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Studies on the Physical Changes in Corn Seeds during Hybrid Drying (Convection and Microwave)

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Abstract: Hybrid seed drying technology, based on convection and microwave drying, is a modern method, and the research on the physical changes in cereal seed resulting from hybrid drying is still in its infancy. The aim of the present paper is to study the uniformity of the drying process by examining the physical changes occurring in corn seeds. An innovative drying equipment, combining convective and microwave drying, was used to dry corn seeds (variety DKC5068). The convective drying was performed during the pneumatic transport of the seeds, using hot air at a maximum temperature of 50 °C; the microwave-based drying was performed using 2.45 GHz microwaves. Thus, the seeds were volumetrically heated at a temperature which does not exceed 44 °C. The physical changes in corn seeds were measured in terms of moisture, volume, cracking and color. The results regarding the moisture and volume changes in the seeds during the drying process proved that moist seeds are more homogeneous than dry seeds. The change in volume also changed the stiffness of the seeds, which showed greater homogeneity after drying compared to wet seeds. Hybrid drying led to an average shrinkage of 8.76% compared with the original seed volume, while the percentage of seeds showing cracks after drying increased by 22%. Generally, the drying process also led to color changes, but in the case of hybrid drying the results were inconclusive. Hybrid drying of corn seeds requires a shorter time and does not significantly influence physical characteristics, compared to other drying technologies.

Keywords: moisture; stress crack; stiffness; color

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1. Introduction

In order to preserve harvested agricultural seeds with a higher moisture content, they must be dried to reduce the moisture content to below 14% [1,2]. Convective drying is currently the most widely used method for dehydrating seeds. Keeping the seeds at a high temperature for a long time reduces the efficiency of drying by obtaining an unsatisfactory quality of dried seeds [3–5]. In order to improve the heat transfer efficiency, to reduce the drying time, and to keep the quality of drying seeds and other foods, several innovative technologies in heating and drying have been developed [6–9]. The hybrid drying technology, where, in addition to convective drying, microwave drying is also integrated, is considered part of the fourth-generation of technologies [9,10].

In the process of drying corn seeds, the moisture content decreases, leading to physical changes. Physical changes in cereal grains during growth or moisture content decrease are usually described by changes in mass, volume, density, color, and porosity [11]. Numerous studies have shown that the physical properties of cereal seeds and seeds of other crops depend mainly on their water content [12]. Other research shows that seed moisture content affects not only seed size, but also modulus of elasticity values, external friction coefficient values, slope angle, and cohesion [13,14]. Heterogeneity between the different components of corn seeds causes uneven temperature and moisture content distributions in the seed during drying, with a higher concentration of moisture content in the germ and a lower one in the endosperm [15]. During convective drying, the moisture of the seeds decreases unevenly, and the von Mises stresses vary in the structure of the seeds, significantly increasing the cracking index. The uneven decrease in seed moisture increases the susceptibility of seeds to mechanical damage, which will lead to a considerable loss of seed quality [15–17]. Continuous application of high-frequency waves to the seeds leads to rapid volume drying of the seeds, causing a likelihood of mechanical damage through cracking. To avoid this, intermittent application of high-frequency waves during the drying stage gives the seeds a higher physiological quality and reduces damage [18]. The mass and volume of the seeds decreases during the drying process due to the loss of moisture and a change in geometry through shrinkage, which leads to an increase in stiffness [19]. Hybrid drying of corn seeds at temperatures below 50 °C does not significantly affect the physical changes and quality of the dried seeds [20]. Corn seeds dried by convection at temperatures above 60 °C undergo color changes (ΔE), which increase linearly with increasing drying temperature [21]. When seeds are dried with microwaves at different microwave powers, no significant discoloration occurs in the color compounds of the observed seeds. During microwave treatment, the color parameters show a different behavior, which cannot be explained, apart from via the structural change caused during the treatment [22]. Research has shown that the color characteristics of dried products are significantly affected by drying methods [23,24].

The present study aims to determine the physical changes in corn seeds that occur during hybrid drying. Moisture, volume, shrinkage index, stiffness, stress crack index, and color were determined.

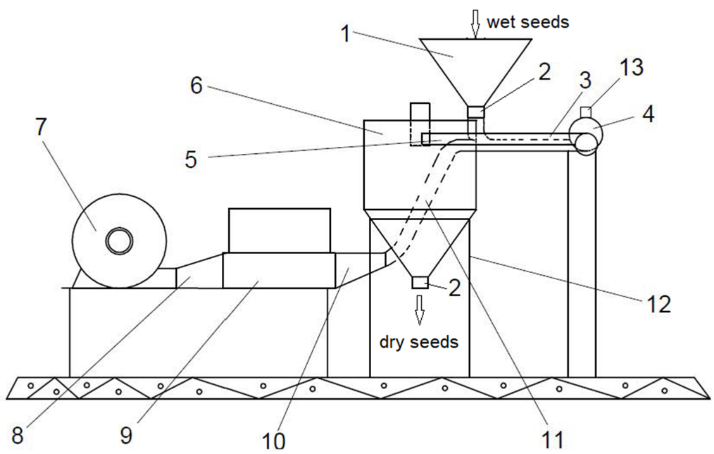
2. Materials and Methods

2.1. Materials

Analysis of physical changes during the drying process was performed on corn (*Zea mays L.*) hybrid DKC5068. For this, 500 kg of corn seeds was used, which was subjected to cleaning to remove physical impurities from the seed mass, and then selected before drying.

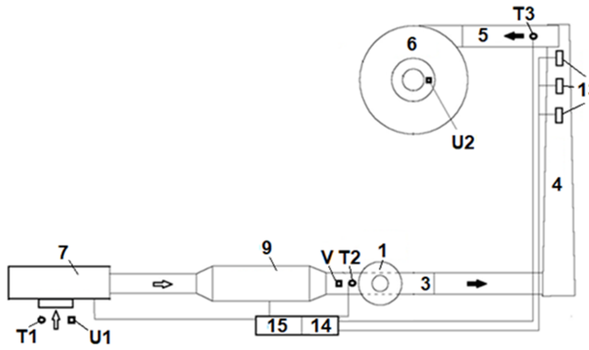
2.2. Description of the Hybrid Drying Equipment

The hybrid drying equipment (convection and microwave) used for drying corn seeds is shown in Figure 1a,b.



(**a**)

Figure 1. *Cont.*



(**b**)

Figure 1. The hybrid dryer: (**a**) side view, (**b**) top view; 1. Wet seed hopper; 2. Lock; 3. Tangential pipeline inlet seeds; 4. Hybrid truncated cone dryer; 5. Tangential pipeline outlet seeds; 6. Cyclone; 7. Fan; 8, 10. Link pieces; 9. Air heating battery; 11. Warm air pipe; 12. Support brackets; 13. Antennas; 14. Temperature monitoring; 15. Energy monitoring; T1. Air temperature sensor, T2. Input air temperature sensor; T3. Output air temperature sensor; U1. Input air humidity sensor; U2. Output air humidity sensor; V. Air velocity sensor.

2.3. Warm Air Convection System

The dryer's warm air generation system supplies the necessary amount of thermal agent (warm air), at a maximum temperature of 70 °C, to carry out the convective seed-drying process. The convection unit consists of a fan (7) type CA-172-2T-10 IE3, providing a maximum flow of 2300 m^3/h at a maximum total pressure of 10,980 Pa, with an installed electric motor power of 7.5 kW, and two connecting sections (8, 10) between which is positioned the air heating battery (9) type CVA m 315 equipped with spiral electric resistors with an installed power of 12 kW. The electric resistance heating system has an air temperature control unit with the possibility of setting the desired temperature during the drying process. The air temperature was measured with K-type thermocouples (range 0–200 °C, resolution 0.25 °C) directly at three points to monitor the temperature: at the air inlet to the fan (7), at the inlet pipe (3) to the truncated cone dryer, and at the outlet pipe (5) of the used air from the dryer (Figure 1b). Air humidity monitoring was performed using Pro tag wireless sensors (range 0–95% RH, resolution 0.12% RH, measurement error ±2% RH over the temperature range −40 °C and −85 °C). Air velocity monitoring was performed on the inlet pipe (3) of the hybrid dryer with a digital hot wire anemometer type Testo 405i (air velocity range 0–30 m/s, resolution 0.01 m/s, accuracy ± 0.1 m/s).

2.4. Microwave Heating System

The volumetric heating system of the corn seeds in the microwave drying process consists of three magnetron antennas with a maximum power of 800 W each, working at a frequency of 2.45 GHz, which are positioned at the top of the truncated cone dryer (Figure 1b). The microwave drying process was carried out intermittently at the three magnetrons. The microwave energy generator was adjusted in such a way that the power shut off for 2 s and switched on for 1 s.

2.5. Operation of the Hybrid Dryer

After conditioning, the corn seeds were convectively dried only when their moisture content exceeded 16–17%. To ensure optimal preservation of corn seeds, according to the standards, the moisture content of the seeds must be less than 14%. The hybrid drying equipment was fed with moist seeds at the top (1), which moved gravitationally through the lock (2) to the pipe (3) from where the seeds are taken up by a stream of warm air which has previously been heated in the battery (9) and conveyed pneumatically with an air velocity of 16.54 m/s, being introduced tangentially at the bottom of the hybrid dryer in the form of a truncated cone (4). Inside the dryer, the corn seeds have a complex trajectory. By a combination of circular and transverse movements, they are transported pneumatically from the large base to the small base of the hybrid dryer (4). Inside the dryer, the seeds are dried both convectively, because of the warm conveying air, and as a result of the action of the electromagnetic waves generated by the three magnetron antennas (13) arranged at the top of the hybrid dryer (4). The seeds are discharged tangentially from the dryer through the pipe (5) arranged tangentially to the small base of the dryer. The dried corn seeds are transported through the pipe (5) to the cyclone (6) where they are separated from the moisture-laden spent agent. The spent agent is discharged at the top of the cyclone and the dry corn seeds remain at the bottom of the cyclone until they are discharged through the lock (2) (Figure 1a,b).

2.6. Drying Procedure

In convective drying, the seed moisture gradient decreases from the outside to the inside of the seeds as the temperature increases from the outer to the inner layers, whereas in microwave drying, the heating of the seeds is volumetric and moisture is efficiently removed from the inside of the seed as well. The drying time varies depending on the seed variety and the initial moisture content of the seed entering the hybrid dryer.

The experimental protocol for obtaining the results is based on random selection before and after drying from a 50 kg mass of 10 samples, each sample having a number of 10 seeds. Experimentally, three repetitions were carried out where the value for each of the physical characteristics of moisture, shrinkage index, stiffness, and color were determined before and after drying.

2.7. Physical Properties

2.7.1. Determination of Seed Moisture

The moisture of DKC5068 hybrid corn seeds was measured according to the specific regulations for the quality of agricultural crops imposed in Romania. Three replicates were measured for each of the 10 samples both at the beginning and at the end of the hybrid drying process. The samples were oven-dried at 103 °C for 72 h and after cooling in the exicator to room temperature they were weighed. This procedure was repeated until the observed change in mass was less than 0.01 g. Sample weight was recorded using a digital balance accurate to ±0.001 g (Kern, PLJ360-314). The moisture content (M_c) of the samples was expressed in percent mean values of moisture content in percent wet basis, and their standard deviations were calculated.

2.7.2. Shrinkage Ratio

A volumetric displacement technique using toluene as the working solvent [25] was used to measure the shrinkage ratio of dried corn. The volumes were determined from 10 samples of corn seeds. Three replicates were measured for each sample and the average values were recorded. The shrinkage ratio (S_r) was calculated, as shown in Equation (1).

$$S_r = 1 - {}^{V_d}\big/_{V_0} \tag{1}$$

where V_0 and V_d denote corn seed volume before and after drying, respectively.

2.7.3. Stiffness Measurement

Practically it was determined that the air temperature inside the dryer should not exceed 50 °C in the hybrid drying process. By losing moisture, the seeds also change their texture. The behavior of corn seeds during compression loading is one of its textural properties. The textural parameter analyzed in this paper is seed stiffness through compression tests, which varies from sample to sample. The slow loading compression test was performed on all corn seed samples. Three repetitions were performed for each sample at the beginning of drying and at the end of drying. The test equipment consisted of a load cell and a computer running MESUR™GaugePlus texture measurement software (MARK-10

Corporation). A MARK-10 Type 7l dynamometer (range 0–1000 N, resolution 0.2 N) was used for compression testing. The trigger load was set at 0.2 N. Before contact with the specimen, the travel velocity of the test head in the form of a metal cylinder mounted on the dynamometer was 60 mm/min, and during compressive stress it was 30 mm/min. The load range measured by the measuring head was set up to 600 N. Each individual corn seed was placed on the bottom plate of the machine across its width. The maximum force F (N) or the force at the point of ultimate strength, from which the seed cracks, was obtained for each test. Compression tests were performed for force versus displacement.

2.7.4. Stress Crack Test

The change in the volume of cereal seeds during the drying process is due to the shrinkage that occurs in the seeds with the loss of moisture. When the drying process is carried out correctly, the low drying temperatures, low seed moisture, and the shrinkage phenomenon do not affect the seeds' quality. Stress cracks are internal fissures in the horneous (hard) endosperm of a corn kernel. The pericarp (or outer covering) of a stress-cracked kernel is typically not damaged, so the kernel appears unaffected, even if stress cracks are present. The internal stresses do not build up as much in the soft, floury endosperm as in the hard, horneous endosperm; therefore, corn with a higher percentage of horneous endosperm is more susceptible to stress cracking than softer grain. The most common cause of stress cracks is high-temperature drying that rapidly removes moisture [26]. The maximum temperature of corn seeds inside the dryer during hybrid drying was 44 °C, as determined by Multiphysics simulations [27].

For the determination of the stress crack index (SCI), 100 intact corn seeds with no external damage were randomly selected before and after drying. Samples were placed in a box where they were illuminated and checked for single, double, multiple, or no cracks. The stress crack index (SCI) for each sample was determined using Equation (2), as proposed by [28]:

$$SCI = (1 \times \text{single crack\%}) + (3 \times \text{double crack\%}) + (5 \times \text{multiple crack\%}) \quad (2)$$

2.7.5. Color Measurement

The change in the color of corn seeds is another parameter that changes during the drying process. This is due to the pigments in the upper layers of the seeds, which change color by removing moisture. The color of wet and dry seed samples was measured using a color analyzer (RGB-2000). This analyzer measures color in a 10 bit/color channel, where each color space (R—red color; G—green color; B—blue color) has 1024 intervals from dark to luminous. The transformation from the experimentally measured RGB space via the color analyzer is converted to CIELab space, which is independent of the measurement model. Three parameters, L^* (lightness), a^* (red) and b^* (yellow) were recorded for each seeds sample. The total color difference (ΔE) between wet and dry seeds was calculated using Equation (3).

$$\Delta E = \sqrt{(L_0 - L^*)^2 + (a_0 - a^*)^2 + (b_0 - b^*)^2} \quad (3)$$

2.8. Statistical Analysis

Excel software (2019, Microsoft Office, Redmond, WA, USA) was used to analyze the data. The experimental results were reported as mean values ± standard deviations of three replicates. The coefficient of variation CV (%) was used to assess the degree of variability of the experimental data obtained. Depending on the size of the coefficient of variation CV obtained from the data analysis, one can obtain the following: low variability (CV% $\leq$ 10), medium variability (10 $\leq$ CV% $\leq$ 20) or high variability (CV% $\geq$ 20).

3. Results and Discussion

Drying of corn seeds using the hybrid drying equipment resulted in physical changes that are summarized in Table 1. The physical parameters of corn seeds were measured both before and after drying. The ten samples studied were randomly selected (from an overall quantity of 50 kg seeds) at the beginning of drying and after drying, with three replicates for each sample. The physical parameters taken into account were moisture, volume, stiffness, color, and shrinkage index of the seeds. Wei S et al. have shown that, in convective drying, the moisture and temperature distribution in the product is heterogeneous [15], while the simple microwave drying (without convection) causes an additional degree of non-uniformity in moisture distribution, because of the uneven temperature distribution [6,29]. Consequently, the hybrid drying aims to reduce the non-uniformity of moisture distribution within the corn seeds.

Table 1. Physical changes in corn seeds subjected to drying.

No. Sample	Mc_i (w.b. %)	Mc_f (w.b %)	V_i (mm^3)	V_f (mm^3)	S_r	$F_{i\,max}$ (N)	$F_{f\,max}$ (N)	ΔE
1	16.07 ± 0.48	13.69 ± 0.18	193.63 ± 29.23	175.27 ± 32.38	0.10 ± 0.010	314.73 ± 44.48	436.35 ± 21.12	0.57
2	16.18 ± 0.51	13.42 ± 0.23	199.00 ± 32.18	183.49 ± 22.26	0.08 ± 0.019	341,38 ± 22.62	456.81 ± 11.65	0.68
3	16.31 ± 0.33	13.78 ± 0.13	188.25 ± 42.28	168.47 ± 41.20	0.11 ± 0.008	309.16 ± 49.59	423.13 ± 28.29	0.43
4	16.56 ± 0.27	13.45 ± 0.24	190.94 ± 38.11	172.99 ± 28.31	0.10 ± 0.012	384.22 ± 11.52	461.01 ± 10.08	0.26
5	15.98 ± 0.45	13.81 ± 0.17	197.84 ± 33.21	184.24 ± 27.10	0.07 ± 0.018	352.29 ± 31.17	423.34 ± 32.11	0.32
6	16.28 ± 0.24	12.88 ± 0.14	194.58 ± 21.30	180.60 ± 19.42	0.08 ± 0.016	332.41 ± 26.11	429.96 ± 37.12	0.16
7	16.72 ± 0.42	13.01 ± 0.28	189.41 ± 36.21	174.14 ± 38.12	0.08 ± 0.012	343.31 ± 35.24	446.16 ± 16.82	0.44
8	16.42 ± 0.22	13.29 ± 0.11	191.45 ± 24.17	173.43 ± 41.17	0.10 ± 0.007	327.98 ± 36.15	439.12 ± 22.24	0.38
9	16.25 ± 0.19	13.47 ± 0.29	189.78 ± 34.27	171.87 ± 34.28	0.10 ± 0.015	312.12 ± 39.51	419.32 ± 26.34	0.29
10	16.48 ± 0.38	12.96 ± 0.32	194.91 ± 27.38	176.05 ± 29.39	0.10 ± 0.011	326.11 ± 28.58	444.02 ± 19.51	0.19
x_{med}	16.32	13.37	192.97	176.05	0.09	334.37	437.92	0.37
s	0.22	0.33	3.62	5.14	0.01	22.52	14.29	0.16
CV (%)	1.38	2.52	1.88	2.92	14.31	6.73	3.26	44.09
R^2	0.388		0.879		-	0.417		-

where M_{ci} = moisture of corn seed before drying (wet base); M_{cf} = moisture of corn seed after drying (wet base); V_i = volume of corn seed before drying; V_f = volume of corn seed after drying; S_r = shrinkage ratio; $F_{i\,max}$ = ultimate strength force to compression maximum compressive destruction force of corn seed before drying; $F_{f\,max}$ = ultimate strength force to compression maximum compressive destruction force of corn seed after drying; ΔE = total color difference of corn seed subjected to drying.

The analysis of experimental data regarding the initial moisture of the corn seeds introduced into the hybrid drying equipment was performed by calculating the standard deviation and the coefficient of variation.

According to the literature, in the final part of convective drying performed at 40 °C, corn seeds lose 3% of their moisture after 110 to 220 min, thus reaching a final moisture content of 13% [15,17,30,31]. By combining convective drying with radio frequency (RF) heating (at a wave frequency of 27.12 MHz), for the same drying temperature, the seeds lose 3% from the initial moisture content, reaching the 13% moisture content after 50 min [32]. In hybrid drying (convection and microwave), based on a microwave frequency of 2.45 GHz and a drying temperature not exceeding 44 °C, an average moisture of 13.37% was reached in 5 to 15 min. The analysis of the uniformity of moisture distribution in the dried corn seeds resulted in a, ±0.33% deviation from the average, which was a value slightly higher than that for the moist seeds. The coefficient of variation obtained for dry seeds was 2.52%, thus indicating a small variability (Table 1).

The average volume of corn seeds obtained through hybrid drying was 176.05 mm^3 for an average moisture content of 13.37%. These results are comparable with the ones obtained in tests based on convection drying of corn seeds, in which a volume of 175.27 mm^3 was obtained for a moisture content of 13.5% [13]. The data obtained for the volume of dried seed samples from hybrid drying had a deviation of ±5.14 mm^3 from the mean, with a coefficient of variation of 2.92%. Dimensional variability was higher in dry seeds compared to moist seeds, as shown in Table 1. There was an average decrease in the seed volume of 8.76% when hybrid drying was used. These findings are consistent with the data from previous research regarding the shrinkage of convection-dried corn seeds [17].

The stiffness of both moist and dry corn seeds was measured using compression tests, under slow loading until the seed failed by cracking; the maximum force or the ultimate strength was recorded. The analysis of stiffness data of seed samples with 16.32% moisture led to the conclusion that the average value of the cracking force was 334.37 ± 22.52 N; for the fried seeds, with a moisture content of 13.37%, the cracking force was 437.92 ± 14.29. The values present in the literature for convection-dried corn seeds with moisture content higher than 16% range between 380 N and 390 N. For dry corn seeds with a moisture content lower than 13%, the maximum cracking force values were between 410 N and 425 N [13,32].

When lowering the moisture content of corn seeds through hybrid drying, a slight increase in the maximum average force leading to the seeds starting to crack was observed. This phenomenon was also noticed when convective drying was used. Due to the composite structure of corn seeds (pericarp, hard endosperm, soft endosperm, germ), the temperature and moisture gradient in the seed structure is different in convective drying, compared to hybrid drying (convection and RF heating); this fact might explain the differences in seed stiffness [30,32]. In the meantime, it was noticed that, when hybrid drying was applied, the dried corn seeds were more homogenous in terms of stiffness, compared to wet corn seeds.

The percentage of cracked corn seeds, caused by stresses developed in the seeds, is shown in Table 2.

Table 2. Stress crack analysis of sampled corn before and after drying.

Status Seeds	Undamaged (%)	Stress Crack Categories Single (%)	Double (%)	Multiple (%)	SCI
wet seeds (16.18%)	89	5	3	3	29
dry seeds (13.40%)	67	16	11	6	79

Cracks in the wet seeds can occur before harvest, in the harvesting process, or during seed cleaning and sorting. Tension cracks in dry seeds are generally associated with rapid drying of corn at high temperature, followed by rapid cooling with air to room temperature. The hybrid drying process used in our tests eliminated the effects of rapid cooling by introducing pneumatic transport air into the drying equipment and drying at a maximum temperature of 50 °C, and in the cyclone, this is removed along with moisture at a lower temperature. The seeds are cooled slowly by conduction from the maximum temperature of 44 °C reached in the drying process to 22 °C, after which they are discharged from the cyclone to the outside at a temperature not falling below 15 °C. This slow conduction cooling tends to reduce stress cracking, as does the delayed cooling used in drying [28]. This would allow relaxation of internal stresses with less cracking in the corn seeds. The severity of stress cracking in artificially dried corn by a combination of microwave heating and air convection was assessed using the stress cracking index (SCI). SCI is a weighted index of corn quality based on the number of kernels that takes into account the crack patterns followed, i.e., with one crack, two cracks, and multiple cracks. In various previous papers, comparisons have been reported based on a single crack pattern due to stress in the kernel, or based on the total number of cracked kernels due to stress [26,33,34]. The SCI value, which combines all three types of stress cracking and weights them according to severity, is a more useful general index for evaluating stress cracking in corn and allows qualitative comparisons in the drying process [20,28].

As shown in Table 2, the seeds entered into the hybrid drying process with a moisture content of 16.18%, a percentage of 89% uncracked seeds, and a stress cracking index of 29; after hybrid drying, when the seed moisture content decreased to 13.40%, the percentage of uncracked seeds decreased to 67% and the stress cracking index increased to 79. These results indicate that in the hybrid drying process, when approximately 3% of moisture was removed by hybrid drying in order to bring the seeds to the limit of preservation, the number of cracked corn seeds also increased. The obtained results are in agreement with those obtained by other researchers, who have estimated the SCI stress cracking index when drying corn seeds by convection only [20,28,31,35]. Therefore, even at lower drying temperatures, the reduction in seed moisture is a factor that causes them to crack.

Analyzing the data regarding the physical characteristics obtained before and after hybrid drying of corn seeds, it can be stated that, in terms of moisture, moist seeds were more homogeneous than dry ones, while in terms of stiffness, moist seeds were less homogeneous than the dry ones. In terms of volume, moist seeds were more homogeneous than dry seeds, which might also be explained by the different shrinkage of the seeds during drying, with average shrinkage reaching 8.76% of the original volume before hybrid drying. The percentage of cracked corn seeds after drying increased by 22% and SCI increased by 50%.

There should be no variation in color between moist and dry seeds; changes in color indicate biochemical transformations of an enzymatic nature that can adversely affect the seeds quality, especially when the seed temperature is high and maintained for a long time [36,37]. Researches on convection-dried corn seeds, at temperatures above 60 °C, have proved that a linear increase in color change occurs when the drying temperature is increased [21,38]. Other researches have shown that microwave drying of seeds, at different powers, did not lead to a significant discoloration. The analysis of the color of dry corn seeds, based on the CIELab system, has shown a small variation in color (expressed through ΔE) between moist and dry seeds, with an average value of 0.37 ± 0.16.

4. Conclusions

The drying of corn seeds in a hybrid dryer, combining convection drying with microwave drying, was investigated. The physical changes occurring during the hybrid drying process were compared with those in the convection drying process, performed by other researchers. Moisture, volume, shrinkage index, stiffness, stress crack index, and color change were evaluated. The results have shown that in hybrid drying (convection and microwave), corn seeds lose 3% of their moisture content at the end of drying, in 5 to 15 min. In comparison, in hybrid drying (convection and radio frequency heating), corn seeds lose the same percentage of moisture after 50 min, while for simple convection, the drying time is between 110 and 220 min. Previous research has shown that it is more difficult to remove the moisture of corn seeds towards the end of the drying process, but in hybrid drying, due to the volumetric heating effect of microwaves, the seeds lose their moisture more rapidly. The results regarding the volume loss of hybrid-dried (convection and microwave) corn seeds were comparable with the ones obtained for the convection drying. Therefore, it was concluded that hybrid drying did not significantly reduce the volume of corn seeds during the process. In hybrid drying the decrease in the moisture content of corn seeds led to a slight increase in the average maximum force for which they crack, compared with the results obtained for convective drying. Thus, in hybrid drying, the corn seeds became stiffer compared to the convectively dried corn seeds. The stress cracking index (SCI) of hybrid-dried corn seed was comparable to the SCI obtained by other authors when convective drying of seeds was used. The factors that caused cracking in corn seeds were a sudden drop in temperature and a significant reduction in seed moisture. In hybrid drying of corn seeds the moisture reduction was 3% and the temperature of the dried seeds decreased slowly. Future research directions will be carried out in order to investigate the impact of pneumatic seed transport velocity on the formation of cracks and on the germination index of dry seeds.

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