Impact of Drying on Dimensions of Corn Kernel Grown at Different Agrotechnological Levels

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Summary

This paper examines the dimensions (length, width, and thickness) and some physical characteristics (density, volume, sphericity) of corn kernel grown at extensive and intensive agrotechnology levels. The research was conducted during three years (2002, 2003, and 2004) on hybrids 'Bc 4982', 'Bc 462', 'Bc Jumbo', 'Florencia', and 'Stefania', dried at four temperature levels (70°C, 90°C, 110°C, and 130°C). In order to determine the difference in dimensions, they were measured before drying as well. It was found that there were significant differences in corn kernel dimensions before and after drying process, as well as between samples exposed to different drying temperature levels.

Key words

corn kernel, dimensions, density, volume, sphericity

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Received: February 8, 2007 | Accepted: April 16, 2007

Introduction

Corn is, after wheat and rice, the third most widely grown crop globally, while it is the most produced crop in Croatia, followed by wheat, barley, and oats. (Gagro, 1997).

Due to such a high share of corn in the crop production, the breeding industry does not stop discovering new corn hybrids. Such wide diversity of hybrids, designed for the domestic production areas, ranges from FAO group 100 (very early hybrids) for mountain regions, to FAO group 700 (late hybrids) for plain areas.

For the purpose of human nutrition and animal feed the corn kernel should be stored and preserved at least in the periods between two harvests. The cost-efficiency of preservation technology depends on proper utilization of physical traits of kernel. These values are interrelated and inevitably change with variations of any one of external influences.

The basic and the most often used practice in corn kernel processing is kernel drying. The drying process must be such that kernel quality is preserved (germination or nutrient value). In addition to kernel quality preservation, the drying process should be cost-efficient and the dryer's effect must be as high as possible. The aim of drying process is to keep in the kernel the hygroscopic water, i.e., the quantity of water which is essential for its latent life. This quantity is scarce, so it reduces biological activity of plant microorganisms to minimum. The allowed temperatures which the kernel may be heated at in course of the drying process depend on intended use of dried kernel, dryer type and traits of hybrid (Katić, 1996).

In assessing relation between individual dimensions of kernel, of any culture, forms and proportions of kernel are usually determined by three measurements – length, width, and thickness. These measurements allow determining with enough accuracy total surface and volume of kernel (Židko et al., 1982). Also, this author states that the volume of corn kernel linearly changes in relation to the kernel moisture content. This linear law is not affected by initial moisture, drying regime (drying air temperature, drying air rate) or kernel wetting regime.

Kernel dimensions, mass, shape, surface condition, and color are essential physical traits for sorting or calibrating the kernel. Variations in kernel length, width, and thickness enable the kernel separation by use of different types of screen. Kernel can be separated by width and length but also by thickness as well if the screen opening is ellipse-shaped (McLean, 1989). When filling up silo cells, kernels if uneven in size split, in a way that larger kernels fall in the middle, and smaller or cleaned ones fall in the peripheral areas of the cell. This can cause the creation of focuses or, so called ''nests'', effecting the kernel deterioration (Sito, 1994).

The drying process is also affected by kernel size. In short, this influence may be reduced to the size of free surface of kernel from which moisture is lost during the drying process, and to airflow resistance of kernel layer. The volume loss in drying process can amount to as much as 40%, and this also changes heap porosity, which affects the drying process. Since the hybrids vary by kernel size, the airflow resistance through the layer of the same thickness will also vary in different hybrids (Katić, 1985).

The investigations showed that the kernel dimensions (length, width, and thickness) in the drying process are not reduced evenly and that the changes can vary. The drying air temperature increase from 85°C up to 100°C significantly influences the variance in kernel dimensions. The airflow rate (0.8; 0.9; 1.3 m s^{-1}) did not have significant effect on kernel physical traits variance during the drying process (Sito, 1994).

Further, it was found that the corn hybrid 'Bc 592', dried at temperatures of 110°C and 130°C, changed its volume. It is determined that air temperature affects the volume variance. In addition, at drying temperature of 130°C kernel thickness was reduced. There were also changes in the kernel structure (stress cracks, micro and macro fissures) due to excessively high drying air temperature, or too long exposure to such temperature (Sito, 1991).

Kernel dimension largely affects the drying process, because of airflow resistance of kernel layer. Kernel density is defined as a ratio between material mass and specific volume of grainy materials (Jurič, 1997). Kernel shape in a specific load determines the formation of space between kernels in varying size, which is referred to as inter-kernel space. Hectoliter mass fundamentally depends on this space. In order to avoid mistakes in quality determination it is necessary to determine density.

The sphericity coefficient is a mathematical parameter expressing the characteristic of an object relative to that of a sphere (Mohsenin, 1970; Stroshine at al., 1987). It directly influences the fluidization process itself. By definition, fluidization is a process through which the solid particle layer, by contact with gas or fluid, is lead to the condition similar to boiling fluid. In the process, the solid phase particles and fluidization medium (gas or fluid) are mixed together. In order to facilitate the application of airflow laws on corn kernel during the fluidization process, it must be replaced with some of known forms. The formula according to Mohsenin (1970) denotes the kernel sphericity as a ration between mean geometric diameter and the largest diameter of corn.

For example, in the fluidization process of the 'Bc 462' corn kernel, the following mean kernel dimensions were determined: length 12.42 mm, width 8.06 mm, and thickness 5.1 mm. By using the Mohsenin formula the sphericity coefficient of this hybrid was established as 0.64 (Pliestić, 1995).

Materials and methods

The research was conducted on five corn hybrids from the FAO 400 vegetation group 'Bc 4982', 'Bc 462', 'Bc Jumbo', 'Florencia', and 'Stefania'. Three hybrids out of five were Croatian hybrids (Bc Institute, Zagreb), whereas the hybrids 'Stefania' and 'Florencia' have been introduced by the US firm Pioneer. Three of the hybrids were dent hybrids ('Bc 4982', 'Jumbo 48', and 'Florencia'); one was a semi flint ('Bc 462') and the last was a hard dent ('Stefania'). Hybrids were planted under both, low-N and high-N, fertilization levels (low and high cropping intensity) in Northwestern Croatia at the Faculty of Agriculture Zagreb experimental field during the 2002-2003 -2004 growing season in silt loam soil. The high-N input involved fertilization with 500 kg ha^{-1} NPK (8:26:26) and 100 kg ha^{-1} urea in basic fertilization and 150 kg ha^{-1} urea in pre-planting fertilization. Nitrogen fertilization between rows was 94.50 kg ha^{-1}. The low-N input involved only 400 kg ha^{-1} NPK (8:26:26) in basic fertilization (Ritchie et al., 1986).

The weather data during the growing process were obtained from the meteorological station Zagreb-Maksimir for the period from 2001 to 2004. The precipitation data show that in the second year of the research precipitation level was below average (581.7 mm), while in the first year (978.8 mm) and in the third year (922.3 mm) it was above average; the average for the period from 1963 to 1992 was 836.0 mm.

The mentioned hybrids were selected because of their high share in corn production, which makes this research relevant for the growing practice. All hybrids were both picked and shelled manually. In this way it was possible to avoid machine-incurred damage to the kernels and this gave the basis for research (Krička 1990). Namely, when corn is harvested by combines there is always the problem of kernel damage, which causes difficulties in post-harvest kernel manipulation (Košutić, 1981).

The samples of hybrids were analyzed in natural and dryer conditions. The drying was performed in the laboratory dryer model with a facility to regulate temperature and airflow rate. The working medium (air) temperatures were maintained at 70°C, 90°C, 110°C, and 130°C, while the kernel layer airflow rate was maintained at 1.0 m s^{-1}. After drying, one sample was randomly taken from each hybrid with accurately determined number of kernels.

For each group, kernel dimensions (length, width, and thickness), sphericity, volume and density were determined.

Sphericity results from kernel dimensions depend on kernel shape. Sphericity coefficient expresses the shape of an object relative to that of a sphere, and it is determined by Mohsenin (1970) and Stroshine et al. (1986) expression which is:

$$\Phi = \frac{\left[\left(\frac{\pi}{6}\right)abc\right]^{\frac{1}{3}}}{\left[\left(\frac{\pi}{6}\right)a^3\right]} = \left(\frac{bc}{a^2}\right)^{\frac{1}{3}} = \frac{(abc)^{\frac{1}{3}}}{a}$$

where:

a-is kernel length – the maximum diameter (circumference diameter) (mm),

b-is kernel width – medium diameter (circumference diameter) (mm),

c-is kernel thickness – minimum diameter (mm).

The corn kernel basic dimensions (length, width, thickness) expressed in mm, were measured by use of moving measuring tool Digital Caliper 0-150 mm.

Density and volume were determined by use of the scale Mettler Toledo with Density determination kit-33360. For weighing, the liquid, i.e., ethanol, was used (as kernel does not absorb ethanol), density of which was previously determined at 0.785 g ml^{-1} at the temperature of 25°C. Air temperature of the environment ranged from 23°C to 27°C.

The results were processed by GLM procedure in the SAS system package, version 8.00 (SAS Institute, 1997), more specifically by variance analysis, while the mean value differences were compared by use of LSD test for $p = 5\%$.

Results and discussion

Five corn hybrids were grown during three vegetation seasons at low- and high-intensive growing practices. The kernel samples of each hybrid were dried at four air temperature levels (70° C, 90° C, 110° C, and 130° C). Using statistical data processing mean values of sphericity, density, and volume were calculated.

Table 1 shows mean values of sphericity, density, and volume relative to the kernel drying temperature during three years when research was conducted.

By comparison of mean sphericity values it was determined that thermal treatments did not significantly affect the difference of sphericity. It was noted that sphericity is the highest in samples dried at temperature of 130 ° C, where it was 0.664, and the lowest one in samples dried at 70°C where it was 0.655. Unlike sphericity, significant differences were noted in density and volume. So, the lowest density value was determined in samples dried at 90°C and it was 1.010, and the highest value was found in samples dried at temperature of 70°C and it was 1.156.

Table 1. Mean values of sphericity, density and volume relative to corn kernel treatment during three year research

Treatment	Sphericity	Density (g cm^{-3})	Volume (m^3)
Natural sample	0.658a±0.040	1.150a±0.054	0.871d±0.040
70°C	0.655a±0.052	1.156a±0.215	0.882d±0.097
90°C	0.656a±0.047	1.010b±0.054	0.912c±0.046
110°C	0.658a±0.041	1.077b±0.072	0.932b±0.061
130°C	0.664a±0.047	1.050c±0.117	0.962a±0.097
p value	0.47	< 0.0001	< 0.0001
LSD	0.01	0.027	0.016

Mean values ± SD, for each treatment separately, with the same mark do not significantly vary (p<0.05)

There was also a significant difference in volume, which ranged from 0.871 in natural treatment conditions to 0.962 in samples dried at 130°C. The obtained sphericity coefficients were within the limits of the results obtained by Stroshine et al. (1986).

Also, by comparing mean sphericity values within the individual drying temperature levels shown in the Table 1 it can be determined that sphericity increases with the drying temperature level kernel was previously exposed to. It can be explained by the fact that drying procedure at higher drying temperature causes higher rate of kernel moisture loss, which can change its structure. It, then, reflects on kernel dimension and thus, on its volume and sphericity.

Table 2 shows mean sphericity, density and volume values of examined hybrids during the three year investigation.

The data from the Table 2 show that there is a significant difference in sphericity, density and volume in examined hybrids that were subject of the three year investigation. The sphericity was the highest in hybrid Bc 462 and it was 0.688, and the lowest in hybrid Florencia, 0.638. The density ranges between 1.059 in hybrid Bc Jumbo 48 and 1.196 in hybrid Bc 462. The lowest volume value was found in Bc 462 and it was 0.853, and the highest one in hybrid Bc Jumbo 48 and it was 0.948.

Table 3 shows mean values of sphericity, density, and volume of examined hybrids during the three year research in relation to growing practices intensity.

Table 3 shows that there are no significant differences in density and volume in samples grown at both growing practice levels. The lowest density and sphericity values were found in conditions of low intensity growing system, unlike the volume where the lowest values were found at high-intensity growing practice.

Table 4 shows mean values of sphericity, density and volume of hybrids during the three year research.

The Table 4 makes it evident that the sphericity and density values found in the second year of investigation

Table 2. Mean sphericity, density and volume values of examined hybrids during the three year investigation

Hybrid	Sphericity	Density (g/cm^3)	Volume (m^3)
Bc 4982	0.642c±0.041	1.106b±0.064	0.907b±0.056
Bc 462	0.688a±0.052	1.196a±0.211	0.853c±0.102
Bc Jumbo 48	0.662b±0.041	1.059c±0.065	0.948a±0.061
Florencia	0.638c±0.039	1.063c±0.099	0.947a±0.075
Stefania	0.662b±0.037	1.110b±0.066	0.904b±0.053
p value	< 0.0001	< 0.0001	< 0.0001
LSD	0.009	0.026	0.016

Mean values ± SD, for each treatment separately, with the same mark do not significantly vary (p<0.05)

Table 3. Mean values of sphericity, density and volume of examined hybrids in relation to growing practice intensity during the three year research

Practice intensity	Sphericity	Density (g cm^{-3})	Volume (m^3)
Low intensity	0.662a±0.047	1.099a±0.108	0.917a±0.076
High intensity	0.655b±0.045	1.115a±0.141	0.907a±0.082
p value	0.047	0.089	0.860
LSD	0.007	0.018	0.011

Mean values ± SD, for each treatment separately, with the same mark do not significantly vary (p<0.05)

Table 4. Mean values of sphericity, density and volume of hybrids during the three year research

Year	Sphericity	Density (g cm^{-3})	Volume (m^3)
1.	0.659a±0.043	1.099b±0.082	0.915a±0.072
2.	0.666a±0.048	1.126a±0.187	0.904a±0.098
3.	0.650b±0.046	1.095b±0.073	0.917a±0.064
p value	0.0009	0.013	0.123
LSD	0.008	0.022	0.014

Mean values ± SD, for each treatment separately, with the same mark do not significantly vary (p<0.05)

(extremely dry) are the highest and amount to 0.666 for sphericity and 1.126 for density. The significantly lowest values were recorded in the third year ranging from 0.650 for sphericity to 1.095 for density. In the year three, the conditions were markedly rainy during the growing process. As for the volume values there are no major differences between samples grown in different years of the research and the lowest values were found in the second year, 0.904, and the highest one in the third year, 0.917.

In order to determine the interaction of the examined parameters, a combined variance analysis for sphericity, density and volume of kernels during the research was carried out. The results are given in Table 5.

Table 5 shows that in the growing process, the year (p=0.0001) and growing practice intensity (p=0.02) have highly significant interaction with sphericity and the examined hybrids (p<0.0001). However, thermal treatments

Table 5. Combined variance analysis for sphericity, density and volume during the three year research

Variance source	p value					
	Sphericity		Density		Volume	
Year (G)	***	0.0001	***	0.0002	*	0.011
Hybrid (H)	***	<0.0001	***	<0.0001	***	<0.0001
G × H	NS	0.84	***	<0.0001	***	<0.0001
Grow. practice (A)	*	0.02	***	0.004	**	0.007
H × A	NS	0.10	***	0.0002	**	0.002
G × A	NS	0.27	***	0.0003	***	0.0004
G × H × A	***	0.001	***	<0.0001	***	<0.0001
Treatment (T)	NS	0.29	***	<0.0001	***	<0.0001
H × T	*	0.02	***	<0.0001	***	<0.0001
A × T	NS	0.45	***	0.001	*	0.04
G × T	**	0.01	***	<0.0001	***	0.0002
H × A × T	*	0.04	***	<0.0001	***	<0.0001
G × H × T	*	0.03	***	<0.0001	***	<0.0001
G × A × T	NS	0.09	***	<0.0001	***	0.0007
G × H × A ×T	***	0.001	***	<0.0001	***	0.002

***, **, *, NS significant with p = 0.001; 0.01; 0.05 and not significant, in this order

the kernels were exposed to did not have essential influence on kernel sphericity (p=0.29). Also, Table 5 shows that in different interaction combinations the different significant interactions of individual parameters with sphericity were found. However, the interaction of all parameters (year, hybrid, growing practice, and treatment) with sphericity was found to be highly significant (p=0.001).

Also, it can be noted that the year (p=0.0002) and growing practice intensity level (p=0.004) have highly significant interaction with density in the growing process, as well as the hybrids (p<0.0001) and the treatments (<0.0001). The combination of interactions as well as the interaction of all parameters with kernel density is found to be highly significant.

Further, we noted that the year as parameter significantly interacts with volume (p=0.011), followed by growing practice intensity (p=0.007) in the growing process. Highly significant interaction is noted in the hybrids (<0.0001), as well as in the thermal treatments (<0.0001). Interaction of all parameters (year, hybrid, growing practice, and treatment) with kernel sphericity was determined as highly significant (p=0.002) as well as in the case of sphericity and density.

Conclusions

On the basis of the three year research conducted during 2002, 2003, and 2004, and influence of drying air temperature of 70°C, 90°C, 110°C, and 130°C on kernel dimensions (length, width, and thickness), sphericity, density, and volume of hybrids 'Bc 4982', 'Bc 462', 'Bc Jumbo', 'Florencia', and 'Stefania' grown in two different growing practices the following conclusions may be drawn:

All examined physical properties of corn kernel, sphericity, density, and volume, are not reduced at even rate in the drying process. The mean values for all examined hybrids were: for sphericity 0.658, for density 1.107 (g cm^{-3}) and for volume 0.912 (m^3). In all three years of the research a highly significant interaction of all examined parameters (year, hybrid, growing practice, thermal treatment) with kernel density and volume was found in all examined samples of corn hybrids. It can be determined that samples significantly differ in kernel density and volume in terms of specific years of research, hybrids, growing practices and thermal treatment procedures. It results that each kernel, given its shape, is a particular unit with its own characteristics, i.e., that the kernel layer is not a homogenous body but a heterogeneous system with uneven properties.

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acs72_33