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INFLUENCE OF DRYING AIR TEMPERATURE ON MAIZE GRAIN BREAKAGE

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ABSTRACT

Along with wheat, maize is the most represented crop in Croatia. Due to the moisture in the drying process and big variety of hybrids, major technological changes are needed for utilisation of drying process. In order to determine the correct process for the dryer, the grain of FAO group 400 maize is used as a basis. This paper analysed 5 FAO 400 hybrids, single-phase dried at temperatures of 110 ℃ and 130 ℃, with the grain moisture content of 24.89% to 36.26%. It was observed that the drying period depends on the hybrid regarding its morphological characteristics. Furthermore, grain damage in the study of dynamic fracture toughness ranged from 27.6% to 70.8% at an air temperature of 110 ℃, and at an air temperature of 130 ℃ the fracture ranged from 30.4% to 74.0%, indicating that the strength of the grain depends on its morphological structure.

Keywords: *maize grain, drying, breakage, FAO group*

INTRODUCTION

Harvesting maize with a combine intended for drying usually begins when the grain moisture is between 28-32% in this part of Europe (Wall et al., 1975, Henry and Kettlewell, 2012), or when black layer is completely formed above the top of the germ. Namely, the higher the grain moisture, the increased in grain breakage is higher in the process of combining which lead to the loss in the process of drying, and later in storage (Peplinski et al., 1994; Krička et al., 2019).

Drying as a way of preserving grain, which due to climatic factors could not be done naturally, is a continuation and completion of the natural ripening of grain. The main goal of drying is to remove excess water from the grain, i.e. to preserve only the amount of water that the grain needs for latent life, which is reduced to minimal biological activity of the present microorganisms on the grain surface (Krička et al., 2018, Munkvold et al, 2019).

The speed and quality of grain drying depends on the drying method itself. Thus, for example, in natural drying, the ambient air temperature is close to the grain temperature, so drying process is slow. However, when the drying air is heated, the drying of the grain takes place faster. As the temperature of the air increases, its relative humidity decreases, so the difference in humidity between the grain and the air increases, and faster drying (Malumba et al., 2010) is promoted. The drying efficiency is influenced by the air with its thermal intensity, relevant humidity, flow rate and the design of the drying machine.

The maize grain that is dried in the dryer is delivered simultaneously from different plots. Such grain is of different hybrids with different humidity, and in the process of drying they mix with each other. During drying, this change of hybrids with different grain moisture is also reflected in the different physical properties of these grains, especially when it comes to drying speed, i.e. the ability to release water which needs to be removed by drying (Maier and Bakker-Arkema, 2002). It is known that maize hybrids differ from each other is structure, size, chemical composition, appearance, etc. (Gely and Santalla, 2000). However, one of the grain properties considered in the drying process is the rate at which the grain releases its excess water (Altay and Gunasekaran, 2006; Chung et al., 2009). Namely, by increasing the drying speed the drying capacity increases, and thus the drying costs decrease. Therefore, the drying process must be conducted in such a way as to preserve the quality of the grain with optimal drying costs. The most important factor that affects the capacity of the drying machine is the air temperature with which the grain is dried.

Due to all the above, the aim of this paper is to obtain a drying curve at a temperature of 110 °C and 130 °C based on 5 maize hybrids with different initial grain moisture. How in the last thirty years in Croatia drying machines have been tested with FAO group 400 grain, in these research FAO group 400 has also been taken as a reference group.

Furthermore, the dynamic grain load of the investigated maize hybrids will be investigated, in order to determine the strength of an individual hybrid (i.e. mechanical damage) at different drying temperatures.

As the hybrids were grown in the same area (Zagreb County) and harvested on the same day (September 29) by hand and with similar agrotechnics, from different producers, FAO group 400, dent, their names were not marked in the paper, but were guided by marks 1 to 5.

MATERIALS AND METHODS

The studies were performed on 5 maize hybrids of FAO group 400 (dent). Just before drying the maize kernels, the grain was shelled from the cob (to avoid damage and quartered for the purpose of obtaining the same samples.

After that, the grain moisture was determined by the standard method HRN ISO 6540: 2002 in the laboratory dryer INKO ST-40, Croatia.

The drying process itself was carried out in a single phase using a laboratory model of the dryer. The grain was dried by convection in a stationary layer weighing about 350 g in five repetitions. The laboratory model of the drying machine consists of an energy part (heater) and a fan. Air velocity and temperature were regulated by means of variable resistors. At the top of the dryer there is a bowl in which the grain is placed and dried. The air temperature at the inlet to the dryer was measured using a digital PT 100 probe, and the grain temperature in the air stream with a mercury thermometer.

In addition to the sum of the dryer, an "airflow" (anemometer) instrument was used to measure the air speed (m/s). Its accuracy is + -0.1. However, as the diameter of the anemometer head was larger than the diameter of the dryer where the sample was located, a deflector was used. Since the deflector was used, the changed air speed had to be corrected.

Furthermore, a psychrometer was used - an instrument for measuring the ambient air temperature, and indirectly for determining the relative humidity. Then the scale Libra 6000D was used for measuring the mass of samples and its accuracy is + -0.1g.

To determine the grain strength, studies were performed on a centrifugal crusher. The crusher is a centrifugal drum that accelerates the grain and directs it to a rigid wall. The housing of the centrifugal drum is made of aluminum sheet and mounted on rubber pads. In the lower part of the drum is an electric motor (220 V and 50 Hz) with a power of 300 W. The inner rotating disk is attached to a vertical central feedstock. When moving through the drum, the grain is mixed according to the laws of mechanics for relative motion. The speed at which the grain is thrown towards the roundwood can be adjusted and is proportional to the circumferential speed of the centrifuge rotor. The studies were performed at a spin speed of 1000 rpm. The speed was measured with a Smiths hand instrument. For each sample (dried at 110 °C and 130 °C) is taken 250 grains and on a precise scale the mass of the samples was analysed. After each individual bead passed through the drum, the beads were captured in a vessel at the exit of the drum. Subsequently, all grains that visually showed any visible damage were isolated. The mass of undamaged grain was weighed, and the fracture percentage was calculated.

RESULTS AND DISCUSSION

In order to determine the drying speed of maize grains, the initial moisture was determined, and the given theoretical final humidity at which the grain should be dried was 14%. The experiment was performed on a laboratory dryer, and the data were reflected on the accompanying instruments. Table 1 shows the temperature and speed of the drying air, grain temperature, temperature and relative humidity of the ambient air, and the initial and final moisture of the maize grain.

Measurement of water release rate from 5 FAO Group 400 maize hybrids was performed every 5 minutes. Table 2 shows the equations of drying to final moisture.

Comparing the drying time in percentages within the hybrid, it can be seen that at an air temperature at the inlet to the dryer of 110 °C in relation to the air temperature at the inlet to the dryer of 130 °C in the hybrid:

- OSSK 430 drying time lasts longer by 40.0%; w_1 = 36.26%
- Pajdaš drying time lasts longer by 56.25%; w_1 = 33.67%
- Bc 424 drying time lasts longer by 125.0%; w_1 = 28.53%
- Bc 415 drying time lasts longer by 12.5%; w_1 = 27.39%
- OSSK 403 drying time lasts longer by 66.67%; w_1 = 24.89%

Table 1 Display of average values of maize hybrids

Hybrid	t_{ad} (°C)	v (m/s)	θ_g (°C)	t_{ar} (°C)	t_0 (°C)	ϕ_0 (%)	w_1 (%)	w_2 (%)
OSSK 430	110	2.41	91.1	111.0	21.2	51.6	36.26	13.95
	130	2.86	89.9	130.2	24.2	36.8	36.26	13.70
Pajdaš	110	2.5	88.8	110.4	21.9	35.8	33.67	13.59
	130	2.57	103.6	130.4	22.4	46.6	33.67	13.05
Bc 424	110	2.34	91.8	111.3	20.2	30.7	28.53	13.48
	130	2.50	114.8	130.4	22.0	28.0	28.53	13.52
Bc 415	110	2.43	95.6	110.6	23.2	30.1	27.39	12.95
	130	2.17	109.3	131.0	23.0	30.0	27.39	13.57
OOSK 403	110	2.29	89.8	110.8	24.0	32.6	24.89	13.34
	130	2.19	106.2	131.2	22.8	33.2	24.89	12.93
$\dot{x}$	110	2.39	91.4	110.8	22.1	36.2		
	130	2.46	104.8	130.6	22.9	34.9		
s	110	0.08	2.6	0.4	1.5	8.9		
	130	0.29	9.3	0.4	0.8	7.3		

Legend: t_{ad}-default air temperature; v- air velocity at the dryer exit; θ_g-grain temperature; t_{ar}-real air temperature; t_0- ambient air temperature; ϕ_0- relative air humidity; w_1- initial moisture content; w_2- moisture content after drying

Table 2 Maize grain drying equations for 5 maize hybrids

Hybrid	t_{ad} (°C)	w_1 (%)	Exponential equation	Correlation coefficient
OSSK 430	110	36.26	$w = 31.63e^{-0.008\tau}$	0.9718
	130	36.26	$w = 34.904e^{-0.013\tau}$	0.9888
Pajdaš	110	33.67	$w = 30.641e^{-0.007\tau}$	0.9777
	130	33.67	$w = 31.436e^{-0.011\tau}$	0.9860
Bc 424	110	28.53	$w = 26.653e^{-0.008\tau}$	0.9824
	130	28.53	$w = 27.333e^{-0.017\tau}$	0.9883
Bc 415	110	27.39	$w = 26.236e^{-0.016\tau}$	0.9925
	130	27.39	$w = 26.127e^{-0.016\tau}$	0.9875
OOSK 403	110	24.89	$w = 23.598e^{-0.011\tau}$	0.9876
	130	24.89	$w = 23.908e^{-0.02\tau}$	0.9872

Legend: t_{ad}-default air temperature; w_1- initial moisture content

The initial humidity of the samples varied and ranged from 24.89% to 36.26%. The air speed varied by 110 °C (air temperature) from 2.29 m/s to 2.5 m/s, and by 130°C (air temperature) from 2.17 m/s to 2.86 m/s, which gave average air velocities of 2.39 m/s and 2.46 m/s, respectively, caused by different porosity of maize grains. The grain temperature ranged for 110 °C (air temperature) from 88.8 °C to 95.6 °C, and for 130 °C (air temperature) from 89.9 °C to 114.8 °C, while the average grain temperature was 91.42 °C that is 104.8 °C. This all gave different drying lengths. From table no. 2. it is seen that the drying of hybrid grains with the highest humidity does not take the longest, both for the drying air temperature of 110 °C and for the drying air temperature of 130 °C. In samples with moisture w_1 = 33.67%, within the hybrid itself, the drying time of the grain at the air temperature at the inlet to the dryer of 130 °C lasts longer by 56.25%. The same data for humidity samples w_1 = 36.26% is 40.0%. The same data are interesting for hybrids with very small humidity differences, which amount to moisture w_1 = 28.53%; 125.0%, and for the hybrid moisture w_1 = 27.39%; 12.5%. These data lead to the conclusion that the drying period depends on the hybrid, i.e. on the morphology of its air.

After drying the maize grain, the dynamic damage (fracture) was examined using a centrifugal crusher. Table 3 shows all visual grain damage and the measured mass of undamaged grain to calculate the fracture percentage.

Table 3 Damage to maize grain with respect to its dynamic strength

Hybrid	t_{ad} (°C)	breakage (%)	whole grain %	t_0 (°C)	ϕ (%)	mass of 1000 grain (g)	w_2 (%)
OSSK 430	110	27.6	72.4	22.0	36.0	280.8	13.95
	130	30.4	69.6	22.0	36.0	273.6	13.70
Pajdaš	110	70.8	29.2	22.0	36.0	309.6	13.59
	130	74.0	26.0	22.0	36.0	308.8	13.05
Bc 424	110	61.6	38.4	24.0	31.0	300.8	13.48
	130	53.6	46.4	24.0	31.0	285.2	13.52
Bc 415	110	49.2	50.8	24.0	31.0	326.8	12.95
	130	65.6	34.4	24.0	31.0	343.6	13.57
OOSK 403	110	66.4	33.6	24.0	31.0	230.0	13.34
	130	72.0	28.0	24.0	31.0	228.4	12.93

It is noticed that the drying temperatures (110 °C and 130 °C) do not affect the grain breakage to a greater extent, although the breakage is slightly higher at drying temperatures of 130 °C. However, according to the mass of 1000 grains, it is seen that the hybrid with the highest mass has a lower percentage of refraction compared to the hybrid with the lowest mass. Thus, although it was expected that the hybrid with the largest grain would also have the highest percentage of refraction, the opposite happened. From this it can be concluded that the main problem is in the morphology of maize grains.

CONCLUSION

Although research is being conducted on FAO 400 maize grain harvested on the same day, their humidity differed by almost 10%, which indicates that when testing the dryer, it should be more precisely defined which hybrids should be used. Within the hybrids themselves, it is observed that the drying period depends on the hybrid or its morphological characteristics. Analysing the damage of maize grain with regard to its strength, there are large differences in fracture between hybrids, a slightly higher fracture is observed at an air temperature of 130 °C compared to 110 °C.

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REFERENCES

Altay, F., Gunasekaran, S. (2006). Influence of drying temperature, water content, and heating rate on gelatinization of corn starches. Journal of Agricultural and Food Chemistry, 54, 4235–4245.

Chung, H.-J., Liu, Q., Hoover, R. (2009). Impact of annealing and heat-moisture treatment on rapidly digestible, slowly digestible and resistant starch levels in native and gelatinized corn, pea and lentil starches. Carbohydrate Polymers, 73(3), 436–447.

Gely, M.C., Santalla, E. M. (2000). Effect of some physical and chemical properties of oilseeds on drying kinetics parameters. Drying Technology, 18(9), 2155-2166.

Henry, R., & Kettlewell, P. (Eds.). (2012). Cereal grain quality. Springer Science & Business Media.

Krička, T., Grubor, M., Matin, A. (2019). Utjecaj FAO grupe hibrida kukuruza na brzinu otpuštanja vode sušenjem i hranidbenu vrijednost zrna. In Proceedings of the 47 International Symposium Actual Tasks on Agricultural Engineering, 323-332.

Krička, T., Matin, A., Horvatić, T., Kiš, G., Voća, N., Jurišić, V., Grubor, M. (2018). Nutritivni sastav oljuštenog zrna ječma nakon termičke dorade sušenjem i uparavanjem. Krmiva: Časopis o hranidbi životinja, proizvodnji i tehnologiji krme, 59(2), 51-60.

Maier, D. E., Bakker-Arkema, F. W. (2002). Grain drying systems. In Proceedings of the 2002 Facility Design Conference of the Grain Elevator & Processing Society, St. Charles, Illinois, USA, July, 28-31.

Malumba, P., Janas, S., Roiseux, O., Sinnaeve, G., Masimango, T., Sindic, M., Deroanne, C., Béra, F. (2010). Comparative study of the effect of drying temperatures and heat-moisture treatment on the physicochemical and functional properties of corn starch. Carbohydrate polymers, 79(3), 633-641.

Munkvold, G. P., Arias, S., Taschl, I., Gruber-Dorninger, C. (2019). Mycotoxins in corn: Occurrence, impacts, and management. In Corn (pp. 235-287). AACC International Press.

Peplinski, A.J., Paulis, J.W., Bietz, J.A., Pratt, R.C. (1994). Drying of high-moisture corn: Changes in properties and physical quality. Cereal Chemistry, 71(2), 129-132.

Wall, J.S., James, C., Donaldson, G.L. (1975). Corn proteins: Chemical and physical changes during drying of grain. Cereal Chem, 52, 779-790.