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THE CONTENT OF SOME TECHNOLOGICAL QUALITY COMPONENTS AND MYCOTOXINS IN GRAIN OF FOUR CULTIVARS OF SPRING WHEAT DEPENDING ON GRAIN STORAGE TIME AFTER HARVEST

Cezary A. Kwiatkowski[1], Elzbieta Harasim[1,*] Antoni Mis[2], Malgorzata Haliniarz[1], Jaroslaw Mazurkiewicz[3] and Marta Tomczyńska-Mleko[4]

[1]Department of Herbology and Plant Cultivation Techniques, University of Life Sciences, Poland; [2]Institute of Agrophysics in Lublin, Polish Academy of Sciences, Poland; [3]Department of Analysis and Evaluation of Food Quality, University of Life Sciences, Poland; [4]Institute of Plant Genetics, Breeding and Biotechnology, University of Life Sciences, Poland.
[*]Corresponding author's e-mail: elzbieta.harasim@up.lublin.pl

The aim of this study was to determine the effect of three grain storage times and the cultivar factor on some parameters used in commodity analysis of spring wheat grains. A field experiment was conducted in Czeslawice (Poland) using the split-plot method in 3 replicates in 27 m^2 plots. This paper presents the effect of storage time (3, 15, 27 months) of grain of four spring wheat cultivars ('Korynta', 'Monsun', 'Tybalt', 'Zadra') on some technological quality characteristics. After harvest, the grains were dried to the moisture content 14% and subsequently stockpiled in a warehouse. It was observed that grains can be stored for a period of even two years with no risk if all the grain storage rules are followed. Short- and long-term grain storage (3-27 months) resulted in satisfactory values of the grain quality characteristics like grain moisture, protein content, and grain hardness index. The storage of grain did not affect negatively grain contamination with mycotoxins. No significant differences were observed in the response of the cultivars studied (grain moisture content, protein content, grain hardness index) to grain storage time. Significant differences among the cultivars were observed in the grain hardness index after 3-month storage. It was also noted that the cultivars 'Korynta' and 'Tybalt' were characterized by lower susceptibility to contamination with mycotoxins than cvs. 'Zadra' and 'Monsun'. The results obtained in this study are a good indicator for cereal producers who store grains for a period of even two years, thus becoming independent of changing price conditions in the cereals market and the changing demand for and supply of animal feed and bread grain across other countries.
Keywords: Cereals, grain storage, Fusarium mycotoxin, mold fungi, spring wheat, price fluctuation.

INTRODUCTION

In the literature of the subject, there is a shortage of studies on the impact of storage time of wheat grain on its technological quality. Therefore, the results of this research fill the gap in this area. It is an innovative study both in Poland and in other countries. It shows that long-term storage (15-27 months) of wheat grain in warehouses is possible without deleterious quality changes in grain (grain moisture, grain hardness, mycotoxin content). Raza *et al.* (2010) reported the importance of storage method and time for grain quality. The conditions in which cereal grain is stored and kept have a considerable effect on its technological quality. As a result of improper grain storage, a number of negative changes often occur, such as an increase in grain moisture content and at the same time a decrease in grain protein content and decreased grain hardness (Kibar, 2016). This in turn creates favorable conditions for contamination of grain with mycotoxins. In such case, grain of poor quality is unsuitable for baking purposes (bread grain), but also for animal feed purposes (a lower nutritional value for animals, a high content of mycotoxins). Moreover, a decrease in the grain hardness index, an increased moisture content, and infection by pathogenic fungi all cause difficulties with the transport of grain, especially for long distances (Edwards, 2004; Chelowski *et al.*, 2012; Kumar *et al*., 2017).

Mycotoxins are products of metabolism of mold fungi and occur both under conventional and organic cereal production systems. Mycotoxins have always accompanied humans and cannot be eliminated completely. We divide them into those produced by cereal pathogenic fungi of the genus *Fusarium*, which infect ears of cereals during field cultivation, and those produced during storage of plant materials under improper storage conditions. Contamination of cereal grains with mycotoxins is a serious problem of agricultural production in many countries (Goswami and Kistler, 2004; Fernandez *et al*., 2007).

Taking into account the above considerations, the study hypothesized that favorable technological quality parameters can be obtained, both under short-term grain storage (3 months after harvest) and long-term storage (15-27 months), on the condition that proper spring wheat storage conditions (temperature, humidity, and irradiation) are observed. An assumption was also made that the individual spring wheat cultivars can show certain variations in the grain quality characteristics as affected by storage time (they differ in the response strength to storage duration). A positive verification of the above hypotheses could be of great importance for agricultural practice and the processing industry. As a result of excess cereal production or price fluctuations in the markets in many countries, grain must often be stored for a long time or transported to other countries.

The aim of this study was to determine the effect of three grain storage times and the cultivar factor on some parameters used in commodity analysis of spring wheat grain.

MATERIALS AND METHODS

***Experimental site and experimental design*:** The field experiment was conducted in 2012-2014 in Czesławice (Lubelskie Voivodeship, Poland). The experiment was set up using the split-plot method in three replications. The area of a single plot was 27 m^2. The experiment was established on grey-brown podzolic soil derived from loess classified as good wheat soil complex. Sugar beet was the previous crop for spring wheat.

The study included the following factors: I. Grain storage time after harvest for the individual spring wheat cultivars: 27 months, 15 months, 3 months; II. Spring wheat cultivars: Korynta, Monsun, Tybalt, and Zadra.

***Agronomic practices*:** Mineral fertilization, adjusted to high soil macronutrient availability, was as follows on a per hectare basis: N – 60 kg, P_2O_5 – 50 kg, K_2O – 80 kg. The following crop protection chemicals were used for all the spring wheat cultivars: herbicide Chwastox Turbo 340 SL (MCPA + dicamba) + Puma Uniwersal 069 EW (fenoxaprop-P-ethyl + mefenpyr-diethyl) – 2.0 + 1.0 l ha^{-1}, growth retardant Cerone 480 SL (ethephon) – 1.0 l ha^{-1}, fungicide Alert 375 SC (flusilazole + carbendazim) at a rate of 1.0 l ha^{-1}. The crop protection agents were applied using a field sprayer under a pressure of 0.25 MPa, at times in accordance with the recommendations of the Institute of Plant Protection - State Research Institute in Poznan, Poland.

In the period 2012–2014, spring wheat was sown in the second 10 days of April and harvested in the first 10 days of August (at full grain maturity).

***Treatments*:** Subsequently, the grain was stored in a granary (a flat storage warehouse) in piles on neutral substrate in the temperature range of 10–15°C. During the storage period, the wheat grain was separated from direct light (sunlight, artificial illumination) by using special blinds and also aerated (mixed) periodically, thus preventing its overheating. The storage warehouse was equipped with the following equipment: a fan and a blower, a device supplying compressed air from the fan to the bulk grain, a perforated floor and perforated ventilation ducts, a measuring and control instrument (air flow rate, temperature, moisture) (Rudzinski, 2011; Kibar, 2016). The determination of the grain content of chemical components, mycotoxin content, and physical characteristics (grain hardness) was made twice: (I) after harvest of spring wheat (August 18, 2012; August 15, 2013; August 16, 2014) and (II) at the end of storage (November 15-18, 2014). Effects of the harvest year-storage time interactions on grain quality parameters were estimated by calculating the absolute differences (+/-) between values of the parameters determined at the initial (I) and the end (II) of storage.

***Chemical and physical analyses*:** The protein and moisture content in spring wheat grain was determined by the NIR (near infrared) method (PN-EN-ISO 20483, 2014), an Inframatic 9500 grain analyzer (Perten Instruments). The grain hardness index was determined by the Single Kernel Characterization System (SKCS), model 4100 (Perten Instruments). The grain mycotoxin content was determined by high performance liquid chromatography HPLC (SYKAM) using different types of detectors (fluorescence, photodiode, refractometric) in order to detect specific types of mycotoxins (Commission Regulation (EC) No 1126/2007, Chelkowski *et al*., 2012).

***Weather conditions*:** Weather conditions during the growing season of spring wheat in particular years are listed in Table 1. The total rainfall during the 2012 growing season of spring wheat was lower than the long-term mean, in 2013 it exceeded the mean value by 50.0 mm, while in 2014 it was almost identical as the long-term mean.

Table 1. Rainfall and air temperature in the growing seasons during the period 2012-2014 as compared to the long-term means (1974-2003) according to the Meteorological Station at Czesławice.

Year	Month					Total
	IV	V	VI	VII	VIII	
	Rainfall (mm)					
2012	25.7	56.9	23.6	26.8	160.0	293.0
2013	20.4	83.6	82.4	99.4	78.5	364.3
2014	44.6	70.8	40.6	93.0	61.5	310.5
Mean for 1974-2003	40.4	53.8	73.6	80.1	66.4	314.3
Year	Temperature (°C)					Mean
2012	8.8	13.4	16.9	20.8	18.5	15.7
2013	8.2	15.0	17.2	19.4	18.7	15.7
2014	9.0	13.5	17.4	18.3	19.0	15.5
Mean for 1974-2003	7.7	13.7	16.5	18.0	17.4	14.7

A period of drought before the harvest of spring wheat (June-July 2012) and at the same time intense rainfall in August 2012, which impeded harvesting of the crop, should be noted. During the period 2013–2014, the amount of rainfall in the months June-August was similar to the long-term mean. The average air temperatures in all the growing seasons and during the harvest of spring wheat grain were very similar to one another, but at the same time they were higher than the long-term mean.

It must be noted, that in addition to the storage time also different weather conditions during the growth and harvest of the crops in the particular years (Table 1) might have indirectly affected the dynamics of quality changes in stored grain.

Statistical analysis

The obtained results were statistically analyzed using Statistica PL, while analysis of variance was performed using Tukey's test at a significance level of P = 0.05. The significance of differences in changes in the evaluated parameters was assessed based on the 95% confidence intervals of the means, while the relationship between storage time and changes in the evaluated parameters by linear regression analysis.

RESULTS

***Characteristics of the initial condition of grain in the harvest year (beginning of storage) of the individual spring wheat cultivars*:** In the case of the cultivars 'Korynta' and 'Tybalt', the initial grain moisture content recorded in the individual harvest years (2012, 2013, 2014) was at a similar, statistically insignificant level. On the other hand, grain of cvs. 'Monsun' and 'Zadra' harvested in 2014 was characterized by a significantly higher moisture content (by respectively 0.61 and 0.59 p.p. (percentage point)) compared to that harvested in the years 2012-2013 (Table 2).

Depending on the harvest year, the protein content in spring wheat grain significantly varied only in the case of cv. 'Korynta' (a significantly lower content of this component was found in grain harvested in 2012 relative to the years 2013-2014). However, grain protein content was strictly related to the cultivar factor – cv. 'Korynta' was characterized by the highest grain protein content (13.38 – 14.17%) in comparison to the other cultivars (Table 2).

The grain hardness index did not differ significantly in the individual harvest years. But in each harvest year, cvs. 'Korynta' and 'Tybalt' were found to exhibit significantly greater grain hardness compared to grain of cvs. 'Monsun' and 'Zadra' (Table 2).

The initial mycotoxin content in spring wheat grain determined immediately after harvest showed significant variations in the case of deoxynivalenol (DON) and nivalenol (NIV); it was significantly higher in grain harvested in 2012 than in the years 2013-2014. Regardless of the harvest year, cvs. 'Monsun' and 'Zadra' were found to exhibit higher

Table 2. Grain quality at the beginning of storage in relation to wheat cultivar and harvest year.

Grain quality parameters	Wheat cultivars and harvest years											
	Korynta			Monsun			Tybalt			Zadra		
	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
Moisture (%)	14.09	13.72	14.02	14.04	13.87	14.56	14.08	13.73	14.06	14.08	13.73	14.49
LSD $_{(0.05)}$ for Korynta = NS*; for Monsun = 0.492; for Tybalt = NS; for Zadra = 0.402												
Protein (%)	13.38	13.88	14.17	12.15	12.29	12.50	12.44	12.49	12.84	11.89	11.99	12.08
LSD $_{(0.05)}$ for Korynta = 0.481; for Monsun = NS; for Tybalt = NS; for Zadra = NS												
Hardness index	65.09	65.25	65.37	64.76	64.87	64.94	65.02	65.23	65.29	64.72	64.84	64.99
LSD $_{(0.05)}$ for Korynta = NS; for Monsun = NS; for Tybalt = NS; for Zadra = NS												

*NS - non-statistically significant difference

Table 3. Mycotoxin concentration (μg kg^{-1} grain) at the beginning of storage in relation to wheat cultivar and harvest year.

Harvest year	Mycotoxins				
	DON*	NIV	T2	HT2	ZEA
2012	28.8	3.43	1.16	2.78	7.17
2013	23.3	3.04	1.10	2.75	7.12
2014	22.9	2.84	1.08	2,63	7.09
LSD$_{(0.05)}$	4.32	0.366	NS**	NS	NS
Wheat cultivars					
Korynta	22.9	2.81	1.05	2.61	6.82
Monsun	27.5	3.32	1.09	2.76	7.17
Tybalt	23.2	2.86	1.06	2.63	6.86
Zadra	28.0	3.43	1.12	2.77	7.21
LSD$_{(0.05)}$	4.22	0.398	NS	NS	0.302

*Explanation: DON – deoxynivalenol, ZEA – zearalenone, NIV – nivalenol, T2 and HT2 – trichothecenes.

**NS - non-statistically significant difference susceptibility to fungal infection and thus a significantly higher content of deoxynivalenol (DON), nivalenol (NIV) and zearalenone (ZEA) mycotoxins in their grain than cvs. 'Korynta' and 'Tybalt' (Table 3).

Characteristics of the technological quality of grain of spring wheat cultivars after different storage periods:

***Grain moisture content*:** Storage time did not affect significantly the moisture content of spring wheat grain. The study did not also find any changes in grain moisture content as affected by the cultivar factor. Significant differences were noted for the interaction between storage time and cultivar (higher grain moisture content of the cultivars 'Monsun' and 'Zadra' after 3-month storage time) (Table 4).

A significant negative correlation was found between grain storage time and grain moisture content (r from -0.87 to -0.90). The linear regression equations show that cv. 'Monsum' was characterized by the highest stability of the parameter in question; in the case of this cultivar, the grain moisture loss rate during storage was slowest and averaged 0.016% per month. The value of the coefficient of determination (R2) indicates that as much as 82% of the variation in grain moisture content is explained by this model (Table 7).

Grain protein content: Storage time did not affect significantly the protein content of spring wheat grain. Among the cultivars compared, cv. 'Korynta' was characterized by the highest (statistically proven) protein content. The significantly highest protein content in cv. 'Korynta' grain (14.24%) was found after 3-month grain storage (Table 5). Similarly, as in the case of moisture content, a significant negative relationship was also found between storage time and protein content (r from -0.89 to -0.95). The linear regression equations show that the lowest decline in protein content occurred in grain of cv. 'Tybalt', on average 0.006% per month (Table 7).

Grain hardness index: The hardness index of spring wheat

Table 4. Moisture content of spring wheat grain (%).

Cultivar	Storage time after harvest (months) and the moisture different (MD) of the results for the individual storage times as determined after grain harvest in a particular year						Mean
	27	MD +/-	15	MD +/-	3	MD +/-	
Korynta	13.36	- 0.73	13.48	- 0.24	13.81	- 0.21	13.55
Monsun	13.42	- 0.62	13.57	- 0.30	14.32	- 0.24	13.77
Tybalt	13.38	- 0.70	13.50	- 0.23	13.87	- 0.19	13.58
Zadra	13.39	- 0.69	13.55	- 0.28	14.24	- 0.25	13.72
Mean	13.39	- 0.68	13.52	- 0.26	14.06	- 0.22	-

$LSD_{(p = 0.05)}$ for storage time after harvest = NS*; for cultivars = NS; for interaction: storage time after harvest × cultivars = 0.675
*NS - non-statistically significant difference

Table 5. Total protein content in spring wheat grain (%).

Cultivar	Storage time after harvest (months) and the protein different (PD) of the results for the individual storage times as determined after grain harvest in a particular year						Mean
	27	PD +/-	15	PD +/-	3	PD +/-	
Korynta	13.24 a*	- 0.14	13.79 a	- 0.09	14.24 b	+ 0.07	13.76 A**
Monsun	11.98 a	- 0.17	12.16 a	- 0.13	12.53 a	+ 0.03	12.22 B
Tybalt	12.33 a	- 0.11	12.41 a	- 0.08	12.88 a	+ 0.04	12.54 B
Zadra	11.74 a	- 0.15	11.88 a	- 0.11	12.10 a	+ 0.02	11.90 B
Mean	12.32 a	- 0.14	12.56 a	- 0.10	12.94 a	+ 0.04	-

$LSD_{(p = 0.05)}$ for storage time after harvest = NS; for cultivars = 1.203; for interaction: storage time after harvest × cultivars = 0.442
*NS - non-statistically significant difference

Table 6. Hardness index of spring wheat grain.

Cultivar	Storage time after harvest (months) and the hardness index different (HD) of the results for the individual storage times as determined after grain harvest in a particular year						Mean
	27	HD +/-	15	HD +/-	3	HD +/-	
Korynta	65.22	+ 0.13	65.31	+ 0.06	65.44	+ 0.07	65.32
Monsun	64.87	+ 0.11	64.91	+ 0.04	64.98	+ 0.04	64.92
Tybalt	65.16	+ 0.14	65.28	+ 0.05	65.35	+ 0.06	65.26
Zadra	64.83	+ 0.11	64.88	+ 0.04	65.02	+ 0.03	64.91
Mean	65.02	+ 0.12	65.09	+ 0.05	65.19	+ 0.05	-

$LSD_{(p = 0.05)}$ for storage time after harvest = NS; for cultivars = NS; for interaction: storage time after harvest × cultivars = NS
*NS - non-statistically significant difference

grain did not differ significantly as affected by different grain storage times after harvest (3-27 months) and ranged 65.02–65.19. No statistically confirmed differences were found in the grain hardness index under the influence of the cultivar factor, either (Table 6).

A significant positive relationship was revealed between grain storage time and hardness index (r from 0.75 to 0.86). The regression equation indicates that grain hardness increased slowest in cv. ‘Korynta’, on average by 0.0024/month, but only 56% of the variation in this trait is explained by this model (Table 7). As far as the three other cultivars are concerned, grain storage time contributed to a slightly higher rate of increase in the hardness index, with the coefficient of determination ranging from 0.69 to 0.73.

Grain mycotoxin content: Analyzing the results of the investigation of the mycotoxin content in spring wheat grain (coefficients of deviation from the initial content in the harvest year), we conclude that the raw material proved to be safe and good (Table 8). The content of individual mycotoxins did not exceed the levels that make grain suitable for both animal feed and food purposes (Commission Regulation (EC) No 1126/2007, Polish Nutritional Standards 2014). The significantly higher grain content of DON and NIV (after 27-month storage) resulted from the initial (in the harvest year) content of these mycotoxins (Table 3). The extension of after-harvest grain storage to 15-27 months did not cause a significant increase in mycotoxin content.

Significantly lesser and statistically similar DON, NIV and ZEA were recorded for ‘Monsun’ and ‘Zadra’. While, a like and significantly more DON, NIV and ZEA were quantified for ‘Korynta’ and ‘Tybalt’ compared to other cultivars. Whereas, varying storage times did not differ significantly for

Table 7. Regression equations and coefficients of correlation (r) and determination (R^2) describing the effect of grain storage time (x) on changes in the technological parameters of the selected spring wheat cultivars (y).

Wheat Cultivar	Moisture	Protein	Hardness index
Korynta	y = -0.0726-0.0215x; r = -0.88; R^2 = 0.78	y = 0.0808-0.0088x; r = -0.93; R^2 = 0.86	y = 0.0506+0.0024x; r = 0.75; R^2 = 0.56
Monsun	y = -0.1506-0.0156x; r = -0.90; R^2 = 0.82	y = 0.0378-0.0085x; r = -0.93; R^2 = 0.86	y = 0.0199+0.003x; r = 0.85; R^2 = 0.72
Tybalt	y = -0.0536-0.0212x; r = -0.89; R^2 = 0.80	y = 0.0405-0.0061x; r = -0.89;R^2 = 0.78	y = 0.0326+0.0034x; r = 0.83; R^2 = 0.69
Zadra	y = -0.1317-0.0185x; r = -0.87; R^2 = 0.77	y = 0.0269-0.0072x; r = -0.95; R^2 = 0.90	y = 0.0098+0.0035x; r = 0.86; R^2 = 0.73

Table 8. Mycotoxin content in the spring wheat grain samples analyzed (mycotoxin concentration μg kg^{-1} grain).

Specification	Mycotoxins				
	DON*	**NIV**	**T2**	**HT2**	**ZEA**
	Storage time after harvest (months) and the mycotoxin content different (MD) of the results for the individual storage times as determined after grain harvest in a particular year				
27	29.8	3.49	1.18	2.81	7.24
MD +/-	+ 1.0	+ 0.06	+ 0.02	+ 0.03	+ 0.07
15	24.2	3.09	1.11	2.76	7.19
MD +/-	+ 0.9	+ 0.05	+ 0.01	+ 0.01	+ 0.07
3	23.7	2.88	1.09	2.65	7.14
MD +/-	+ 0.8	+ 0.04	+ 0.01	+ 0.02	+ 0.05
$LSD_{(0.05)}$	5.38	0.392	NS**	NS	NS
Mycotoxin content different (MD) of the results for grain of the particular wheat cultivars from the individual storage times as determined after grain harvest in a particular year					
Korynta	23.4	2.84	1.06	2.63	6.86
MD +/-	+ 0.5	+ 0.03	+ 0.01	+ 0.02	+ 0.04
Monsun	28.6	3.40	1.11	2.79	7.26
MD +/-	+ 1.1	+ 0.08	+ 0.02	+ 0.03	+ 0.09
Tybalt	23.8	2.89	1.07	2.65	6.90
MD +/-	+ 0.6	+ 0.03	+ 0.01	+ 0.02	+ 0.04
Zadra	29.2	3.52	1.14	2.80	7.31
MD +/-	+ 1.2	+ 0.09	+ 0.02	+ 0.03	+ 0.10
$LSD_{(0.05)}$	4.725	0.497	NS	NS	0.352

*Explanation: DON – deoxynivalenol, ZEA – zearalenone, NIV – nivalenol, T2 and HT2 – trichothecenes.
**NS - non-statistically significant difference

synthesis of mycotoxins. The calculated mycotoxin content different demonstrate that this situation is due to the predisposition of the individual cultivars in relation to storage time (because in the case of the cultivars 'Zadra' and 'Monsun' MD was higher than for cvs. 'Korynta' and 'Tybalt') (Table 8).

DISCUSSION

The results of the study presented in this paper demonstrate that proper storage of wheat grain (over a period of even 3-27 months) does not contribute to a deterioration in its quality parameters. The flat warehouse used in this study had all the characteristics necessary for proper grain storage – the walls well separated from the foundation, a tight roof that provides good insulation against heat, the floor protected against moisture, an electric lighting system, equipment that enables mechanical aeration of grain. Kibar (2016) showed that if internal grain storage conditions in a warehouse are continuously controlled, there are no differences in the quality of grain stored for 0 - 90 days. A similar opinion is expressed by Linina and Ruza (2015) who studied grain stored for 60 - 200 days. One of the more important conditions is to maintain temperature at 10°C. Minimal losses of components (protein) and only slight fluctuations in grain moisture content are observed at such temperature (Kibar, 2016). As shown by the results of this study, the initial grain nutrient content (determined immediately after grain harvest) is important for the quality of grain stored. Apart from agronomic practices, this quality is influenced by weather conditions during the growing season and cereal harvest. This has been proven, among others, by Champeil *et al.* (2004), Karaoglu *et al.* (2010), Strelec *et al*. (2010), and Linina and Ruza (2015). Rothkaehl and Abramczyk (2007) also noted that adverse weather conditions may affect the grain quality suitable for the milling industry.

Karaoglu *et al.* (2010) showed that regardless of storage temperature and grain moisture content, up to 3-month storage time did not result in a deterioration in the quality and technological parameters of wheat grain. Other studies have revealed that cereal grain dried to a moisture content of 14% can be bulk stored safely in warehouses for 150 weeks, i.e. for almost 3 years. The condition is to control storage humidity and temperature (Task Force Report, 2003). The above thesis was confirmed in the present study. Raza *et al.* (2010) proved that a decrease in flour yield was observed with increasing wheat grain storage time. Polat (2013), in turn, proved that improper storage conditions can cause a deterioration in grain quality (including a decrease in protein content) in a short time (several weeks).

Linina and Ruza (2015) stressed the role of the cultivar factor in determining the quality of grain stored. This corresponds with the results of this study – the most favorable quality parameters were found in cv. 'Korynta'. Kibar (2015), on the other hand, did not find significant differences in the response of wheat cultivars to storage time. Raza *et al.* (2010) observed a varied response of wheat cultivars to storage time. They found the grain moisture content to increase after 12-month storage. The reason for this was the higher humidity in the ambient environment. Erekul and Kohn (2006) as well as Jiang *et al.* (2009) claimed that the quality of grain of a specific wheat cultivar is genetically determined, but it is also modified to a large extent by the rainfall and temperature during plant growth and by agronomic factors

Mis *et al.* (2000) declared grain hardness as a very important quality characteristic. Appropriate hardness of grain determines its resistance during storage and transport. Thus, it indirectly affects other grain quality parameters (Hruskova and Svec, 2009). The present study proves that even long-term storage (27 months) of spring wheat grain in piles (when the grain storage rules were followed) did affect positively the mechanical resistance of grains as expressed by the hardness index. Apart from that, the present study demonstrated that all the spring wheat cultivars included in this study were characterized by a similar grain hardness index. The value of the grain hardness index was in agreement with the standards given by Grundas (2004).

Grains undergo huge storage loss, which is significantly due to fungal contamination; on the other hand nutrient deficiency also coexists. The spoilage mainly occurs due to moisture absorption during storage leading to fungal growth at high temperature and humidity, so, grain moisture is the key for fungal contamination to occur (Salas and Dill-Macky, 2005; Morcia *et al.*, 2013; El-sadany *et al.*, 2017). With low disease intensity in fungus-colonized seeds, the toxin can be produced in larger amounts during longer storage at an elevated humidity (22% or greater). A temperature of 22-25°C promotes a higher rate of zearalenone formation, about ten times higher compared to a lower temperature in the order of 12–14°C (Bottalico, 1998). The research conducted in Poland has not hitherto shown significant contents of zearalenone in domestic grain. Its presence was found in field-infected maize grain at an amount of 3 mg kg^{-1} (Bottalico, 1998; Chelkowski *et al.*, 2012). On the other hand, the content of this toxin in wheat ranged from 10 to 200 μg kg^{-1}. Most frequently, fungi producing deoxynivalenol (DON = vomitoxin) occur on cereal grains and diseased plants both in Poland and in other countries, which was confirmed by this study. Deoxynivalenol is produced by the species *F. culmorum* and *F. graminearum*, the same species that show the ability to synthesize zearalenone (Chelkowski *et al.*, 2012). Hence, DON often occurs together with zearalenone (Bottalico and Perrone, 2002; Inch and Gilbert, 2003; Rocha *et al*., 2005; Pereyra and Dill-Macky, 2008; Lori, 2009).

***Conclusions*:** The hypothesis adopted in the study has been confirmed. The obtained results show that storage of grain of spring wheat varieties over a period of more than 3 months

(15-27 months) does not lead to significant negative changes in the quality characteristics of grain.

The results of this study have shown that by maintaining proper storage conditions, satisfactory technological quality of spring wheat grain (moisture content, protein content, grain hardness index, and minimal mycotoxin contamination) can be obtained during long-term (15-27 months) storage of grain compared to short-term storage (3 months).

The cultivars 'Tybalt' and 'Zadra', characterized by the lowest decline in protein content over the storage period, also had a positive effect on improving grain hardness. Grain of cvs. 'Korynta' and 'Tybalt' was characterized by lower contamination with mycotoxins than in the case of cvs. 'Monsun' and 'Zadra'.

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