultivars responded differently to this factor. Berner et al. (2008) reported grain yield of spelt to be under reduced tillage conditions 8% lower than in the conventional tillage system. Earlier we found (Sugar et al., 2019), that spelt wheat is a real alternative to common wheat for low input production both for low-quality and fertile soils. Nevertheless, the low yield potential is an important factor that reduces the spelt acreage and therefore it is necessary to draw attention to the agronomic factors whose optimization would allow us to increase yields and make them stable (Andruszczak, 2017).

In many European countries, the agricultural policy is oriented towards organic farming, whose prime objective is to solve environmental and food safety problems (Jablonskyte-Raščė et al., 2013). Hulled wheat species (i.e. emmer and spelt) are usually dedicated as primary crops in organic or small-area farms and are generally tolerant of less-advanced cultivation technologies (Rachon et al., 2020). Despite their lower yields, spelt is characterized by high protein and gluten content (Rachon et al., 2020). Even at low fertilization level, spelt grains have higher contents of protein (16-17%) compared to common wheat (Keller et al., 1999; Smolková et al., 2000; Wiwart et al., 2004; Kohajdova and Karovicova, 2008). Jablonskytè-Raščė et al. (2013) reported 25.2% and 31.3% higher protein and gluten for spelt than for common wheat. In the study of Lacko-Bartošova et al. (2010) wet gluten content was significantly influenced also by the year of growth, that means by the weather conditions during the vegetative period. In their study, the highest wet gluten was found in that year, when the weather conditions with higher temperatures and insufficient or normal distribution of rainfalls caused the highest gluten formation. Chemical plant protection significantly increased the Zeleny sedimentation value and grain protein content (Andruszczak, 2017). Andruszczak (2017) also concluded that spelt yield and grain chemical composition are primarily determined by the individual traits of a given cultivar. Still, it is possible to affect yield quantity and quality through agronomic factors. Leaf area index (LAI) is a good indicator of crop status and it is closely linked to several other crop and soil variables such as biomass, yield, crop nitrogen uptake, nutrition status and water stress occurrence (Casa et al., 2012).

This study aimed to evaluate the effect of production technology (conventional and organic plant nutrition) on the yield, the yield components, some yield quality parameters and some vitality parameters of spelt wheat varieties in changing weather conditions.

MATERIAL AND METHODS

The field study was conducted in the growing seasons of 2020/2021 and 2021/2022 at the Agricultural Institute of the Centre for Agricultural Research in Martonvásár (47^0 30'N, 18^0 82'E) in Hungary. Three genotypes of spelt wheat, Mv Martongold, Franckenkorn and Mv Vitalgold, were sown in plots. All the genotypes except Franckenkorn (German origin) were bred at Martonvásár. Around 9 m^2 (1.44×6 m) plots were used for each (fertilizer×variety) treatment. The chernozem soil of the experiment is a non-acidic loam with a deep A horizon (Table 1).

Table 1. Main physical and chemical properties of the soil at the experimental site at different layers at Martonvásár (Hungary)

Depth (cm)	0-30	30-60	60-90
Bulk density (g cm-3)	1.47	1.49	1.49
Soil organic matter (%)	2.82	2.02	1.39
pH	7.2	7.4	7.5
Sand fraction (%)	27	26	24
Silt fraction (%)	40	41	44
Clay fraction (%)	33	33	32

Owing to its favourable hydraulic properties (water holding capacity is 0.2 cm^3 cm^{-3}) and high soil organic matter content, based on the EU-SHG European Soil Database (Tóth et al., 2015), the experiment site belongs to one of the most fertile regions of Central Europe. Data of monthly precipitation and air temperature were recorded at the meteorological station at Martonvásár (Figure 1).

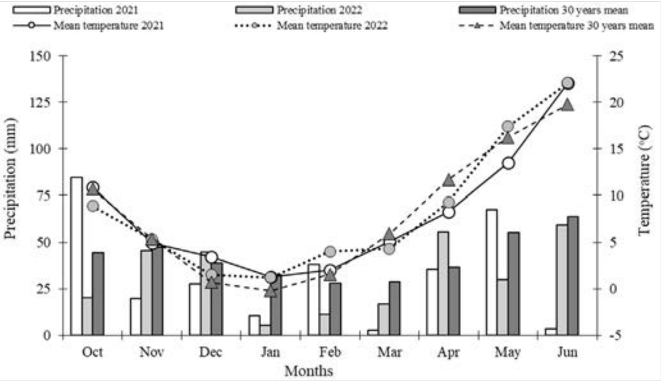

Figure 1. The average monthly air temperature and monthly sum of precipitation in growing period of 2021 and 2022

Total precipitation (mm) and average air temperature (C°) in the years of the study (2021-2022) were compared with the averages for the period 1991-2021. The winter period was in both years warmer than the previous 30 years' mean. However, the mean temperatures of March and April were in both years under the averages for the period 1991-2021. The growing season in 2022 was warmer than in 2021, being characterized by warmer February (with 4 °C mean temperature, 2 °C higher than in 2021 and 2.5 °C higher than the 30-year average) and May (17.4 °C mean temperature, by 1.2 °C higher than in 2021 and 3.9 °C higher than the 30 years average). The early spring season was dry in both years. However, the distribution of the precipitation was in 2021 more unfavourable with totally dry March (2.8 mm precipitation). In 2022 subaverage precipitation in the season from January to March was compensated in April with abundant precipitation.

The two-factor experiment was set up as a split-plot design in four replicates. The fertilizer treatments were: 1. Control, 2. Azoter: Azoter-F soil bacteria (equivalent to 40 kg/ha N content) + Greensoil Humin fertilizer (equivalent to 150 kg/ha P and K content), 3. Compost (with 40 kg/ha N content), 4. Compost+ABC: Compost (with 40 kg/ha N content) + biophosphate (Animal bone char, ABC) (with 100 kg/ha P content), 5. 40 kg/ha N fertilizer, 6. 80 kg/ha N fertilizer, 7. 120 kg/ha N fertilizer (in the form of ammonium-nitrate).

Azoter-F is a member of the Azoter bacteria fertilizer product family. Its components are: *Azotobacter chroococcum*: a nitrogen-fixing bacterium that supplies the plant with sufficient nitrogen during the whole vegetation period; *Azospirillum brasilense*: a nitrogen-fixing bacterium that bears temperatures above 40 °C and this way the plant is supplied with nitrogen during the hot summer periods as well; *Bacillus megaterium*: phosphorus mobilizing bacterium that stimulates the reproduction of cellulose decomposing bacteria and the formation of potassium; *Trichoderma aureoviride* fungus: eliminates Fusarium in the soil. After proper treatment soil will be infection free (https://azoter.hu/en/products/azoter-f/).

Azoter-F was dispersed at a dosage of 10 l/ha with a hand sprayer close to stool and turned into the soil with a hand cultivator in early spring. The dosage was equivalent with 40 kg/ha nitrogen content. The GreenSoil Humin H+PK fertilizer is an organic-mineral fertilizer with 25% humic acid, 30% organic matter and enriched with phosphorus, chlorine-free potassium, calcium, sulphur and important micronutrients. It's components: 4% P_2O_5, 7% K_2O, 10% CaO, 4% SO_3, 25% humic acid, 30% organic matter and micronutrients (cooper, zinc, boron, magnesium, selenium and iron). The applied compost fertilizer with 1% total nitrogen was applied (40 kg/ha) before sowing and it was immediately after application worked into the soil. Treatment compost (1% total N content) + Biophosphate contained next to compost (40 kg/ha N) animal bone char (with 100 kg/ha P active substance). It was immediately after the application worked into the soil. In the treatments, Control, Azoter-F, Compost and Compost+Biophosphate were carried out only for ecological plant protection. The nitrogen-fertilized plots were treated with conventional pesticides. In ecological treatments was used SteriClean as bactericide, fungicide and virucide after each moisture period in the concentration of 1l/ha. SteriClean is a biocide product with broad anti-microbiological spectrum, with immediate results without chemical remains. It is non-toxic, safe to use, re-entry and its food safety time is 0 days. As insecticide against pupa of cereal leaf beetle (*Oulema melanopus*) was used green soap (with 38% fatty acid content) in concentration of 1%.

Planting took place on 24 October 2020, and on 21 October 2021 and the plots were harvested on 22 July 2021 and 07 July 2022. Grain yield was estimated from the harvested plot yields and was converted to tons per hectare. Ear number was counted on a 1-meter row, and was multiplied by the number of rows in 1 m^2 (8.3). The grain number per ear was counted on ear samples taken before harvest. Thousand kernel weight was determined after harvest by counting and weighting of 1000 grains. The quality parameters (protein content, gluten content and Zeleny sedimentation value) were determined with the FOSS InfratecTM Nova grain analyzer. FOSS analytical solutions provide convenient routine analysis options with either near-infrared (NIR) or automated chemical analysis for reference analysis. Grains can be analysed quickly, easily, and directly without any sample preparation. LAI was measured by a non-destructive method using an AccuPAR ceptometer (Meter Group, 2019). Eight measurements were made below the canopy, four parallel and four across the rows in each plot. The parallel and perpendicular measurements were averaged.

The maximum LAI values were measured in the third decade of May, on the 11th in 2021; and on the 12th in 2022. The chlorophyll content of the flag leaves at flowering was determined by using a Minolta Chlorophyll Meter, SPAD-502 (Minolta, 2019). The measurements were made at the middle of the leaf lamina of the flag leaves on 4th June 2021 and on 27th June 2022. The SPAD values were converted to total chlorophyll values by using the conversion equation of Zhu et al., 2012. 20 measurement results of each plot were averaged, and the mean values were used in the statistical analysis. The performance of spelt, the effects of the different fertilizer as well as the performance of the different varieties were evaluated with One-way ANOVA (Analysis of Variance) with post-hoc Tukey HSD (Honestly Significant Difference). A difference was regarded to be significant in case the corresponding t-test resulted in a smaller than 0.05 probability (*P*) value.

RESULTS AND DISCUSSION

Grain yield and yield components

The primary factor influencing the grain yield of spelt (Table 2-3) was the year. This was in contrast to some previous research (Rachon et al., 2020; Burgos et al., 2001), which found that spelt yield varied statistically in specific years, indicating a reduced reliance on weather. The significant drought that occurred in 2021's early spring, combined with an unfavorable precipitation distribution that included nearly no precipitation in March, may be the cause of this paradox. In 2021 and 2022, the grain yield ranged from 2.6 to 5.6 t/ha and 4.0 to 5.3 t/ha, respectively. These values are similar to or higher than those commonly reported (Kwiatowsky et al., 2015; Andruszczak, 2017; Rachón et al., 2020), and less than those reported by Lacko-Bartošova et al. (2010), who measured in 2008 by suitable weather conditions, on soil with very good nutrients level, even grain yield of 6.9 t/ha of spelt without fertilization. On average, there was a yield difference of around 1 t (21%), whereas in the control, it was 1.26 t/ha. Even with 40 kg/ha N, the greatest grain production of 5 t/ha was recorded in 2022. N-fertilization, however, increased grain yield in 2021 to the N_{80} level (4.8 t/ha). Grain yield did not differ significantly between the organic fertilization treatments however, it was highest in the plots treated with Azoter bacteria in both years. This indicates a non-significant yield surplus of 0.3 t compared to the control, but a significant yield loss of 0.9 and 0.6 t/ha compared to the fertilized N_{40} treatment (with the same amount of N) in 2021 and 2022, respectively. Grain yield could not be increased by adding compost and compost+biophosphate.

Franckenkorn had the highest grain yield among the three varieties in 2021. Compared to Mv Vitalgold, Mv Martongold produced higher yields in 2022 (with comparable values). These findings are consistent with the research conducted by Lacko-Bartošova et al. (2010), who found the most adoptable spelt wheat variety for the growing conditions of the south Slovakia Franckenkorn. This variety showed the highest yield (6.76 t/ha) and acceptable quality parameters.

In 2022, there were 61 more spikes in the control treatment on one m^2 area than there were in 2021 (Table 2-3). It was 40-66 and 30-63 more in the case of organic fertilizer treatments and 100-209 and 209-289 more in the case of N fertilized treatments in 2021 and 2022, respectively, compared to the control treatment. In both years, the greatest increase was caused by N_{40}. Averaged the two years, Mv Martongold had produced the most spikes. The spike number of Mv Vitalgold was the lowest in both years. The spike number data was in 2021 lower but in 2022 higher than in the study of Andruszczak (2017), who found in conventional production with 60 kg/ha N on average 437 spikes per 1 m^2. In an earlier study (Andruszczak et al., 2011) they reported 493 spikes per 1 m^2 of spelt. Rachoń and Szumiło (2009) obtained ear density at the higher level of 544-658 per m^2. Our spike number data in 2022 are in accordance rather with Lacko-Bartošova and Otepka (2001), who found spike numbers of 501-519.

In 2022, there were 2.4 more spikelets per spike (Table 1-2) in the control than in 2021. It was strongly affected by the fertilizer applications. However, it was enhanced only in 2021 by N_{120}. Averaged the two years, Franckenkorn had produced the most spikelets per spike. It was the lowest in both years for Mv Martongold.

The control treatment had 6.5 grains more grains per spike (Table 2-3) in 2022 compared to 2021. Azoter bacteria improved grain number among organic fertilizer treatments in 2021, no effect was seen from the other treatments. In 2021 and 2022, there were 5.9 and 1.8 more grains per spike in N_{40} fertilized plots, respectively, compared to the control. In 2022, there were further 0.9 more grains, compared to N_{40}. On higher N-levels, the grain number did not increase. Compared to the other two varieties, Franckenkorn produced an average of five grains more per spike in 2021.

Table 2. Yield and yield components of spelt at different N supply in 2020/2021

Treatment (TR)	Cultivar	Hulled grain yield (t/ha)	Spike number per m^2	Spikelet number per spike	Grain number per spike	Thousand grain weight (g)
Control	Mv Martongold	2.60	275	9.3	14.8	41.9
	Franckenkorn	3.47	294	14.5	25.0	47.8
	Mv Vitalgold	2.48	206	14.5	24.8	49.0
N_{40} Azoter	Mv Martongold	2.82	289	12.5	22.0	45.8
	Franckenkorn	3.62	308	15.5	33.8	45.8
	Mv Vitalgold	3.03	302	13.8	24.0	44.7
N_{40} Comp	Mv Martongold	3.00	358	13.5	25.8	47.4
	Franckenkorn	3.52	354	15.8	30.3	44.9
	Mv Vitalgold	2.57	260	13.0	23.0	41.2
N_{40} Comp. + AC	Mv Martongold	3.03	350	13.5	23.3	46.5
	Franckenkorn	3.23	289	15.3	27.8	43.6
	Mv Vitalgold	2.60	254	13.3	22.0	44.3
N_{40}	Mv Martongold	3.79	344	14.5	29.5	48.9
	Franckenkorn	4.56	433	15.0	29.3	48.4
	Mv Vitalgold	3.88	298	13.3	23.5	49.5
N_{80}	Mv Martongold	4.73	446	15.0	26.8	47.3
	Franckenkorn	5.44	406	15.0	28.3	48.6
	Mv Vitalgold	4.24	358	12.5	24.3	47.2
N_{120}	Mv Martongold	5.14	462	14.0	25.5	49.5
	Franckenkorn	5.59	471	16.0	27.5	44.6
	Mv Vitalgold	4.57	469	14.3	25.0	43.8
Mean TR	Organic control	2.85 ^{a}	258 ^{a}	12.8 ^{a}	21.5 ^{a}	46.2 ^{ab}
	N_{40} Azoter bact.	3.16 ^{a}	300 ^{ab}	13.9 ^{ab}	26.6 ^{b}	45.4 ^{ab}
	N_{40} Comp.	3.03 ^{a}	324 ^{b}	14.1 ^{ab}	26.4 ^{ab}	44.5 ^{a}
	N_{40} Comp+AC	2.95 ^{a}	298 ^{a}	14.0 ^{ab}	24.4 ^{ab}	44.8 ^{a}
	N_{40}	4.08 ^{b}	358 ^{bc}	14.3 ^{ab}	27.4 ^{bc}	48.9 ^{b}
	N_{80}	4.80 ^{c}	403b ^{cd}	14.2 ^{ab}	26.5 ^{ab}	47.7 ^{ab}
	N_{120}	5.10 ^{c}	467 ^{e}	14.8 ^{b}	26.0 ^{ab}	46.0 ^{ab}
Mean Cultivar	Mv Martongold	3.59 ^{a}	361 ^{a}	13.2 ^{a}	24.0 ^{a}	46.8 ^{a}
	Franckenkorn	4.20 ^{b}	365 ^{a}	15.3 ^{b}	28.9 ^{b}	46.2 ^{a}
	Mv Vitalgold	3.34 ^{a}	307 ^{b}	13.5 ^{a}	23.8 ^{a}	45.7 ^{a}

AC - animal carbon; * significant difference between means at *P* = 0.05

Table 3. Yield and yield components of spelt at different N supply in 2021/2022

Treatment (TR)	Cultivar	Hulled grain yield (t/ha)	Spike number per m^2	Spikelet number per spike	Grain number per spike	Thousand grain weight (g)
Org. control	Mv Martongold	4.08	354	12.3	25.0	48.5
	Franckenkorn	4.31	323	16.0	29.8	47.0
	Mv Vitalgold	3.95	279	17.3	29.3	49.3
N_{40} Azoter	Mv Martongold	4.48	375	14.5	26.5	47.3
	Franckenkorn	4.58	392	16.5	30.8	46.4
	Mv Vitalgold	4.20	379	17.0	29.5	49.4
N_{40} Comp	Mv Martongold	4.47	373	15.3	27.3	47.6
	Franckenkorn	4.59	342	16.8	30.0	47.1
	Mv Vitalgold	4.04	331	14.8	25.0	48.4
N_{40} Comp. + AC	Mv Martongold	4.43	379	14.3	27.0	48.3
	Franckenkorn	4.46	367	13.0	23.0	46.1
	Mv Vitalgold	4.01	333	17.5	29.5	46.6
N_{40}	Mv Martongold	5.16	564	17.0	29.5	46.6
	Franckenkorn	4.91	596	17.0	30.3	47.2
	Mv Vitalgold	4.90	423	17.0	29.5	46.9
N_{80}	Mv Martongold	5.31	527	16.5	29.8	44.4
	Franckenkorn	5.11	525	18.8	34.0	46.4
	Mv Vitalgold	4.94	619	16.5	28.3	47.3
N_{120}	Mv Martongold	5.16	656	16.3	27.5	45.8
	Franckenkorn	4.86	598	18.0	32.3	45.0
	Mv Vitalgold	4.93	571	15.3	26.0	45.3
Mean TR	Organic control	4.11 ^{a}	319 ^{a}	15.2 ^{ab}	28.0 ^{ab}	48.2 ^{a}
	N_{40} Azoter bact.	4.42 ^{a}	382 ^{bc}	16.0 ^{ab}	28.9 ^{ab}	47.7 ^{ab}
	N_{40} Comp.	4.37 ^{a}	349 ^{ac}	15.6 ^{ab}	27.4 ^{ab}	47.7 ^{ab}
	N_{40} Comp + AC	4.30 ^{a}	360 ^{c}	14.9 ^{a}	26.5 a	47.0 ^{abc}
	N_{40}	4.99 ^{b}	528 ^{d}	17.0 ^{ab}	29.8 ^{ab}	46.9 ^{abc}
	N_{80}	5.12 ^{b}	557 ^{de}	17.3 ^{b}	30.7 ^{b}	46.0 ^{bc}
	N_{120}	4.98 ^{b}	608 ^{e}	16.5 ^{ab}	28.6 ^{ab}	45.4 ^{c}
Mean Cultivar	Mv Martongold	4.73 ^{a}	453 ^{a}	15.2 ^{a}	27.7 ^{a}	47.1 ^{ab}
	Franckenkorn	4.69 ^{ab}	433 ^{a}	16.5 ^{b}	29.9 ^{b}	46.6 ^{a}
	Mv Vitalgold	4.42 ^{b}	410 ^{a}	16.5 ^{b}	28.3 ^{ab}	47.6 ^{b}

AC - animal carbon; * significant difference between means at $P = 0.05$

Thousand-kernel weight (TKW) is one of the main yield quantity and quality parameters, which depends not only on the genotype but primarily on the weather conditions during growth (Andruszczak, 2017). Thousand-grain weight (TKW) (Table 2-3) was higher compared to the majority of previous research. The average TKW of spelt was 44.1 g for Packa et al. (2013) and 44.7 g for Rachon et al. (2014). However, in 2008, in the right weather circumstances, Lacko-Bartošova et al. (2010) reported an even greater TKW of spelt (49.8 g). In agreement with earlier studies, TKW was mostly influenced by the genotype and the weather of the particular year. In comparison to 2021, the TKW in the control treatment increased by 2.1 g in 2022. Only in 2021 did TKW significantly increase in response to fertilizers by N_{40}. In 2022 TKW was the highest in the control (48.3 g). Similar to the findings of Andruszczak (2017) TKW was higher in the organic fertilizer treatments than in N-fertilized treatments. The greater grain number, which typically has a negative ratio with grain weight, could be the cause. TKW did not significantly differ between varieties in 2021, however, in 2022 it was highest for Mv Vitalgold. The TKW of Franckenkorn (46.2 g and 46.5 g in 2021 and 2022, respectively) were higher than the TKW of this variety in the study of Lacko-Bartošova et al. (2010) (44.3 g). Comparable TKW values were measured by Andruszczak (2017). Our findings supported the notion that TKW is primarily dependent not only on the genotype but on the weather conditions during growth (Andruszczak, 2017; Lacko-Bartošova et al., 2010).

Quality parameters of spelt grain

The protein content of spelt grains (Table 4-5) was in control treatment 14.1% and 13.7% in 2021 and 2022, respectively. Organic fertilizers did not increase protein content in none of the experimental years. The protein content increased significant up to N_{120} in 2021 and up to N_{40} in 2022. The N_{40} treatment in 2022 caused even 5% higher protein content compared to the control, the higher N-dose did not raise it. The higher N-dose (80 and 120 kg/ha) increased the protein content of spelt only in 2021 in moderate extent. The higher values in 2022 better matched the 16-17% protein content of spelt in previous research (Rachon et al., 2020; Pagnotta et al., 2009; Piergiovanni et al., 1996 and Suchowilska et al., 2009). Our findings from 2022 further supported the notion that spelt grains had a higher protein content (16-17%) compared to common wheat, even under lower levels of fertilization (Keller et al., 1999; Smolková et al., 2000; Wiwart et al., 2004; Kohajdova and Karovičová, 2008). The organic fertilizer treatments using applied doses did not affect the protein content. Compared to the other two types, Mv Martongold had a greater protein content in 2021. Each variety showed a higher protein content in 2022, with difference minor variation between those.

In 2021 and 2022, the gluten content (Table 4-5) of grains was in control treatment at 25.8 and 27.6, respectively. A significant difference between the gluten content of both years was observed in N-fertilized treatment with significantly higher values for 2022. Similar to the protein content, gluten content increased up to N_{120} and N_{40}, in 2021 and 2022, respectively. The organic fertilizers did not affect the gluten content. The study conducted by Lacko-Bartošova et al. (2010) revealed that gluten content is significantly influenced also by the year of growth, that means by the weather conditions during the vegetative period. Lacko-Bartošova et al. (2010) found gluten content of variety Franckenkorn 42.5% without fertilization. In our study, Franckenkorn had similar higher values only in 2022 on higher N-levels. Compared to the other varieties, Mv Martongold had a greater gluten content in 2021. In 2022 there was a little variation in the greater gluten content among the varieties.

Zeleny sedimentation values (Table 4-5) were in control treatment 48.8 and 49.2, in 2021 and 2022, respectively. Zeleny value could be enhanced by 80 and 120 kg/ha N-treatments (up to 59), and by N_{40} (up to 78), in 2021 and 2022, respectively. Compared to the other varieties (48.6 and 49.03), Mv Martongold had a higher Zeleny value (53.1) in 2021. Zeleny values did not significantly differ among the varieties in 2022.

Table 4. Yield quality parameters, maximal leaf area index (LAI) and chlorophyll content (SPAD) of spelt at different N supply in 2020/2021

Treatment (TR)	Cultivar	Protein content (%)	Gluten content (%)	Zeleny index	LAI_{max}	SPAD
Org. control	Mv Martongold	14.3	27.6	47.5	1.18	38.6
	Franckenkorn	14.2	24.5	48.7	1.45	35.6
	Mv Vitalgold	13.9	25.2	50.1	1.46	34.9
N_{40} Azoter	Mv Martongold	14.5	26.6	53.9	1.54	38.5
	Franckenkorn	13.9	25.7	48.8	1.45	35.4
	Mv Vitalgold	13.9	26.6	47.9	1.39	37.0
N_{40} Comp	Mv Martongold	14.3	29.2	53.6	1.45	38.1
	Franckenkorn	13.4	24.2	46.7	1.80	33.2
	Mv Vitalgold	13.4	25.3	44.7	1.36	35.0
N_{40} Comp. + AC	Mv Martongold	14.2	28.6	49.3	1.31	41.0
	Franckenkorn	13.6	24.7	46.0	1.46	34.6
	Mv Vitalgold	13.7	26.0	45.5	1.56	34.3
N_{40}	Mv Martongold	14.5	32.5	49.6	2.15	45.9
	Franckenkorn	13.8	27.8	48.4	2.64	41.6
	Mv Vitalgold	14.3	28.9	51.2	2.21	38.9
N_{80}	Mv Martongold	15.5	35.4	57.8	2.94	48.7
	Franckenkorn	14.3	28.7	48.2	3.52	45.3
	Mv Vitalgold	14.9	32.4	53.3	2.95	43.1
N_{120}	Mv Martongold	16.1	37.2	62.9	3.31	49.7
	Franckenkorn	15.6	31.6	57.2	3.51	44.1
	Mv Vitalgold	15.2	33.4	57.4	3.28	44.8
Mean TR	Organic control	14.1^{a}	25.8^{a}	48.8^{a}	1.36^{a}	36.4^{a}
	N_{40} Azoter bact.	14.1^{a}	26.3^{a}	50.2^{ab}	1.46^{a}	37.0^{a}
	N_{40} Comp.	13.7^{a}	26.2^{a}	48.3^{a}	1.53^{a}	35.4^{a}
	N_{40} Comp + AC	13.8^{a}	26.4^{a}	46.9^{a}	1.44^{a}	36.6^{a}
	N_{40}	14.2^{b}	29.7^{b}	49.7^{ab}	2.33^{b}	42.1^{b}
	N_{80}	14.9^{b}	32.2^{bc}	53.1^{b}	3.14^{c}	45.7^{b}
	N_{120}	15.6^{c}	34.1^{c}	59.2^{c}	3.37^{c}	46.2^{b}
Mean Cultivar	Mv Martongold	15.1^{a}	28.8^{a}	53.07^{a}	1.98^{a}	42.9^{a}
	Franckenkorn	14.1^{b}	26.7^{b}	48.61^{b}	2.26^{a}	38.5^{b}
	Mv Vitalgold	14.2^{b}	28.3^{b}	49.03^{b}	2.03^{a}	38.3^{b}

AC - animal carbon; * significant difference between means at $P = 0.05$

Table 5. Yield quality parameters, maximal leaf area index (LAI) and chlorophyll content (SPAD) of spelt at different N supply in 2021/2022

Treatment (TR)	Cultivar	Protein content (%)	Gluten content (%)	Zeleny index	LAI_{max}	SPAD
Org. control	Mv Martongold	13.8	26.7	50.8	3.43	42.4
	Franckenkorn	13.5	26.8	46.6	3.62	39.5
	Mv Vitalgold	13.7	29.3	50.2	3.54	40.0
N_{40} Azoter	Mv Martongold	13.9	29.3	46.6	3.78	43.4
	Franckenkorn	13.0	25.6	43.6	3.82	38.8
	Mv Vitalgold	13.8	29.1	50.0	3.62	38.9
N_{40} Comp	Mv Martongold	13.3	29.2	45.0	3.35	41.8
	Franckenkorn	13.4	26.7	43.5	3.87	37.9
	Mv Vitalgold	13.4	27.9	46.1	3.37	37.8
N_{40} Comp. + AC	Mv Martongold	14.1	30.7	49.3	3.45	39.9
	Franckenkorn	13.2	26.2	44.6	3.74	37.6
	Mv Vitalgold	14.0	30.0	48.8	3.57	38.9
N_{40}	Mv Martongold	18.6	39.6	77.6	5.84	37.7
	Franckenkorn	18.9	38.5	77.4	7.03	42.8
	Mv Vitalgold	18.2	40.0	77.9	6.72	45.4
N_{80}	Mv Martongold	18.9	43.6	79.2	7.01	47.7
	Franckenkorn	18.9	39.4	77.6	7.72	44.1
	Mv Vitalgold	18.8	40.0	78.3	7.35	46.7
N_{120}	Mv Martongold	17.7	41.8	79.0	7.26	48.7
	Franckenkorn	18.5	40.7	77.9	7.82	46.0
	Mv Vitalgold	19.2	40.1	78.5	6.92	46.0
Mean TR	Organic control	13.7 ^{a}	27.6^{a}	49.2 ^{a}	3.53 ^{a}	40.6 ^{a}
	N_{40} Azoter bact.	13.6 ^{a}	28.0 ^{a}	46.7 ^{ab}	3.74 ^{a}	40.4 ^{a}
	N_{40} Comp.	13.4 ^{a}	27.9 ^{a}	44.9 ^{b}	3.53 ^{a}	39.2 ^{a}
	N_{40} Comp + AC	13.8 ^{a}	29.0 ^{b}	47.6 ^{a}	3.59 ^{a}	38.8 ^{a}
	N_{40}	18.6 ^{b}	39.4 ^{c}	77.6 ^{c}	6.53 ^{b}	42.0 ^{a}
	N_{80}	18.9 ^{b}	41.0 ^{c}	78.4 ^{c}	7.36 ^{c}	46.2 ^{ab}
	N_{120}	18.5 ^{b}	40.8 ^{c}	78.5 ^{c}	7.33 ^{c}	46.9 ^{b}
Mean Cultivar	Mv Martongold	15.5 ^{a}	33.8 ^{a}	59.3 ^{a}	4.70 ^{a}	42.9 ^{a}
	Franckenkorn	15.4 ^{a}	31.5 ^{a}	57.3 ^{a}	5.20 ^{a}	40.9 ^{a}
	Mv Vitalgold	15.5 ^{a}	33.1 ^{a}	59.5 ^{a}	4.88 ^{a}	41.8 ^{a}

AC - animal carbon; * significant difference between means at $P = 0.05$

Maximum leaf area index (LAI_{max}) and chlorophyll content of the flag leaf (SPAD)

LAI can be defined as the one-sided green leaf area per unit of horizontal soil area (Campbell and Norman, 1989). LAI_{max} of spelt (Table 4-5) was without N-supply (within the control treatment) 1.36 in 2021 and 3.53 in 2022, respectively. The great difference was caused probably by the different distribution of precipitation in the early spring season. However, organic fertilizers with 40 kg/ha N substance may not increase LAI_{max}, N-fertilization caused a great increase in it. However, higher N-rates (N_{80} and N_{120}) caused the lodging of the stand in 2022. Mv Martongold and Franckenkorn with N-fertilization showed notable lodging (70-90%) in that year. Mv Vitalgold showed any lodging. In 2021 due to the rare stand occured any lodging. The genotype Franckenkorn had in both year (non-significant) higher LAI_{max} than the other varieties.

The average flag leaf chlorophyll content (SPAD) in the control treatment in 2022 was 4.2 higher than in 2021 (Table 4-5). Organic fertilizer treatments did not affect SPAD, except for Azoter bacteria treatment in 2021 where this parameter increased slightly. Nitrogen fertilization increased SPAD values in both years. The increasing effect was significant in 2021 up to N_{80}.

CONCLUSIONS

In contrast to the earlier literary data grain yield and yield components of spelt wheat varieties were mainly affected by the year. All grain yield, number of spikes, spikelets and grains were higher in 2022. However, both growing seasons had similar precipitation (290 mm), which was below the 30-year average (376 mm), the distribution of precipitation was very different. The extreme drought in March 2021 may have a negative impact on spelt grain yield. Grain yield reached maximum in 2022 even at N_{40} (5 t/ha). However, N-fertilization improved grain yield to the N_{80} level in 2021 (4.8 t/ha). In organic fertilizer treatments was non-significant, higher yield compared to the control. The treatment of Azoter bacteria resulted in a non-significant 0.3 t yield surplus compared to the control.

From our previous results (Sugar et al., 2019), it can be concluded that higher N-doses (80 or 120 kg/ha) can improve grain yield mainly under extremely dry weather. Based on data from the present study the N-fertilizer application of 40 kg/ha may also be sufficient to maximize grain yield in drier years if precipitation distribution is more favorable. However, higher N-rates (80 and 120 kg/ha) in wetter years may encourage lodging of spelt.

Grain yield and its components were significantly affected by genotype. On average over two years, Franckenkorn produced the highest grain yield, number of spikelets per spike and number of grains per spike. In 2021, the average grain yield of this variety exceeded Mv Martongold and Mv Vitalgold by 17% and 26%, respectively. In 2022, Franckenkorn and Mv Martongold produced similar yields, exceeding the grain yield of Mv Vitalgold. The yield advantage of Franckenkorn can be attributed to the higher grain number per spike and to the non-significant higher LAI. The second-highest yield of Mv Martongold is associated with the relatively higher TKW value of this variety.

The yield difference between 2021 and 2022 for Mv Martongold and Mv Vitalgold (1.1 tha) was higher on average than for the Franckenkorn variety (0.5 t/ha). This variety could better compensate unfavorable distribution of precipitation in early spring with a higher number of spikelets, a higher number of grain numbers per spike, and with a non-significant higher LAI compared to the other two genotypes.

However, both years were drier than the average over the past 30 years, and more favorably distributed precipitation had a positive impact on grain quality parameters if N-fertilization was added. Genetic differences between varieties in grain quality parameters only manifested under extremely dry weather conditions.

LAI of spelt depended mainly on the years, and it increased with N-fertilization. However, Mv Martongold and Franckenkorn showed notable lodging (70-90%) in 2022 in N-fertilized treatments.

Previously published studies (Sulek et al., 2007; Andruszczak 2017) are supported by our findings that, due to the different metabolisms of each cultivar, their responses to environmental conditions can vary significantly. These results strengthen the importance of choosing of varieties, taking into account the production system and location. Based on the results of two years, we concluded that in general N-fertilization of 40 kg/ha can be effective. The slightly positive effect of higher N-doses on spelt yield manifested was only influenced by extremely dry weather conditions. Because the effect of organic fertilizers on grain yield of spelt was in both years low, the investigation of their effect is necessary for higher doses.

In 2022, against drought, the grain yield of all three varieties was similar to or higher than in most literature. In 2021, when drought combined with unfavorable distribution of precipitation, the variety Franckenkorn showed a lower yield loss than the other varieties. These results also confirm that continuous monitoring of the response of existing and new varieties is essential to adapt to the changing environment.

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