THE EFFECT OF POST-HARVEST PROCESSING IN MODEL LINE AT FOOD MAIZE GRAINS EXTERNAL AND INTERNAL QUALITY

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Abstract
Experimental measurements of post-harvest line were realized in work conditions during maize cleaning and drying. Measurements were realized during maize harvesting with grain moisture 23 - 35 %. Structure of material was monitored before and after cleaning and the external grain quality before and after drying. Grain bulk density, impurities, grain damage and total cleaning effect were evaluated. The purpose of coarse and light trash analysis was the next step to find out the losses of grain quality. The analysis of the internal grain quality from the starch, fats and proteins were then conducted.

Key words: *cleaning; drying; dimension and weight characteristics of grains; cleaning effect; grain quality.*

INTRODUCTION
Cleaning, grading, drying is a basic working operation in post-harvest grain processing. These working operations affect the quality of cleaned and dried grain like a grain dedicated to food and another purpose in a positive and also in a negative way (*Ružbarský et al., 2005*). Requirement for grain purity is made by STN standards. According to the standards, the purity of the grain and the content of the ingredients are decisive for the recognition of cereal grains in their individual quality classes. These requirements place high demands on cleaning, sorting and drying machines in terms of construction and overall machine solutions (*Kroupa et al., 2004*).
The structure and extent of threshing damage depend on not only the threshing conditions (e.g., collision speed), but also the seed properties (*Chowdhury & Buchele 1976; Khazaei et al., 2007*). In maize, seed properties that affect threshing damage degree include seed size, seed shape, and seed moisture content (MC), as these properties affect interaction strengths between seed and threshing cylinder when seeds are threshed from cobs. Of these properties, MC was found to show a significant influence on seed physical damage in French bean; and also affect threshing damage in maize (*Keller et al., 1972; Dauda, 2001; Greven et al., 2001*). Several methods have been developed to evaluate mechanical damage degree. The most commonly used method is visual inspection. Seeds with any visual damage or cracks are picked from the sample to estimate the damage percentage. Mechanical damage level and position in a seed can also be determined by extracting the damaged area stained by use of iodine, fast green, methylene blue, or other stains (*Ng et al., 1998; ISTA, 2015*). Visual inspection and chemical stains can only evaluate external injuries in a seed. Seed vigor test is another way that can evaluate both external and internal damages, where mechanical damage level is estimated by correlating the ability of seed to emerge and develop a healthy seedling. The previous studies conducted on mechanical threshing majorly focused on the damage percentage, with few studies conducted on the influence of damage on seed vigor (*Ajayi et al., 2006; Li et al., 2007*).
Recently, the assessment of the external and internal quality of treated grains on post-harvest lines has been at the forefront. As *Loewer et al. (1994)* and *Jech et al. (2011)* concluded the quality is closely related to Hazard Analysis and Critical Control Points (HACCP). For these reasons, the objective of the study was to evaluate how the post-harvest treatment of maize affects the quality of the treated crop in cleaning, handling, and drying.

MATERIALS AND METHODS

Characteristics of monitored grain material in the process of post-harvest treatment

To assess the cleaning, sorting and drying efficiency of the treated grains in post-harvest treatment, it is necessary to carry out basic experimental measurements of various quantities, which are determined by the relevant standards on the basis of which we have characterized the quality of the work of the machines, the quality of the resulting product and the line as a whole. The monitored parameters in the post-harvest process were separated into two separate sections (a, b):

(a) Monitoring of external quality of food maize grains in the cleaning and drying process

To assess the external quality of the grains, the following factors were monitored before and after drying: grain moisture following standard STN 460610; grain volume weight (kg.m^{-3}, STN 460609); grain size (dimensional) and weight characteristics (STN 460610); grain purity (STN 461100-2); additional mixtures (STN 461050); impurity (STN 461050); grain damage (only macro damage) and characteristics of critical maize grains speed.

(b) Monitoring of internal quality of food maize grains after drying

Internal grain quality is understood the nutritional value, presence of moulds, microorganisms, pests and undesirable substances. For the internal grain quality options the limitations were set to the following analyzes: germinations of whole grains (STN 460311); starch and fat contend, protein content and sediments.

These analyses were performed in an automated laboratory AMYLUM Slovakia, s.r.o. Boleráz.

Brief characteristics of the post-harvest line

Post-harvest line located in AgroDivízia, s.r.o. in Selice has become a model line for carrying out experimental measurements. Due to the fact that this type of machinery is used by several enterprises, a model example is being developed to solve problems that reduce some line quality parameters during post-harvest treatment. The post-harvest grain processing line is mainly oriented on corn processing, but it can also provide post-harvest treatment, expedition, or storage of grains (cereals, maize, legumes, and oilseeds). The technology consists of receiving (underfloor basket), bucket conveyor, pre-cleaning, cleaning, belt conveyor, drying and transport into the grain silo or floor storage (Fig. 1).

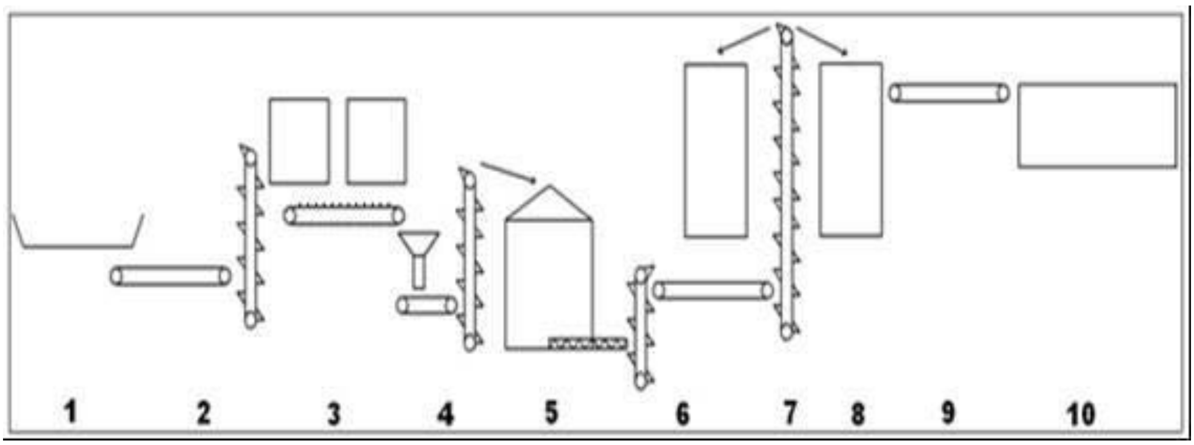

Fig. 1 Composition of the selected (model) post-harvest treatment line (1 – receiving; 2,4,6,7,9 – transport; 3 – pre-cleaning, cleaning; 5 – drying; 8 – grain silo;10 – floor storage).

Used machines, devices and equipment

The machines and equipment of the post-harvest line at AgroDivízia, s.r.o., in Selice were used for experimental measurements. Specialized instruments and equipment that belong to the laboratory equipment at the department DMPB were used to determine the agro-physical properties. They are a sieve cleaner, a humidity meter, digital scales, a grain counter, a volume weight measuring instrument and others.

Evaluation methods used in experiments

Validated statistical calculation procedures were used to evaluate the measured values on the post-harvest line and to evaluate the measured agro-physical characteristics. For determination of basic statistical quantities, evaluation program STATGRAFICS and MS Office 2010 (EXEL 2010) was used.

RESULTS AND DISCUSSION

Evaluation of dimensional and weight characteristics of the grains on monitored crop-plant

In terms of cleaning and grading grains, the most important characteristics of the grains are their dimensions (length, width, thickness), as their size directly influences the choice of size and shape of grain sieve. Further, the variability of the dimensions (the large interval of the respective dimension) affects the lower yield and the grain increase in the II. III. class and waste (Fig. 2-3). The grain size was determined using a digital caliper with an accuracy of 0.01 mm (Traceable).

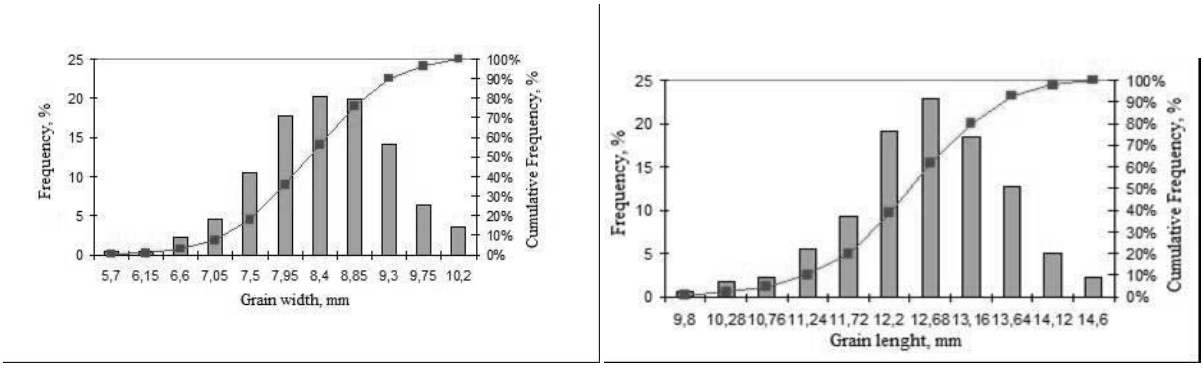

Fig. 2 Histogram of maize grains dimensional characteristics based on the width (left) and length (right)

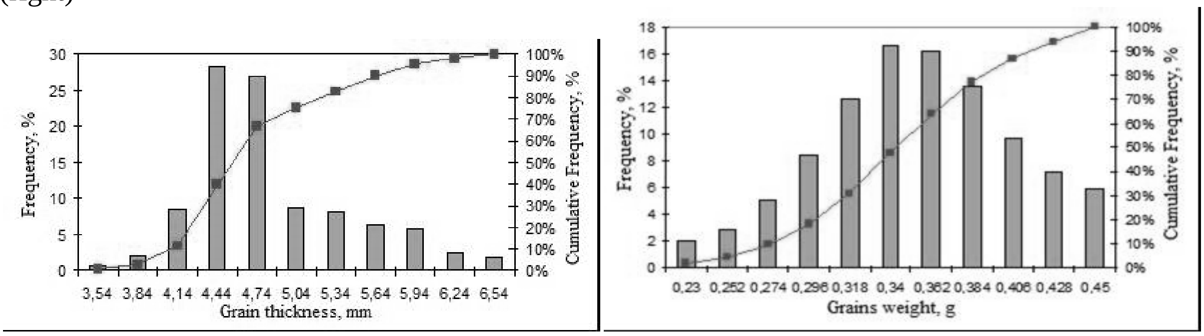

Fig. 3 Histogram of maize grains dimensional characteristics based on the thickness (left) and maize grains weight characteristics (right)

The grain size variation of maize is various. The grain width is in the range of 5.7 to 10.2 mm with an average of 8.24 mm, and length of 9.8 to 14.6 mm with an average of 12.4 mm, and a grain thickness of maize between 3.54 and 6.54 with an average value of 4.72 mm. Corn grain weight ranges from 0.23 to 0.45 grams with an average of 0.34 grams. It should be noted that maize is harvesting at a moisture content of 34% to 20%, resulting in a grain weight fluctuation when cleaning immediately after harvesting.

Determining the critical speed of maize grains in the air stream (flow)

For the purpose of adjusting the airflow speed in the cleaning machines the laboratory measurements of the given quantities were conducted. Based on the measured values, it was determined the critical velocity of the maize grains in the air stream. For maize it represents 8.5 - 13.14 $m.s^{-1}$ with an average value of 10.97 $m.s^{-1}$.

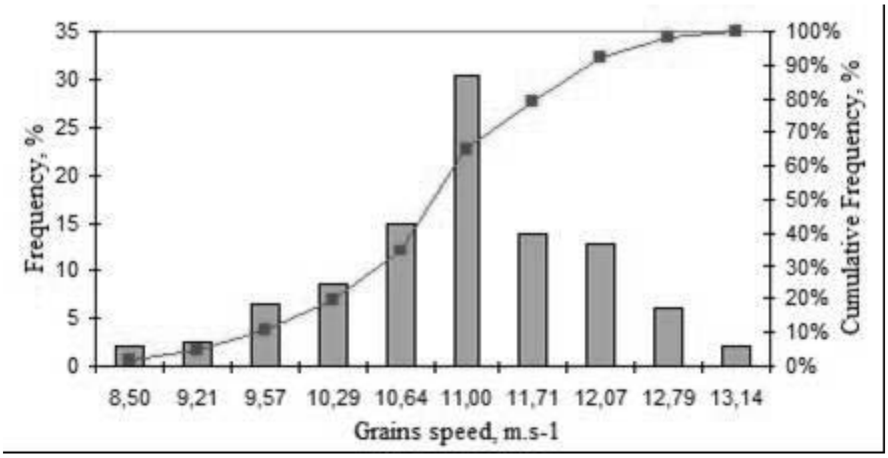

Fig. 4 Characteristics of critical maize grains speed

Evaluation of the external quality of maize grains in the cleaning and drying process

From the point of view of HACCP and food safety, it is necessary to monitor the external and internal quality of the processed product, in the case of this study, it was food maize. The analysis of samples of maize grains collected was performed according to Tab. 1 and Tab. 2 (*n=24*). Tab. 1 and 2 shows the summary results of the monitored external quality parameters of maize grains after the pre-cleaning (treatment) and drying process. The cleaning effect (purification efficiency) of the pre-treatment operation was good to very good 47.5% on average. The bulk density of the grains varied from 882 to 780 kg.m^{-3} depending on humidity. Damage to the grains before and after pre-treatment slightly decreased by separating debris and chopped grains (Tab. 1). A sharp increase in macro damage was observed after drying (Tab. 2). The causes of significant grains damage are more. In authors experience and lessons learned, these are: (a) Failure to comply with threshing system parameters. Corn thresh out was carried out at a high drum speed (17 m.s^{-1}), resulting in higher macro damage, which in some cases was up to 11% compared to the desired 3-5%, (b) Micro damage has been significantly increased, causing grain crumbling in the drying and subsequent handling process. Authors did not monitor what impact on damage has mixing auger in the oven and unloading (push out) auger. As *Gu et al. (2019)* stated, seed postharvest processing is necessary to prepare maize seeds for planting. However, process operations often subject seed to mechanical damage, which reduces seed quality due to external breakage and bruising and internal physiological damage (*Cicero et al. 1998; Ajayi et al. 2006*). Mechanical threshing is one of the processes where damage is caused by abrasions and impacts when seed passes through the machine (*Ajayi et al. 2006; Li et al. 2007*). Thus, mechanical threshing must be controlled to minimize damage during seed production.

Assessment of the effect of the drying process on the internal quality of maize grains

Analysis of the nutritional value of maize grains and their germination was provided in a specialized certified laboratory AMYLUM Slovakia s.r.o. in Boleraz. These analyses were conducted on mixed samples made from two samples previously taken for evaluation of the external quality (*n=12*).Germination is a major indicator of grain quality and viability after drying. An analysis of the internal quality of maize grains from the crop is given in Tab. 3. Germination rates ranged from 86% to 100%. The average germination rate was 92.3%, which is an excellent result for food maize. Other parameters such as starch, fat, and protein are evident from Tab. 3. The content of these variables is conditioned by several factors, especially the hybrid, locality, fertilization, year and post-harvest treatment. Moreover, *Coradi et al. (2019)* concluded that the changes in water contents in the grains during the drying and storage operations intensify the physical losses, even if at the end the grains remain with water content favourable to storage. As mentioned above, the internal quality of the dried maize was excellent and Agriculture Company converted it into cash in the first quality class. It is desirable to note that the temperature of the drying medium ranges from 52 ° C to 65 ° C.

Tab. 1 Assessment of the external maize grain quality before (INPUT) and after (OUTPUT) pre-cleaning (*n=24*)

	RAW MATERIAL INPUT							RAW MATERIAL OUTPUT								
sample	*volumetric weight, $g.l^{-1}$*	*WTG, g*	*impurity, %*	*admixture, %*	*damaged grain, %*	*clean grain, %*	*moisture, %*	*volumetric weight, $g.l^{-1}$*	*WTG, g*	*impurity, %*	*admixture, %*	*damaged grain, %*	*clean grain, %*	*moisture, %*	*cleaning effect, %*	*difference, %*
1	865.00	264.11	6.00	0.08	5.92	94.00	22.00	815.00	289.00	3.25	0.29	2.96	96.75	21.80	45.77	2.96
2	853.00	321.00	9.38	0.18	9.19	90.62	22.60	861.00	257.84	4.54	0.04	4.50	95.46	22.50	51.63	4.69
3	881.00	276.54	8.49	0.00	8.49	91.51	24.00	904.00	312.38	5.70	1.24	4.47	94.30	23.40	32.83	4.02
4	874.00	260.10	7.73	0.81	6.92	92.27	26.00	780.00	248.04	4.04	0.04	4.00	95.96	25.00	47.80	2.92
5	800.00	342.98	8.58	0.67	7.91	91.42	27.50	915.00	275.12	4.70	0.01	4.70	95.30	28.00	45.19	3.21
6	882.00	348.12	11.69	0.43	11.26	88.31	27.50	880.00	209.56	4.82	0.06	4.77	95.18	28.50	58.74	6.49
7	870.00	296.32	10.70	0.70	10.00	89.30	29.00	847.00	371.12	6.96	0.38	6.58	93.04	31.50	34.89	3.41
8	831.00	272.96	15.51	0.70	14.81	84.49	29.50	860.00	390.74	5.01	0.79	4.22	94.99	31.50	67.69	10.59
9	780.00	387.46	8.20	1.69	6.51	91.80	30.00	859.00	368.12	3.86	0.27	3.59	96.14	31.50	52.99	2.92
10	820.00	348.72	8.88	0.25	8.63	91.12	30.50	845.00	387.10	5.66	0.25	5.42	94.34	32.00	36.19	3.21
11	862.00	350.84	11.56	1.37	10.19	88.44	30.50	800.00	345.34	4.45	0.28	4.17	95.55	32.00	61.52	6.02
12	860.00	358.10	15.66	1.43	14.22	84.34	31.50	800.00	335.00	9.61	1.11	8.51	90.39	32.50	38.61	5.72
13	865.00	264.11	6.00	0.08	5.92	94.00	22.00	815.00	289.00	3.25	0.29	2.96	96.75	21.80	45.77	2.96
14	853.00	321.00	9.38	0.18	9.19	90.62	22.60	861.00	257.84	4.54	0.04	4.50	95.46	22.50	51.63	4.69
15	881.00	276.54	8.49	0.00	8.49	91.51	24.00	904.00	312.38	5.70	1.24	4.47	94.30	23.40	32.83	4.02
16	874.00	260.10	7.73	0.81	6.92	92.27	26.00	780.00	248.04	4.04	0.04	4.00	95.96	25.00	47.80	2.92
17	800.00	342.98	8.58	0.67	7.91	91.42	27.50	915.00	275.12	4.70	0.01	4.70	95.30	28.00	45.19	3.21
18	882.00	348.12	11.69	0.43	11.26	88.31	27.50	880.00	209.56	4.82	0.06	4.77	95.18	28.50	58.74	6.49
19	870.00	296.32	10.70	0.70	10.00	89.30	29.00	847.00	371.12	6.96	0.38	6.58	93.04	31.50	34.89	3.41
20	831.00	272.96	15.51	0.70	14.81	84.49	29.50	860.00	390.74	5.01	0.79	4.22	94.99	31.50	67.69	10.59
21	780.00	387.46	8.20	1.69	6.51	91.80	30.00	859.00	368.12	3.86	0.27	3.59	96.14	31.50	52.99	2.92
22	820.00	348.72	8.88	0.25	8.63	91.12	30.50	845.00	387.10	5.66	0.25	5.42	94.34	32.00	36.19	3.21
23	862.00	350.84	11.56	1.37	10.19	88.44	30.50	800.00	345.34	4.45	0.28	4.17	95.55	32.00	61.52	6.02
24	860.00	358.10	15.66	1.43	14.22	84.34	31.50	800.00	335.00	9.61	1.11	8.51	90.39	32.50	38.61	5.72
x	846.77	324.47	9.99	0.73	9.26	90.01	27.97	851.15	311.19	5.14	0.37	4.77	94.86	28.71	47.50	4.49
s	32.10	45.85	2.96	0.55	2.83	2.96	3.45	42.71	59.62	1.64	0.41	1.42	1.64	4.15	10.73	2.28
Vk, %	**3.79**	**14.13**	**29.59**	**75.15**	**30.61**	**3.28**	**12.33**	**5.02**	**19.16**	**31.95**	**89.66**	**29.76**	**1.73**	**14.45**	**22.60**	**50.72**

Tab. 2 Assessment of the external maize grain quality before (INPUT) and after (OUTPUT) drying (*n=24*)

	RAW MATERIAL INPUT							RAW MATERIAL OUTPUT							
sample	*volumetric weight, g.l^-1*	*WTG, g*	*impurity, %*	*admixture, %*	*damaged grain, %*	*clean grain, %*	*moisture, %*	*volumetric weight, g.l^-1*	*WTG, g*	*impurity, %*	*admixture, %*	*damaged grain, %*	*clean grain, %*	*moisture, %*	*difference, %*
1	859.00	368.12	3.86	0.27	3.59	96.14	31.50	850.00	270.82	16.27	0.82	15.45	83.73	10.10	12.42
2	898.00	268.63	4.12	0.04	4.08	95.88	21.50	870.00	264.32	18.60	0.00	18.60	81.40	10.10	14.48
3	830.00	290.92	6.18	1.11	5.08	93.82	20.60	895.00	300.10	12.11	0.06	12.05	87.89	10.20	5.93
4	815.00	289.00	3.25	0.29	2.96	96.75	21.80	905.00	272.71	14.49	0.15	14.34	85.51	10.20	11.24
5	900.00	254.08	9.08	0.03	9.05	90.92	22.00	891.00	271.90	12.28	0.10	12.18	87.72	10.40	3.20
6	860.00	390.74	5.01	0.79	4.22	94.99	31.50	846.00	303.56	15.38	1.50	13.88	84.62	10.50	10.37
7	849.00	335.20	7.32	0.24	7.08	92.68	26.00	850.00	249.50	13.70	0.37	13.33	86.30	10.50	6.38
8	780.00	248.04	4.04	0.04	4.00	95.96	25.00	750.00	250.12	13.05	0.12	12.93	86.95	10.50	9.02
9	899.00	256.08	4.21	0.07	4.14	95.79	33.00	882.00	246.20	15.28	0.16	15.12	84.72	10.70	11.07
10	859.00	368.12	3.86	0.27	3.59	96.14	31.50	879.00	240.40	18.49	0.34	18.15	81.51	10.80	14.63
11	861.00	257.84	4.54	0.04	4.50	95.46	22.50	885.00	278.42	7.57	0.06	7.51	92.43	10.80	3.03
12	878.00	366.88	7.07	0.36	6.70	92.93	24.80	857.00	303.26	15.98	2.20	13.78	84.02	11.10	8.91
13	859.00	368.12	3.86	0.27	3.59	96.14	31.50	850.00	270.82	16.27	0.82	15.45	83.73	10.10	12.42
14	898.00	268.63	4.12	0.04	4.08	95.88	21.50	870.00	264.32	18.60	0.00	18.60	81.40	10.10	14.48
15	830.00	290.92	6.18	1.11	5.08	93.82	20.60	895.00	300.10	12.11	0.06	12.05	87.89	10.20	5.93
16	815.00	289.00	3.25	0.29	2.96	96.75	21.80	905.00	272.71	14.49	0.15	14.34	85.51	10.20	11.24
17	900.00	254.08	9.08	0.03	9.05	90.92	22.00	891.00	271.90	12.28	0.10	12.18	87.72	10.40	3.20
18	860.00	390.74	5.01	0.79	4.22	94.99	31.50	846.00	303.56	15.38	1.50	13.88	84.62	10.50	10.37
19	849.00	335.20	7.32	0.24	7.08	92.68	26.00	850.00	249.50	13.70	0.37	13.33	86.30	10.50	6.38
20	780.00	248.04	4.04	0.04	4.00	95.96	25.00	750.00	250.12	13.05	0.12	12.93	86.95	10.50	9.02
21	899.00	256.08	4.21	0.07	4.14	95.79	33.00	882.00	246.20	15.28	0.16	15.12	84.72	10.70	11.07
22	859.00	368.12	3.86	0.27	3.59	96.14	31.50	879.00	240.40	18.49	0.34	18.15	81.51	10.80	14.63
23	861.00	257.84	4.54	0.04	4.50	95.46	22.50	885.00	278.42	7.57	0.06	7.51	92.43	10.80	3.03
24	878.00	366.88	7.07	0.36	6.70	92.93	24.80	857.00	303.26	15.98	2.20	13.78	84.02	11.10	8.91
x	853.78	314.43	5.92	0.35	5.57	94.08	27.07	873.56	278.48	14.86	0.99	13.88	85.14	10.79	8.94
s	39.27	52.03	2.46	0.47	2.34	2.46	4.36	38.31	24.78	4.55	1.76	3.37	4.55	0.51	5.24
Vk, %	**4.60**	**16.55**	**41.61**	**75.17**	**42.03**	**2.62**	**16.12**	**4.39**	**8.90**	**30.61**	**56.06**	**24.31**	**5.34**	**4.69**	**58.62**

Tab. 3 The internal maize grain quality (*n=12*)

Sample	Cultivar	Moisture, %	Starch, %	Germinability, %	Sediment, %	Fats, %	Proteins, %
1	DK-391	14.6	75.2	98	65	3.0	7.7
2		14.4	74.3	90	70	3.4	9.2
3		12.9	75.3	92	69	3.6	7.9
4		12.9	72.4	90	68	3.2	9.7
5		13.2	73.2	100	72	3.2	8.4
6		13.3	73.6	86	62	3.3	10.9
7		13.5	74.2	90	68	3.2	9.7
8		13.7	73.0	88	70	3.3	10.0
9		13.5	72.0	92	64	3.6	8.0
10		14.1	73.0	90	68	3.2	8.4
11		13.9	72.4	90	68	3.0	7.9
12		14.3	73.0	92	66	3.0	8.4
$\bar{x}$		**13.9**	**73.4**	**92.3**	**67.6**	**3.2**	**8.9**

In these circumstances, the maize grain internal quality is affected by numerous variables which drastically change their values. In addition to these observations other issues can be defined as well even more alarming. Agricultural soil and products are severely polluted by heavy metals, owing to the natural weathering of parent materials, mining, industries, melting, and agricultural activities (*Bilos et al., 2001*). However, contaminations of Cd, Cu, Hg, Pb and Zn in soil and crops caused by agricultural activities or natural weathering processes have only seldom been considered (*Árvay et al., 2013; Tomáš et al., 2014; Stanovič et al., 2015; Demková et al., 2017*).

CONCLUSIONS

The quality of the grain cleaners' work is not only judged by the cleanness of the cleaned product, but also by its performance and the loss of quality grains in the waste. It was also analyzed the gross and fine waste. There were whole grains in the gross (rough) waste, but they were under-sized, poor-quality. There were no whole grains in the fine waste. At this stage, the technical condition of the harvest line can be assessed as good. The first critical point that significantly affects the external quality of maize grains is the actual harvesting and threshing as mentioned above. Overall, the most critical element in the model harvest line is the drying process and its impact on the macro damage.

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