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Effect of storage conditions on the occurrence of mycotoxins and nutrient composition in maize grains

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Abstract

The aim of this study was to determine how citrinin (CIT), aflatoxins ($AFL_{B1+B2+G1+G2}$), ochratoxin A (OTA), zearalenone (ZEA), and deoxynivalenol (DON) concentrations vary under different maize grains storage conditions and how they affect grain quality. Analyses of mycotoxins: $AFL_{B1+B2+G1+G2}$, CIT, DON, ZEA, and OTA, and grain quality: dry matter (DM) content, crude protein (CP), crude ash (CA), crude fibre (CF), crude fat, and starch, were performed at the beginning of the experiment and then after 3 and 6 months of storage. The results of the experiment showed that the duration of storage had the greatest influence on the formation of $AFL_{B1+B2+G1+G2}$ when an average concentration increased about three times after 6 months of storage, regardless of storage conditions. The duration of storage also had a significant effect on CIT accumulation, as it was not detected in the maize grain samples before the experiment, and after 6 months of storage, the concentration ranged from 93 to 184 μg kg^{-1}. It was also noted that there is no risk of an increase in the concentrations of DON, ZEA, and OTA in maize grains when dried grains are stored well (up to 7% moisture content). The DON concentration after 6 months of storage at 12°C and 20°C and in the warehouse decreased about two times, while at 4°C after 3 months of storage it also decreased, and then after 6 months it increased to the same concentration as at the beginning of the experiment. Throughout the experimental period, ZEA and OTA concentrations were slightly above or below the limit of detection (LOD). The nutrient composition after 6 months of storage was only different after storage at 20°C temperature. The increase in starch content was accompanied by an increase in the DM content. Strong positive correlations were observed: as the concentrations of $AFL_{B1+B2+G1+G2}$ and CIT increased, so did the DM content, while the crude protein content increased with increasing the DON concentration.

Keywords: aflatoxins (B1+B2+G1+G2), citrinin, deoxynivalenol, zearalenone, ochratoxin A, maize grain.

Introduction

Maize (*Zea mays* L.) is one of the most important food staples and one of the most widely consumed cereal crops worldwide (OECD/FAO, 2019). Maize grains are composed of ~9% protein, ~4% fat, ~71–74% starch and fibre as well as microelements (beta-carotene, vitamin B complex) and minerals (magnesium, phosphorus, zinc, copper, etc.) (Kumar, Jhariya, 2013; Lu et al., 2019). Global warming offers new opportunities for maize production, especially in the northern parts of Europe (Hakala et al., 2011). In Lithuania, over the last decade maize grain production increased more than two times from 47.5 to 104.7 thousand tonnes (Official Statistics Portal, 2022).

However, maize is also a target for toxigenic fungal infections. Infections can occur during the growing season or after harvest, storage, and transport, often leading to mycotoxin contamination (Eskola et al., 2020). In addition, due to global warming, many plant pathogens, insect pests and other harmful and beneficial organisms will also find new opportunities in Northern Europe (Hakala et al., 2011; Miedaner, Juroszek, 2021a). Insects feed on maize plants and create wounds through which fungal species can invade and produce mycotoxins (Miedaner, Juroszek, 2021b).

Species of *Aspergillus*, *Penicillium*, *Monascus*, and *Fusarium* produce mycotoxins that are of the greatest concern worldwide: aflatoxins (AFL), ochratoxin A (OTA), deoxynivalenol (DON), zearalenone (ZEA), and citrinin CIT) (He, Cox, 2016; Carbas et al., 2021; Pei et al., 2022; Zingales et al., 2022). Some species need tropical / subtropical climatic regions, while others can grow and produce mycotoxins at temperate climatic regions (Zingales et al., 2022). Increased climate variability is expected to increase the likelihood of mycotoxin accumulation in the field as well as in post-harvest storage (FAO, 2020). It is known that good agricultural and storage practices can reduce fungal development as well as mycotoxin contamination (Perrone et al., 2020). Therefore, to prevent over-contamination of food and feed with mycotoxins, it is important to monitor changes

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in mycotoxin concentrations and ensure favourable storage conditions.

Research in China indicates that DON, ZEA, OTA, tenuazonic acid, alternariol, alternariol monomethyl ether, fumonisin B1, and fumonisin B2 can be found in cereal crops intended for infant foods and chronic dietary risk for some of them was not acceptable (Ji et al., 2022). Researchers in Poland and Latvia also detected mycotoxins in food samples of cereals and flour, and some samples exceeded the maximum allowable level. Researchers state that it is necessary to continue monitoring mycotoxin occurrence in food samples (Kowalska, Kowalski, 2021; Reinholds et al., 2021). Mycotoxins can have carcinogenic, mutagenic, teratogenic, hepatotoxic, and estrogenic effects in humans or animals (Khodaei et al., 2021). Due to the risk to human and animal health when mycotoxins are ingested with food or feed, the European Commission has set a limit for the mycotoxin content of maize and maize-based products (European Commission, 2006 a; b; 2007).

Efforts to control mycotoxin contamination in food should cover the whole industry from agricultural practices to the table (Ji et al., 2022). Atanda et al. (2011) state that storing grains with the moisture content higher than 13% at 10–40°C temperature can lead to a higher mycotoxin contamination. However, there is still a lack of detailed information on the storage of maize grains and the associated risk of mycotoxins contamination (Phokane et al., 2019). Storage facilities are control points that should be continuously evaluated to ensure a good value for agricultural products (Phokane et al., 2019).

Therefore, the aim of this study was to determine how CIT, AFL, OTA, ZEA, and DON concentrations vary under different maize grains storage conditions and how they affect grain quality.

Material and methods

Samples collection. In 2019, maize (*Zea mays* L.) grain samples were collected from five different regions of Lithuania: Šakiai, Kėdainiai, Radviliškis, Pasvalys, and Plungė districts. Storage facilities were chosen by region and where grain maize hybrids were grown. All samples were taken according to the standard procedures (European Commision, 2009). Incremental samples were taken from five different randomly selected places of storage facility immediately after the grain was put into storage after the harvest. All incremental samples were mixed into one aggregate sample (approx. 4 kg). The final sample (approx. 500 g) was made from the homogenised aggregate sample. All samples were dried to ~7% and stored in paper bags for 6 months at 4°C, 12°C, and 20°C in constant temperature incubators and in the warehouse where environmental conditions varied (Table 1). Conditions were selected to cover a wide range of possible variations in temperate climate regions and to provide the missing scientific information in this area. Grain quality and mycotoxin analyses were performed at the beginning of the experiment and then after 3 and 6 months of storage.

Mycotoxin analysis. For the analyses to evaluate grain contamination with CIT, $AFL_{B1+B2+G1+G2}$, OTA, and ZEA, enzyme-linked immunosorbent assay (ELISA) was used. All samples were analysed in duplicate. The mycotoxins were quantified using Ridascreen® test kits Nos. R5402, R6302, R5202, and R5502 (R-Biopharm, Germany), as instructed by the manufacturer. The manufacturer validated analytical methods with the sample matrices for maize grains. The limit of detection (LOD) of CIT, AFL, OTA, and ZEA was 15, 1.5, 1.3, and 17 μg kg^{-1}, respectively. This method for mycotoxin analysis has been approved by the AOAC Research Institute (Certificate No. 950702). The optical densities of the samples and controls from a standard curve were estimated using a 450 nm filter by a multichannel photometer Multiskan Ascent (Thermo Electron Corp., Finland) supplied with the internal software.

Table 1. Sample of maize grains storage conditions (temperature and humidity)

Storage conditions		Experimental period	Average
Place	Parameter	18 October 2020 – 18 May 2021	
Storage room (depends on outdoor conditions)	temperature °C	2.3–11.8	5.7
	humidity %	54–86	73
Laboratory	temperature °C	18.3–22.5	19.9
	humidity %	22–49	37.6
Refrigerator	temperature °C	3.0–5.4	4.0
	humidity %	29–70	44
Binder thermostat	temperature °C	11.9–12.5	12.1
	humidity %	44–75	58

To determine the sample contamination with DON, the HPLC (high-performance liquid chromatography) system (Shimadzu, Japan) was used. The system consists of a LC20 AT pump equipped with a FCV-10AL quaternary valve, an autosampler SIL-20A, a degasser DCU-20A5, a column oven CTO-20A, and a UV detector (Shimadzu), wavelength of 218 nm, equipped with a YMC-Pack Pro C18, 3 μm (4.0 × 150 mm) column. Data were evaluated using the computer program LCsolution LC/GC, version 5.42 (Shimadzu).

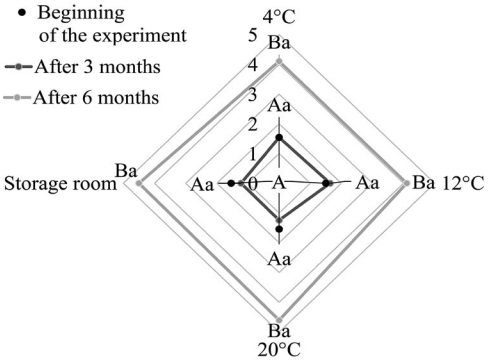
Nutrient composition. Near infrared spectroscopy was used to determine the nutrient composition: crude protein (CP % DM), crude ash (CA % DM), crude fibre (CF % DM), crude fat (% DM), and starch (% DM). Maize grains were ground in an ultra-centrifugal mill ZM 200 (Retsch, Germany) to pass a 1 mm screen. The samples were scanned with a NIRS-6500 device with a sample spinning module (Foss-Perstorp, USA) using wavelengths between 400 and 2500 nm in reflectance. All samples were analysed in triplicate. The obtained spectra were processed with equations installed in the device (for maize grains – equation from VDLUFA Laboratory, Germany). To determine the dry matter (DM) content, the samples were dried at 105°C temperature until the weight was stable.

Statistical analysis was conducted using the SPSS Statistics, version 25 (IBM Inc.). Significant differences between mycotoxin concentrations and between the nutrient composition in the samples were calculated using the one-way ANOVA (LSD post-hoc test). The Pearson correlation analysis was performed to examine the quantitative relationship between the mycotoxins and nutrient composition. The differences and correlations with $P \leq 0.05$ were considered significant.

Results and discussion

Aflatoxins (AFL). Evaluating how the $AFL_{B1+B2+G1+G2}$ concentration depends on the storage period, it was determined that after 3 months of storage, the concentration remained almost the same ($P > 0.05$). After 6 months, the concentration increased about 3 times from 1.5 ± 0.1 to 4.1 ± 0.4 μg kg^{-1} storing at 4°C and 12°C

and from 1.5 ± 0.1 to 4.7 ± 0.6 and 4.5 ± 0.5 μg kg^{-1} storing at 20°C and in the storage room, respectively (Figure 1). The concentration increased similarly under all simulated conditions; therefore, there were no significant differences between the $AFL_{B1+B2+G1+G2}$ concentration when different storage conditions were compared ($P > 0.05$).



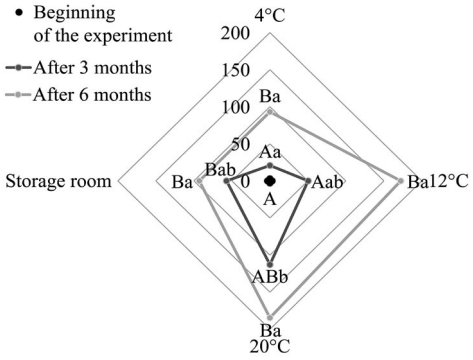
Note. Different lowercase and uppercase letters show significant differences ($P \leq 0.05$) between storage conditions within the same storage period and between storage periods within the same storage conditions, respectively.

Figure 1. Concentration (μg kg^{-1}) of aflatoxins (B1+B2+G1+G2) in maize grains during storage in different storage conditions

There is a lack of scientific information on changes in the AFL concentration during storage in Europe and in temperate climate. However, studies in tropical and subtropical climate regions have shown similar results. Research in Tanzania has also showed a significant increase of $AFL_{B1+B2+G1+G2}$ after 6 months of maize grains storage (Sasamalo et al., 2018). Study in North-Central Nigeria confirmed that maize grains have a significantly higher $AFL_{B1+B2+G1+G2}$ concentration at the storage season than at the harvest (Ezekiel et al., 2021). The increased AFL contamination in maize most commonly is an effect of poor storage practices like poor drying and storing in non-hermetic bags (Walker et al., 2018).

Citrinin (CIT). Before the experiment, maize grains were not contaminated with CIT, while in the storage room where environmental conditions are changing, the CIT concentration after 3 months of storage increased from <LOD to 56.9 ± 21.4 μg kg^{-1} ($P \leq 0.05$) and after 6 months to 92.9 ± 17.5 μg kg^{-1} ($P \leq 0.01$); however, after samples storing at 4°C, 12°C, and 20°C for 3 months, the CIT concentration did not increase significantly ($P > 0.05$) (Figure 2). Nevertheless, at the end of the experiment, the CIT concentration at 4°C, 12°C and 20°C increased from <LOD to 93.1 ± 17.6 ($P \leq 0.001$), 172.3 ± 41.7 ($P \leq 0.001$), and 184.5 ± 49 ($P \leq 0.01$) μg kg^{-1}, respectively. Ezekiel et al. (2021) have also noticed that the CIT concentration in maize grains after the 5 months storage session is significantly higher than at the harvest time. It is known that CIT production occurs during drying and storage, and the major producers are the fungi of the genera *Penicillium*, *Aspergillus*, and *Monascus*. *Penicillium citrinum* occurs most comonly in all kinds of food and feed in almost all climatic conditions (Kamle et al., 2022). The presence of these fungi in stored maize samples might explain the obtained results. Comparing different storage conditions within the same storage period, it was observed that after 3 months the CIT concentration was 5 times higher after samples storing at 20°C than at 4°C. However, there were no significant differences ($P > 0.05$) between the CIT concentration comparing other storage conditions after 3 and 6 months of storage.

There is a lack of information about maize grains contamination with CIT during different storage

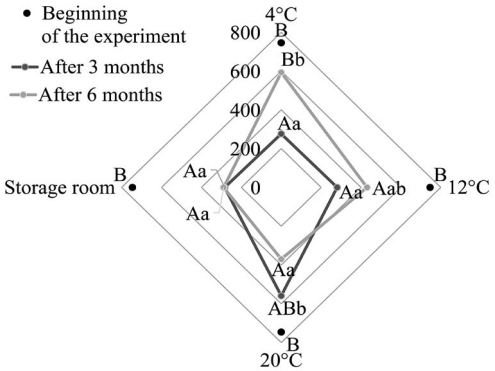


Explanation under Figure 1

Figure 2. Concentration (μg kg^{-1}) of citrinin (CIT) in maize grains during storage in different storage conditions

conditions. Muga et al. (2019) and Li et al. (2020) state that temperature between +25°C and +42°C, higher relative humidity and moisture content facilitate the reproduction and growth of *Aspergillus* and *Penicillium* species and consequently CIT production. The results of the experiments show that CIT is nephrotoxic and may interact with other mycotoxins present in the sample (EFSA, 2012). However, the lack of scientific experiments does not allow one to determine exactly what level of this mycotoxin is already becoming a health risk for humans or animals; therefore, to show the risk of its formation in maize grains during storage, studies on the occurrence of this mycotoxin are needed.

Deoxynivalenol (DON) analysis of stored maize grains did not reveal any significant concentration exceeding the maximum permitted levels (European Commission, 2007) – they were mainly up to 800 μg kg^{-1} (Figure 3). However, during storage, there was a tendency for different temperature regimes and storage exposures to influence the concentration changes of this mycotoxin. It was determined that after 3 months of storage at 4°C, the DON concentration decreased by 2.7 times from 746 ± 112 to 276 ± 20 μg kg^{-1}; however, the concentration increased again after 6 months of storage to 593 ± 110 μg kg^{-1} ($P \leq 0.01$). At 12°C and in the storage room, after 3 months the DON concentration also significantly decreased ($P \leq 0.001$) to 280 ± 23 and 283 ± 28 μg kg^{-1}, respectively. When determining the concentration again after 6 months, it was observed that they remained similar to those after 3 months ($P > 0.05$). At 20°C, the DON concentration significantly decreased ($P < 0.05$) to 288 ± 15 μg kg^{-1} only after 6 months of storage.



Explanation under Figure 1

Figure 3. Concentration (μg kg^{-1}) of deoxynivalenol (DON) in maize grains during storage in different storage conditions

There are not many studies on DON concentration changes in maize grains during storage. Other researchers evaluated DON concentration changes and it was observed that wheat samples storing for 28 days, in samples with moister content <15% and at 15°C and 20°C there is no toxin production by *F. graminearum* (Pei et al., 2022). Zhang et al. (2016) have noticed that when wheat grains were stored for 180 days at 4°C and at room (18–27°C) temperature, the DON concentration averagely decreased by 40–50%. It was noticed that after 3 months of maize grains storage at 20°C the DON concentration was still 2 times higher compared to other storage conditions ($P \leq 0.01$). However, after 6 months the DON concentration was 1.6 and 2 times higher at 4°C than at 20°C and in the storage room, respectively ($P \leq 0.01$). Research with wheat grain also showed that the greatest decrease of DON concentration was at room temperature, and this observation led to the assumption that DON may decompose during storage (Zhang et al., 2016). Other researchers also state that DON concentration decrease might be explained due to its conjugation to masked forms of the mycotoxin or its conversion to other forms such as the acetylated derivative 15-ADON (Bolanos-Carriel et al., 2020).

The results of the experiment showed that there was no risk of an increase in the DON concentration in well-dried (up to 7% moisture content) maize grains, regardless of storage conditions.

Zearalenone (ZEA) and ochratoxin A (OTA). Throughout the storage period, ZEA and OTA concentrations were often below the LOD (Table 2). Therefore, no significant differences were noticed in the ZEA and OTA concentrations in all the storage conditions and between them ($P > 0.05$). The data of our experiment confirms the previous results where ZEA and OTA concentrations during the storage did not have any tendency to change (Worku et al., 2019; Carbas et al., 2021). This usually depends on whether the meteorological conditions during the growth season before the harvest and storage were favourable for *Fusarium* fungi infection (Carbas et al., 2021). Gaël et al. (2020) found out that during storing maize grains for longer time in the triple bagging system with a different amount of biopesticides, the concentrations of ZEA and OTA mostly started to increase significantly after 10 months of storage. The results of our experiment showed that there was no risk of formation of ZEA and OTA in low moisture (around 7%) maize grains, regardless of storage conditions.

Table 2. Concentration (µg kg^{-1}) of zearalenone (ZEA) and ochratoxin A (OTA) in maize grains during storage in different storage conditions

Mycotoxin	Conditions	At the beginning of the experiment	After 3 months	After 6 months
ZEA	4°C	17.9	24.8	<LOD
	12°C		71.8	<LOD
	20°C		25.2	<LOD
	storage room		<LOD	<LOD
OTA	4°C	1.4	<LOD	<LOD
	12°C		<LOD	<LOD
	20°C		1.5	1.6
	storage room		<LOD	<LOD

LOD – limit of detection

Nutrient composition. Significant nutrient composition changes were noticed after 3 and 6 months in the samples that were placed at 20°C (Table 3). After 6 months of storage, the dry matter (DM) and starch content increased by 3.9% and 4.6%, respectively ($P \leq 0.001$); this may have been because conditions (37.6% humidity and 20°C) were much more favourable for maize grains to dry out. Starch is the main nutrient that accumulates in maize grain and its determination is closely linked to the DM content. In the samples that were placed in the storage room after 3 months, DM decreased by 3.7% ($P \leq 0.001$); however, after 6 months it has returned to the original DM content. For the first 3 months, the environment in the storage room was more humid ~79%, and for the next 3 months it was about 67%; this might explain the DM loss after the first 3 months. The CP, CA, CF, and crude fat content did not change significantly during the whole experimental period, regardless of storage conditions.

The research in Slovakia has also showed that environmental conditions can have an impact on moisture content. For the first 3 months of storage in the warehouse where the environment temperature was ~ −4.7°C and humidity ~94%, the moisture of maize grains increased from 13% to 13.9% (Angelovič et al., 2018). A slightly different study by Bruce et al. (2018) has showed that the moisture content can significantly decrease when maize grains are stored in polypropylene bags at 26°C and 54% of humidity; these results confirm our findings.

Correlation. Strong positive correlations ($P \leq 0.01$) were observed between the $AFL_{B1+B2+G1+G2}$ and CIT concentrations and the DM content as well as between the DON concentration and the CP content (Table 4).

As the concentrations of ZEA and OTA were very low, no correlations ($P > 0.05$) between these mycotoxins and the grain nutritive value were observed. Other research also supports a negative correlation between the $AFL_{B1+B2+G1+G2}$ and moisture content (Walker et al., 2018). However, more studies (Garcia-Cela et al., 2018; Kochiieru et al., 2021; Janavičienė et al., 2022) were carried out using other types of grains and flours to

Table 3. Nutrient composition of maize grains after 3 and 6 months of storage at different storage conditions

	Moisture %	DM	CP	CA	CF	Starch	Crude fat
			% in DM				
At the beginning of the experiment	7.21	92.82	9.294	0.558	0.49	64.26	4.284
After 3 months at 4°C	7.74	92.26	9.19	0.50	0.32	64.85	4.42
After 3 months at 12°C	8.31	91.69	9.19	0.43	0.28	64.80	4.35
After 3 months at 20°C	4.95**	95.05**	8.82	0.78	0.11	67.88**	4.50
After 3 months in storage room	10.83***	89.17***	9.18	0.26	0.81	62.58	4.18
After 6 months at 4°C	6.50	93.50	9.36	0.67	0.18	64.28	4.42
After 6 months at 12°C	6.80	93.20	9.32	0.42	0.20	64.22	4.35
After 6 months at 20°C	3.24***	96.76***	8.81	0.78	0.11	68.86***	4.40
After 6 months in storage room	7.78	92.22	9.30	0.42	0.46	63.10	4.30

DM – dry matter, CP – crude protein, CA – crude ash, CF – crude fibre; significant difference compared with the value at the beginning of the experiment: * – $P \leq 0.05$, ** – $P \leq 0.01$, and *** – $P \leq 0.001$

Table 4. Correlations between mycotoxins concentration and nutrient composition

	AFL	ZEA	CIT	OTA	DON
Moisture	−0.388**	0.207	−0.414**	−0.166	−0.139
Dry matter (DM)	0.387**	−0.207	0.413**	0.166	0.142
Crude protein (CP)	−0.194	0.271	−0.164	−0.192	0.381**
Crude ash (CA)	0.225	0.289	0.089	0.105	0.164
Crude fibre (CF)	−0.209	0.344	−0.159	−0.146	0.062
Starch	0.123	−0.259	0.266	0.278	−0.204
Crude fat	0.195	−0.283	0.370*	0.281	−0.255

AFL – aflatoxins (B1+B2+G1+G2), ZEA – zearalenone, CIT – citrinin, OTA – ochratoxin A, DON – deoxynivalenol; significant at * – $P \leq 0.05$ and ** – $P \leq 0.01$

find out how the nutrient composition correlates with the mycotoxins concentration.

Conclusions

1. The duration of storage showed the greatest influence on the formation of aflatoxins ($AFL_{B1+B2+G1+G2}$) when an average concentration increased about 3 times after 6 months of storage, regardless of storage conditions.

2. The duration of storage had a significant effect on the citrinin (CIT) accumulation, as it was not detected in the maize grain samples at the beginning of the experiment; however, after 6 months of storage, the concentration ranged from 93 to 184 μg kg^{-1}, regardless of storage conditions.

3. There is no risk of an increase in the concentrations of deoxynivalenol (DON), zearalenone (ZEA), and ochratoxin A (OTA) in maize grains when stored well dried (up to 7% moisture content), regardless of storage conditions.

4. The nutrient composition after 6 months of storage was only different at 20°C temperature. The increase in starch content was accompanied by an increase in dry matter (DM) content.

5. Strong positive correlations were observed: as the concentrations of $AFL_{B1+B2+G1+G2}$ and CIT increased, so did the DM content, while the crude protein content increased with increasing the DON concentration.

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Laikymo sąlygų įtaka mikotoksinų kiekiui kukurūzų grūduose ir jų mitybinės vertės kitimui

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Santrauka

Tyrimo tikslas – nustatyti, kaip citrinino (CIT), aflatoksinų ($AFL_{B1+B2+G1+G2}$), ochratoksino A, zearalenono (ZEA) ir deoksinivalenolio (DON) koncentracijos kinta skirtingomis kukurūzų grūdų laikymo sąlygomis ir kaip tai paveikia grūdų kokybę. Mikotoksinų $AFL_{B1+B2+G1+G2}$, CIT, DON, ZEA bei OTA ir grūdų kokybės: sausųjų medžiagų, žalių baltymų, žalių pelenų, žalios ląstelienos, žalių riebalų bei krakmolo, analizės buvo atliktos eksperimento pradžioje ir po 3 bei 6 mėnesių laikymo.

Tyrimo rezultatai parodė, kad didžiausią įtaką $AFL_{B1+B2+G1+G2}$ formavimuisi turėjo laikymo trukmė – po 6 mėnesių laikymo, nepriklausomai nuo laikymo sąlygų, jo vidutinė koncentracija padidėjo maždaug tris kartus. Taip pat laikymo trukmė turėjo reikšmingos įtakos CIT kaupimuisi, nes prieš eksperimentą kukurūzų grūdų mėginiuose jo nebuvo aptikta, o po 6 mėnesių laikymo jo koncentracija svyravo nuo 93 iki 184 µg kg^{-1}. Sandėliuojant gerai (iki 7 % drėgnio) išdžiovintus kukurūzų grūdus nėra pavojaus dėl DON, ZEA ir OTA koncentracijų padidėjimo juose. DON koncentracija po 6 mėnesių laikymo 12 ir 20 °C temperatūroje sandėlyje sumažėjo maždaug du kartus, o grūdus laikant 4° C temperatūroje po 3 mėnesių taip pat sumažėjo, tačiau po 6 mėnesių padidėjo iki pradinės koncentracijos. Viso eksperimento laikotarpiu ZEA ir OTA koncentracijos buvo šiek tiek didesnės už žemiausią aptikimo ribą arba jos nesiekė. Grūdų mitybinė vertė po 6 mėnesių laikymo skyrėsi tik juos laikant 20° C temperatūroje. Mėginius laikant šiomis sąlygomis, sausųjų medžiagų ir krakmolo kiekis reikšmingai padidėjo. Nustatytos stiprios teigiamos koreliacijos: padidėjus $AFL_{B1+B2+G1+G2}$ ir CIT koncentracijai, didėjo ir sausųjų medžiagų kiekis, o žalių baltymų kiekis didėjo didėjant DON koncentracijai.

Reikšminiai žodžiai: aflatoksinai (B1+B2+G1+G2), citrininas, deoksinivalenolis, zearalenonas, ochratoksinas A, kukurūzų grūdai.