Biblid: 1450-5029, (2024)28; 1; p 12 - 16
UDK: 633.15
DOI: 10.5937/jpea28-49481

Original Scientific

DYNAMICS OF MOISTURE RELEASE FROM MAIZE HUSKS AS A FUNCTION OF CROP DENSITY

DINAMIKA OTPUŠTANJA VLAGE U LISTOVIMA KLIPA KUKURUZA U ODNOSU NA GUSTINU SETVE

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ABSTRACT

Maize husk mass affects the dynamics of maize kernel moisture release as well as the yield and harvest timing of maize. The aim of this study was to observe the dynamics of moisture release in maize husks depending on the sowing density technology used. At the Zemun Polje location, a trail was established with three hybrids (H1-ZP 4708, H2-ZP4242, H3-ZP4790) in three densities (G1-40,816, G2-69,689, G3-89,286). During the vegetation period, 15 days after fertilization, four samples (V1-V4) were taken to determine the fresh and dry weight of the husk. The leaves were dried in an oven at 60°C for 12 hours.

The effect of the genotype was reflected in the different mass of the maize husks and the dynamics of moisture loss. It was most pronounced in hybrid ZP 4242, which had the highest moisture loss between V1 and V4 samples at 9.86 %. It is also the hybrid with the highest fresh mass of leaves, 88.71 g. The dynamics of mass reduction, i.e. moisture loss, was linear in all hybrids, except for the exceptions by ZP 4242. The effects of sowing density and genotype on the moisture release of the maize husks and thus the maize kernel lead to an optimal harvest and a reduction in the risk of yield loss.

Keywords: *weight; husk; rate of maturation.*

REZIME

Masa listova klipa utiče na dinamiku otpuštanja vlage zrna kukuruza, te i na prinos i vreme berbe kukuruza. Cilj ovog rada bio je da se posmatra dinamika otpuštanja vlage u listovima klipa-komušine u odnosu na primenjenu tehnologiju gustine setve.

Ogled je postavljen na lokaciji Zemun Polje, sa tri hibrida (H1- ZP 4708,H2- ZP4242, H3-ZP4790), i tri gustine (G1-40.816, G2-69.689, G3-89.286). U toku vegetacije 15 dana nakon završetka oplodnje pristupilo se prvom uzimanju uzoraka za merenje mase listova klipa, četitri puta u razmaku od deset dana (V1-V4). Listovi su sušeni u sušnici na 60˚C.12 h.

Efekat genotipa ogledao se u različitoj masi listova klipa i dinamici gubitka vlage. Najizraženiji bio je kod hibrid ZP4242 gde je zabeležen najveći gubitak vlage , između V1 i V4, 9.86 % g. Ujedno to je i hibrid sa najvećom svežom masom listova, 88,71 g. Dinamika smanjivanje mase, odnosno gubitka vlage, kod svih hibrida bila je linearna, sem izuzetaka gde je usled padavina koje su bile u julu (66,7 mm) i augustu (58,2 mm), došlo do povećanja mase listova klipa u kasnijim terminima. Ovo ostupanje zabeleženo je kod ZP4242, u svim gustinama u četvrtom terminu uzorkovanja V4. Prosečna masa listova po gustinama kretala se od 70,88 g do 89,97 g dok je dinamika smanjenja vlage bila najveća u G1, 26, 6% vlage. Na manjim gustinama masa listova klipa bila je veća. Krajnji rezultat efekta gustne setve i genotipa na otpuštanje vlage iz listova klipa a time i zrna kukuruza, je optimalana berba i smanjnje rizika od gubiraka u prinosu.

Ključne reči: *kukuruz, komušina, brzina sazrevanja.*

INTRODUCTION

The outer leafy layer that surrounds the ear of maize is called the husk. Measurements of husk length, number of layers, thickness and width are used to identify its morphological structure *(Jiang et al, 2020)*. According to *Zhou et al. (2016)*, husk properties exhibit wide variances that are regulated by genetics and have different qualities according to the genetic background. Additive genetic effects primarily control the fresh husk weight, dry husk weight, length, width, thickness, and the husk's overall area *(Gui-Hua et al., 2015)*.

The moisture release dynamics in maize husks, like in many other plant materials, involves complex interactions influenced by environmental conditions, internal structural features, and the physical properties of the husk itself. Moisture content in maize husks depends on various factors, including the maturity of the maize, weather conditions during growth, and postharvest handling. The greatest direct determinants of grain dehydration rate following physiological maturity are features related to the husk. The rate of grain dehydration is negatively linked with a number of morphological husk parameters, including husk area, thickness, length, width, and dry weight. Grain moisture and the rate of dehydration have a positive correlation with husk moisture *(Li et al, 2014)*.

Initially, maize husks may contain a substantial amount of water absorbed from the surrounding environment and plant tissues. Temperature and relative humidity play crucial roles in moisture release. Higher temperatures and lower relative humidity generally facilitate faster moisture evaporation. Air circulation and the drying environment affect the rate of moisture release.

The structure of maize husks, with its fibrous and porous nature, influences how moisture is held within the material. Maize husks may exhibit hygroscopic behavior, meaning they can absorb moisture from the air or release moisture depending on environmental conditions. The timing and methods of harvesting, as well as the post-harvest handling practices, can impact the moisture content in maize husks. Excessive moisture can lead to issues such as mold development, rotting, and growth of mycotoxin-producing fungi, negatively affecting the quality and safety of maize husks. Also, to a large extent, the physical characteristics of the kernels and cobs influence the design of the various parts of the corn husking machine *(Netam et. al., 2021)*.

Understanding the dynamics of moisture release in maize husks is crucial for optimizing postharvest processes. Proper conditions and monitoring of environmental factors contribute to maintaining the quality and preventing deterioration of maize seeds during storage or processing. This study aimed to reveal the effects of seeding density and genotype on moisture release from corn husks to optimize conditions during harvest and reduce the risk of yield loss.

MATERIAL AND METHOD

Assay design

The -investigation was set up at the Zemun Polje site in the form of a two-factor trial. Three hybrids from the maturity group FAO 400 (H1- ZP 4708, H2- ZP4242, H3-ZP4790) were selected for sowing in three densities (G1-40.816, G2-69.689, G3-89.286) under natural water conditions. A plot with three subplots is formed. Subplots consisted of a combination of three hybrids at three densities, each combination was sown in three rows and three replicates. Each subplot was one replication. The distance between rows was 70 cm. Space within a row was in three densities (G1-35 cm, G2-20,5 cm, G3-14,5). Maize cob samples were taken from the middle row, out of three, for each combination—a total of five randomly selected maize ears for each subplot. During the vegetation period, 15 days after the end of fertilization, the first sampling was started to measure: fresh husk mass (FHM), dry husk mass (DHM), fresh grain mass (FKM) and dry grain mass (DKM). Each subsequent sampling date was ten days after the previous measurement, for four sampling dates (V1-V4). Maize husk was removed from each ear to determine leaves fresh mass (FHM), and husk leaf area (HLA). After that, the leaves were dried in an oven at 60°C for 12 hours to determine dry mass (DHM) and moisture. The husk leaf area was measured with a LI-300 Area Meter (Li-cor. inc. Lincoln, Nebraska, USA). Each leaf taken out from the cob was measured collectively, and each value was converted to mm2.

After removing the husk and all the kernels from the cob, the fresh mass (FKM) of the maize kernels was measured. To determine the kernel moisture and dry mass (DKM), the fresh mass of the seeds was measured before they were dried to a constant mass in an oven at 105 °C.

$$\text{Moisture content (\%)} = \frac{W2-W3}{W2-W1} * 100$$

W1 = Weight of empty container
W2 = Weight of container with sample before drying
W3 = Weight of container with sample after drying

Meteorological conditions

Table 1. Average daily temperature in 2023

months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	$\bar{X}$
$\bar{X}$	6,5	5,9	10,5	11,7	17,8	21,7	26,4	24,9	23,1	18,5	10,3	7,0	15,35

Table 2. The sum of precipitation by month in the year 2023

months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Σ	70,4	53,9	24,4	64,9	94,6	63,0	66,7	58,2	54,3	23,6	79,0	33,3	?686,3

Statistic analysis

The experimental data were processed using the free SPSS 21 software. For the experiments conducted with two factors, a factorial analysis of variance (F-test) was calculated in the first phase. All results obtained were derived using descriptive statistics by calculating the mean values. The LSD multiple range test was used to test the significance of differences and treatment effects.

RESULTS AND DISCUSSION

The most noticeable was hybrid ZP 4242, which had the highest moisture loss at 9.86 % (V1 and V4 samples). Hybrid H2 was also the hybrid with the highest fresh husk mass, 88.71 g. The dynamics of mass reduction, i.e. moisture loss, was linear in all hybrids, except for the exceptions where, due to rainfall in July (66.7 mm) and August (58.2 mm), the mass of the maize husks increased in the later periods (V4). This deviation was observed in ZP4242 at all densities in the fourth sampling period V4. The husk's dry mass ranged from 16.31g to 19.26 g, corresponding to H1 and H3. The density had a varied function on the average husk mass, from 70.88 g to 89.97 g, and the moisture degradation dynamics peaked at G1 with 6.8% moisture. The husk's dry mass ranged from 16.36 g to 21.61 g, corresponding to G4 and G1. At lower densities, the maize husk mass was higher (Table 3).

According to Cui et. al. (2016), the husk mass correlates with the morphological characteristics of the cob and the yield, as well as with the plant growth.

The significance test of the differences in variance of the results obtained shows that genotype influences the variation in husk mass (fresh and dry) ($p<0.05$), while the significance of density for these traits is at both significance levels ($p<0.05$, $p<0.01$). The interaction of these two factors is significant for husk dry matter (Table 6).

Table 3. Dynamics of changes in the fresh weight of cob leaves (%) when growing maize hybrids in different sowing densities at the Zemun Polje location.

Time of sampling	Hybrid-husk mass/g										
	ZP4708			ZP4242			ZP4790			$\overline{X}$	
	Fresh	Dry	MC	Fresh	Dry	MC	Fresh	Dry	MC	Fresh	Dry
	95.61	18.87	80.26	125.19	25.06	79.98	121.26	25.76	78.76	120.43	24.62
V2	70.28	14.73	79.04	125.17	27.72	77.85	92.77	23.84	74.30	98.71	23.40
V3	59.94	15.74	73.74	77.51	19.18	75.25	57.75	15.37	73.39	74.33	19.94
V4	37.84	11.20	70.40	89.30	21.66	75.74	52.88	14.62	72.35	66.43	18.47
$\overline{X}$	65.92	15.14	75.86	104.29	23.41	77.21	81.17	19.90	74.70	89.97	21.61
V1	89.20	17.78	80.06	125.75	24.79	80.29	90.27	18.67	79.32	103.28	20.91
V2	99.83	22.16	77.80	97.47	19.95	79.53	79.12	17.72	77.60	91.37	19.95
V3	79.32	22.39	71.77	75.91	18.10	76.16	78.39	22.02	71.91	83.58	21.83
V4	59.33	15.52	73.84	52.09	12.55	75.91	54.53	15.02	72.46	57.63	15.60
$\overline{X}$	81.92	19.46	75.87	87.81	18.85	77.97	75.58	18.36	75.32	83.96	19.57
V1	86.34	17.83	79.34	89.97	16.22	81.97	89.25	19.89	77.71	86.39	17.88
V2	80.01	17.97	77.54	88.30	15.73	82.19	106.56	25.17	76.38	89.03	19.17
V3	39.84	10.16	74.49	70.06	16.41	76.58	69.26	17.17	75.21	54.77	13.85
V4	48.59	12.14	75.01	47.84	11.95	75.02	56.79	15.88	72.04	53.34	14.54
$\overline{X}$	63.69	14.52	76.60	74.04	15.08	78.94	80.46	19.53	75.34	70.88	16.36
Total	70.51	16.37	76.78343	88.71	19.11	78.46	79.07	19.26	75.64	81.61	19.18

V1 - (18.07.2023.); V2 - (27.07.2023.); V3 - (08.08.2023.); V4 - (17.08.2023.); MC-moisture content (%);

The husk area for H2 (1709.81 mm^2) is the largest determined in this study based on the information collected. The area of the husk leaves in hybrid H1 was the smallest. Sowing density also showed variation in the leaf area. The leaf area decreased with increased sowing density. The exception is H1, where the largest area was measured at G2 (Table 4.). The husk provides protection but also supplies energy for the growth of the ear. It protects the grain from fluctuations in the environment and increases the weight of the grain. According to *Zhou et al. (2020)*, after removing leaves from the ear, the average grain weight was reduced by 14.3% compared to the control, which includes all cob leaves. In addition, the structure of chloroplasts in the maize husk is comparable to that of leaves mesophyll and may serve as a short-term storage for sugars that support ear development *(Wang et al. 2023; Suva et al. 2010)*. The primary source and effect of the dominance and superiority of maize is precisely its extremely wide, very diverse and enormous potential in morphological variability *(Bekrić and Radosavljević, 2008)*, which is also reflected in the husk morphology.

Table 4. The leaf area of husk in different sowing densities

Density	Husk leaf area (mm^2)			
	ZP4708	ZP4242	ZP4790	$\overline{X}$
G1	1159.66	1709.81	1484.97	1451.48
G2	1412.75	1513.98	1413.85	1446.86
G3	1175.50	1423.77	1673.77	1424.34
$\overline{X}$	1249.30	1549.19	1524.20	**?**

G1- sowing density 40.816, G2- sowing density 69.689, G3- sowing density 89.286.

Initially, kernel moisture content varied from 86% to 88% in all hybrids and densities. During the observed period the moisture content of maize kernels dropped to 50%. In addition to a linear movement with sampling date, moisture moved linearly with sowing density and hybrids. Variation of kernel moisture was significantly influenced by sowing density. Moisture rate release decreases as density increases. In G1V4, a hybrid kernel of H1 had the lowest moisture content of 49.43%. In the following testing at the second-density G2, this hybrid also had the least amount of moisture. The highest influence on H3, which attained the lowest moisture content of 55.14%, came from the third density, G3. In maize breeding and crop production, rapid dehydration of maize kernels is crucial for selecting suitable hybrids *(Zhou et al., 2018)*. The morphological characteristics of the husk leaves affect the reduction of moisture content in the seeds. Reduced moisture content in the husk leads to a decrease in moisture content in the harvested kernel and affects the dynamics of kernel drying *(Tabaković et al., 2018; Kang and Zuber, 1989)* (Table 5).

Table 5. Dynamics of moisture release in kernel

Time of sampling	Density	Kernel moisture (%)			
		H1	H2	H3	$\overline{X}$
V1 (18.07.2023.)	G1	86.68	87.21	88.02	87.74
V2 (27.07.2023.)		81.38	82.81	79.45	80.79
V3 (08.08.2023.)		65.20	68.24	75.85	68.60
V4 (17.08.2023.)		49.43	65.95	61.43	57.93
$\overline{X}$		**70.67**	**76.05**	**76.19**	**73.76**
V1 (18.07.2023.)	G2	87.42	88.45	87.71	87.84
V2 (27.07.2023.)		84.11	84.24	78.70	83.70
V3 (08.08.2023.)		62.01	69.96	70.19	67.81
V4 (17.08.2023.)		53.25	61.98	61.04	57.44
$\overline{X}$		**71.70**	**76.16**	**74.41**	**74.20**
V1 (18.07.2023.)	G3	87.77	86.87	87.67	87.76
V2 (27.07.2023.)		82.89	85.61	78.72	83.08
V3 (08.08.2023.)		70.30	76.02	71.90	72.13
V4 (17.08.2023.)		58.16	56.13	55.14	57.91
$\overline{X}$		**74.78**	**76.16**	**73.36**	**75.22**
Grand Total		**72.38**	**76.12**	**74.65**	**74.39**

H1-hybrids ZP4708; H1-hybrids ZP4242; H1-hybrids ZP4790;

Based on the significance test of the differences between the variance of the obtained results, the genotype influenced the variation of husk mass (dry and fresh) ($p<0.05$), while for these traits the importance of density was at both significance levels ($p<0.05$, $p<0.01$). The interaction of these two factors is significant for husk dry mass ($p<0.05$) (Table 6). The influence of genotype on the traits analyzed in the trial concerned fresh and dry husk mass. The most significant differences were obtained between hybrids H1 and H2 for the two traits, fresh and dry husk weight. The difference between H1 and H3 is significant for the dry husk mass. The leaf area of the husk is significantly different between H1 and the other two hybrids (H2 and H3). These three hybrids did not differ in the characteristics of kernel mass, both dry and fresh, and leaf husk area (Table 4). Sowing density showed differences in husk mass between G1 and G3 for dry and fresh husk mass, while dry husk mass was different at all densities. Density also did not affect the differences obtained in kernel mass. Leaf areas were significantly different between G1 and G2 as well as G2 and G3. (Table 7).

Table 6. Tests of Between-Subjects Effects

Source	F				
	HLA	FKM	DKM	FHM	DHM
Intercept	6183.696	5878.533	656.085	1828.092	2488.923
Density	3.198*	0.300	0.250	8.721**	15.79**
Hybrid	9.745**	0.801	0.260	2.510*	3.536*
Density × Hybrid	2.556*	0.768	0.291	1.137	2.161*
Error	75065.86	4718.754	2796.827	155798.2	6322.009

HLA- husk leaf area; FKM-fresh mass of kernel, DKM- dry mass of kernel, FHM-fresh husk mass; DHM-dry husk mass; *-significant level ($p<0.05$), **-significant level ($p<0.01$).

Table 7. Significance of differences in relation to crop density and hybrid

Mean Difference (I-J)													
Density		Dependent Variable					Hybrid		Dependent Variable				
(I)	(J)	HLA	FKM	DKM	FHM	DHM	(I)	(J)	HLA	FKM	DKM	FHM	DHM
G1	G2	5.40	0.59	0.18	6.01	2.03*	H1	H2	299.88**	1.94	0.62	18.20*	2.73*
	G3	102.60 *	0.10	0.44	19.09*	5.24*		H3	274.89**	1.97	0.17	8.55	2.88*
G2	G31	97.19*	0.59	0.18	6.01	2.03*	H2	H3	24.99	0.03	0.45	9.6	0.15

HLA- husk leaf area; FKM-fresh mass of kernel, DKM- dry mass of kernel, FHM-fresh husk mass; DHM-dry husk mass; *-significant level ($p<0.05$), **-significant level ($p<0.01$).

CONCLUSION

The most commonly used indicator for predicting the maturity of corn grain and determining the appropriate time to harvest is the moisture content of the grain. Corn hybrids suitable for high plant density include those with lower moisture content, which causes corn kernels to dry out faster after reaching physiological maturity.

In our study, we investigated the dynamics of moisture release by observing the fresh and dry mass of kernels and husks. There is a strong dependency between these two characteristics. No variations in the dynamics of changes in fresh and dry mass of kernel were observed, as the hybrids in the test belong to the same maturity group. The variations in leaf area in this study show that plant density has a significant influence on leaf area. Compared to crops with higher plant numbers, leaf area was more developed at lower densities.

The corn cob leaves, which envelop the corn cob and act as a barrier against infection, are crucial for controlling the growth and ripening of the grain.

Acknowledgment: supported by the Ministry of Education, Science and Technological Development, Republic of Serbia, for financial support, no. 451-03-66/2024-03/200040; 451-03-66/2024-03/ 200010.

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Received: 26. 02. 2024. Accepted: 04. 04. 2024.