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Original Scientific Paper

OPTIMIZATION OF CORN DRYING METHODS: A COMPARATIVE STUDY OF TRADITIONAL VARIETIES AND MODERN HYBRIDS

OPTIMIZACIJA METODA SUŠENJA KUKURUZA: UPOREDNO PROUČAVANJE TRADICIONALNIH SORTI I SAVREMENIH HIBRIDA

Ana MATIN[1], Ivan BRANDIĆ[1], Vanja JURIŠIĆ[1], Ivana TOMIĆ[1], Božidar MATIN[2], Tajana KRIČKA[1], Mateja GRUBOR[1], Filip PUCKO[1], Nives JOVIČIĆ[3], Karlo ŠPELIĆ[1]*

[1]*University of Zagreb Faculty of Agriculture, 10000 Zagreb, Svetošimunska cesta 25, Croatia;*
[2]*University of Zagreb Faculty of Forest and Wood technology, 10000 Zagreb, Svetošimunska cesta 23, Croatia;*
[3]*The University of Applied Sciences Velika Gorica, 10410 Velika Gorica, Zagrebačka 5, Croatia*
**Correspondence: ibrandic@agr.hr*

ABSTRACT

Understanding the effects of different drying methods on different corn varieties, both before and after drying, is crucial for selecting the most suitable hybrids and optimizing drying techniques. In this study, traditional white and red corn varieties and modern hybrid were investigated and the efficiency of vacuum drying and fluidized bed drying at temperatures of 70°C, 80°C and 90°C were compared.

The results show that vacuum drying is generally more effective in maintaining quality, while fluidized bed drying offers a significantly faster drying rate. Hybrid corn showed the fastest moisture loss, while traditional varieties showed greater resistance to drying. These results provide valuable insights into the most suitable drying conditions for the different corn varieties, which ultimately improve product quality and overall processing efficiency. Future research should investigate additional technological factors such as energy consumption, drying uniformity and effects on nutrient composition to further refine drying methods for commercial application.

Keywords: *drying methods; traditional corn varieties; technological optimization*

REZIME

Razumevanje učinaka različitih metoda sušenja na različite sorte kukuruza, kako pre tako i nakon sušenja, ključno je za odabir najprikladnijih hibrida i optimizaciju tehnika sušenja. U ovom istraživanju ispitane su tradicionalne sorte belog i crvenog kukuruza i moderni hibrid, te je upoređena efikasnost sušenja u vakuumu i sušenja u fluidizovanom sloju na temperaturama od 70°C, 80°C i 90°C.

Rezultati pokazuju da je sušenje pod vakuumom generalno efikasnije u održavanju kvaliteta, dok sušenje u fluidizovanom sloju nudi značajno bržu brzinu sušenja. Hibridni kukuruz pokazao je najbrži gubitak vlage, dok su tradicionalne sorte pokazale veću otpornost na sušenje. Ovi rezultati pružaju dragocen uvid u najprikladnije uslove sušenja za različite sorte kukuruza, što u konačnici poboljšava kvalitet proizvoda i ukupnu efikasnost prerade. Buduća istraživanja trebalo bi da ispitaju dodatne tehnološke faktore kao što su potrošnja energije, ujednačenost sušenja i učinci na sastav hranljivih materija kako bi se dalje poboljšale metode sušenja za komercijalnu primenu.

Ključne reči*: metode sušenja; tradicionalne sorte kukuruza; tehnološka optimizacija*

INTRODUCTION

Corn (*Zea mays*), an annual plant from the *Poaceae* family (grasses), is one of the most economically important and best-studied crops in the world. Due to its adaptability and variability, it can adapt to any climate and different growing conditions. It originates from Central America and was brought to Europe in the late 15th or early 16th century, while in Croatia it was introduced in the 16th century. FAOSTAT (2023) states that global corn production exceeds one billion tons per year on about 200 million hectares of land. Almost all corn parts can be used for processing, and more than 500 different corn products are produced today. Corn is very useful to produce food for humans and animals due to its large amount of nutrients (carbohydrates, proteins, oils, minerals, vitamins, cellulose, etc.). In addition to food, corn is also used in other industries, e.g. to produce biofuels, alcohol, plastics, building materials, explosives, rubber, ceramics, textiles, but also as an ornamental and medicinal plant. Some of the corn grown for grain is used for silage and similar green mass purposes. The use or purpose of corn depends on the respective growing region and its needs and possibilities. Martinez and Fernandez (2019) state that in the USA in 2017, 43.9% of the corn produced was used for animal feed, 56% for human consumption, ethanol and industrial use and only 0.2% for grain production. The growth of the world's population, socio-economic and geopolitical conditions and changes in climatic and meteorological growing conditions, as well as increasing market demand for a quantitative and qualitative increase in corn production, mean that production and logistics processes need to be adapted and production optimized, but also that more resistant plants and higher quality fruits are emerging. New technologies and automation are the basis for optimizing the production process, i.e. cultivation, transport and storage, i.e. they include the segments of labor, space, machinery and equipment, and an important part is the raw materials, i.e. the grain. The aim is to improve the quality, speed and efficiency of production as well as sustainability, reduce the negative impact on the environment and reduce costs, damage and losses in each segment of the process (*Brandić et al., 2024*). In addition to standard yellow corn, there are also white and red corn varieties, all of which have higher grain quality and nutrient content compared to hybrids, with the exception that white corn does not contain β-carotene. On the other hand, hybrids are the result of research and target selection of genetic traits that are desirable for the most successful, easy and profitable production. Resistance to pests, diseases and unfavorable weather conditions such as drought are challenges that must be overcome to make corn production as safe and successful as possible (*Ahmad et. al., 2024*). Corn is often harvested with high grain moisture content to reduce the risk of frost, insect damage and disease.

The drying process is often the cause of damage to grain corn, resulting in significant economic losses. The degree of maturity of the grains at harvest and the drying temperature are well documented as important criteria for efficient drying of grain corn. As moisture loss increases prior to harvest, corn grains become more resistant to high drying temperatures.

Proper drying of corn is a basic requirement for maintaining its quality, whether it is intended for consumption, further processing or use as grain, where quality is critical for successful future production (*Matin et al., 2023; Matin et al., 2024*). Corn is usually harvested with a grain moisture content between 25 and 35 %. To maintain grain quality, the moisture content must be reduced to 14 % by drying. Drying can take place either on the cob or as loose grain, with convection drying being the most used method. In recent years, vacuum drying and fluidized bed drying have also gained in importance.

Vacuum drying, also known as pressure drying, takes place at reduced pressure, which lowers the boiling point of the water. This process helps to preserve sensitive nutrients and food properties, especially color. Compared to conventional hot air drying, vacuum drying works at lower temperatures. According to Parikh (2015), this method is optimal because thermally unstable materials would decompose at atmospheric pressure and higher temperatures, while temperatures that are too low would prolong the drying process. In addition, vacuum drying takes place in an environment with a low oxygen content, which increases the oxidative stability of the dried material. However, the main disadvantages of vacuum drying include the high initial cost due to the expensive equipment and the limitation of heat transfer mainly by conduction from the heater (*Bhattacharjee et. al., 2024*).

In fluidized bed drying, on the other hand, individual particles are suspended in a stream of hot air or gas. This method increases the speed and efficiency of drying (*Law and Mujmundar, 2006*). Other advantages include easy handling and maintenance of the equipment, uniform drying and flexibility in terms of the quantity and size of the material to be processed. However, fluidized bed drying also has disadvantages, such as high energy consumption and unsuitability for drying sticky or heat-sensitive materials (*Hovmand, 2020*).

The aim of this study is to compare the drying efficiency of different grain varieties at the same temperatures but with different methods and drying times. In particular, the differences between new corn hybrids and traditional white and red varieties will be investigated. The results will be used to determine which drying method is the most efficient and energy efficient.

MATERIAL AND METHOD

The study was conducted on three corn samples, a corn hybrid and varieties of white and red corn, grown on the Croatian mainland in 2023. To avoid possible damage to the corn during the study, the corn was picked on the cob and shelled by hand. Since the corn grain samples had different initial moisture contents, it was necessary to equalize these values so that the samples could be compared for further investigations. The samples were rehydrated to approximately 32% moisture (according to the proposed regulation on testing dryers with 32 to 14% moisture) (*Krička et al., 1998*), i.e. to the average moisture that prevailed in the field during the grain harvest. The samples were cleaned of all impurities and contaminants, and only healthy grains were taken for analysis. Rehydration was performed by direct exposure to the grain mass with a precisely defined amount of distilled water according to the instructions of the State Institute of Standardization and Metrology. The rehydrated sample was defined as the starting sample for further tests. The water content was determined by drying the grains of each sample weighing approximately 3 g in a dryer at 105 °C for 4 hours according to the protocol (HRN ISO 6540: 2002).

Drying was carried out in two ways and at three temperatures of 70 °C, 80 °C and 90 °C until an equilibrium moisture content of 14 % was reached. The first method was fluidized bed drying with a Retsch TG 200 fluidized bed dryer, the second method was drying under vacuum with a Memmert vO101 vacuum dryer at a pressure of 500 mbar. Statistical data processing was performed with the SAS package version 9.3. (*SAS Institute, Cary, NC, USA*).

RESULTS AND DISCUSSION

It can be seen from table 1. that each sample has a different initial moisture content, with the white corn variety having the highest moisture content (15.32 %) and the red corn variety the lowest (13.72 %). Due to these differences, a rehydration procedure was carried out to ensure the reliability of the research results. After rehydration, the white maize variety retained the highest moisture content (24.82%), while the red corn variety had the lowest (23.95%). Similar results were also obtained by Gomes et. al, 2020 in their research. While ripening in the field as well as during transportation and storage, moisture and water exposure can significantly affect the grain. Pliestić et. al. (2000) investigated multiple rehydration of grains and concluded that repeated rehydration increases water absorption and accelerates drying. This phenomenon is attributed to the disruption of the capillary structure of the grain during multiple rehydration and drying cycles, particularly affecting capillaries with uneven diameter along their length (*Kieser, 2015*).

Table 1. Moisture content of corn grains after harvest and in the state after rehydration

Sample of corn	Moisture after harvest (%)	Moisture after rehydration (%)
White	15,32 ± 0,14	24,82 ± 1,580
Red	13,72± 0,08	23,95 ± 0,503
Hybrid	13,93 ± 0,06	24,07 ± 0,393

The study investigates the behavior of different maize varieties during drying under fluid conditions by analyzing the relationship between moisture content, drying time and temperature. Polynomial regression models are applied to create 3D surface diagrams that provide a visual representation of drying trends. For example, Figure 1 shows fluidized bed drying, while Figure 2 shows vacuum drying. The results contribute to a better understanding of the dynamics of moisture degradation and support the optimization of the drying process.

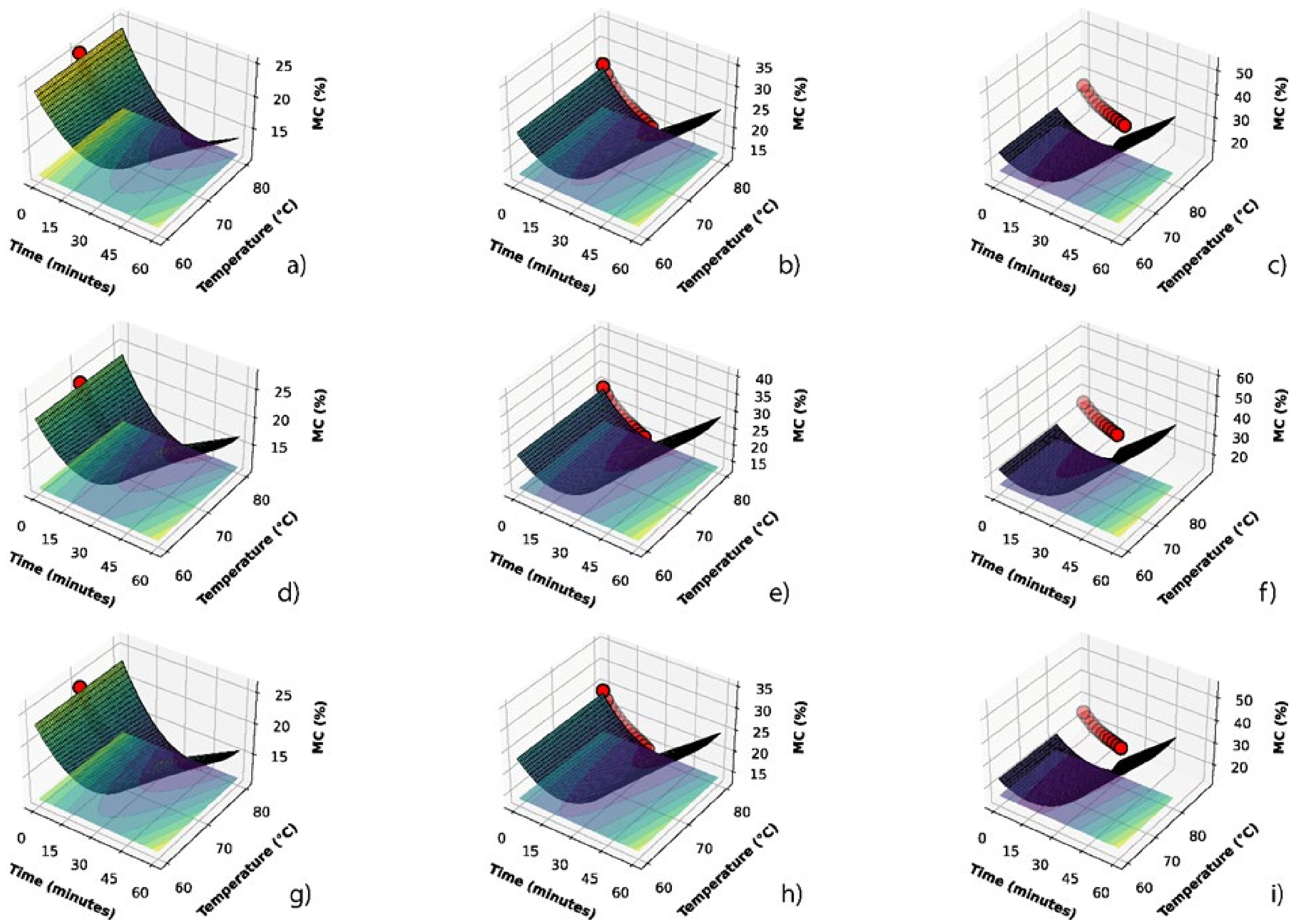

Fig. 1. 3D Surface Plots of Moisture Content Over Time and Temperature for Fluid Drying Condition

Figure 1 shows that each corn variety took the longest time to reach equilibrium moisture content at 70°C and the shortest time to reach the same moisture content when dried at 90°C.

Comparing the different corn hybrids/varieties at the same fluidized bed drying temperatures, the drying time required to reach equilibrium moisture content is different.

Drying at 70°C took 34 minutes for the white corn variety (a), 26 minutes for the corn hybrid (d) and 28 minutes for the red corn variety (g). In other words, the white corn variety took the longest and the hybrid corn variety the shortest to reach equilibrium moisture content at 70°C.

When drying at 80°C to equilibrium moisture content, the figure shows that the white variety took 26 minutes (b), the hybrid variety 22 minutes (e) and the red variety 24 minutes (h), meaning that the white variety took the longest and the hybrid variety the least time to reach a moisture content of 14%.

When drying at 90°C to equilibrium moisture content, the white variety took 22 minutes (c), the hybrid 18 minutes (f) and the red variety 20 minutes (i).

As with drying at 70 and 80 °C, the white variety required the most time and the least time to reach a moisture content of 14 %. Comparing the fluid drying values, it can be concluded that the type of variety and the temperature significantly influence the drying speed, and that the hybrid dries the fastest. The results are in line with those who conducted a similar study (*Momenzadeh et. al., 2011 and Liu et. al., 2023*).

From the data presented in Figure 2, the white variety took the longest to reach equilibrium moisture content when dried at 70 °C, i.e. 18 minutes (a), while the red variety and the hybrid reached equilibrium moisture content in 16 minutes (d and g). When dried at 80 °C, equilibrium moisture content was reached after 16 minutes (b) for the white variety, 14 minutes (h) for the red variety and 12 minutes (e) for the hybrid. When dried at 90 °C, the white variety took 14 minutes to reach equilibrium moisture content (c), while the red variety and the hybrid reached equilibrium moisture content in the same time span of 10 minutes (f and i).

Analysis of the vacuum drying images suggests that the variety and temperature significantly affect the drying rate, with the hybrid drying the fastest, which is consistent with the fluidized bed drying results. These results can be explained by the morphological differences between the red and white varieties, which require a longer drying time to achieve optimum grain moisture.

The results align closely with the findings of previous studies by Wang et al. (2020) further supporting their conclusions. Based on the exponential equations, the coefficient of determination was between 0.9437 and 0.9861. The analysis of these coefficients confirms that the results obtained are highly comparable and that the analysis of water release from corn grains was performed with precision. This is also confirmed by comparisons with literature data on grain drying processes (*Kričká et al., 2004; Matin et. al., 2017; Matin et. al., 2018; Matin et. al., 2022*). In industrial drying processes, it is often unavoidable to dry different corn varieties simultaneously despite their different initial moisture content. Due to the different water release rates of individual hybrids, single-phase drying to a target moisture content can result in uneven drying, where some grains are over-dried while others retain moisture beyond the allowable limits. The results of this study are consistent with these documented findings, further supporting the influence of variety-specific drying characteristics on moisture uniformity.

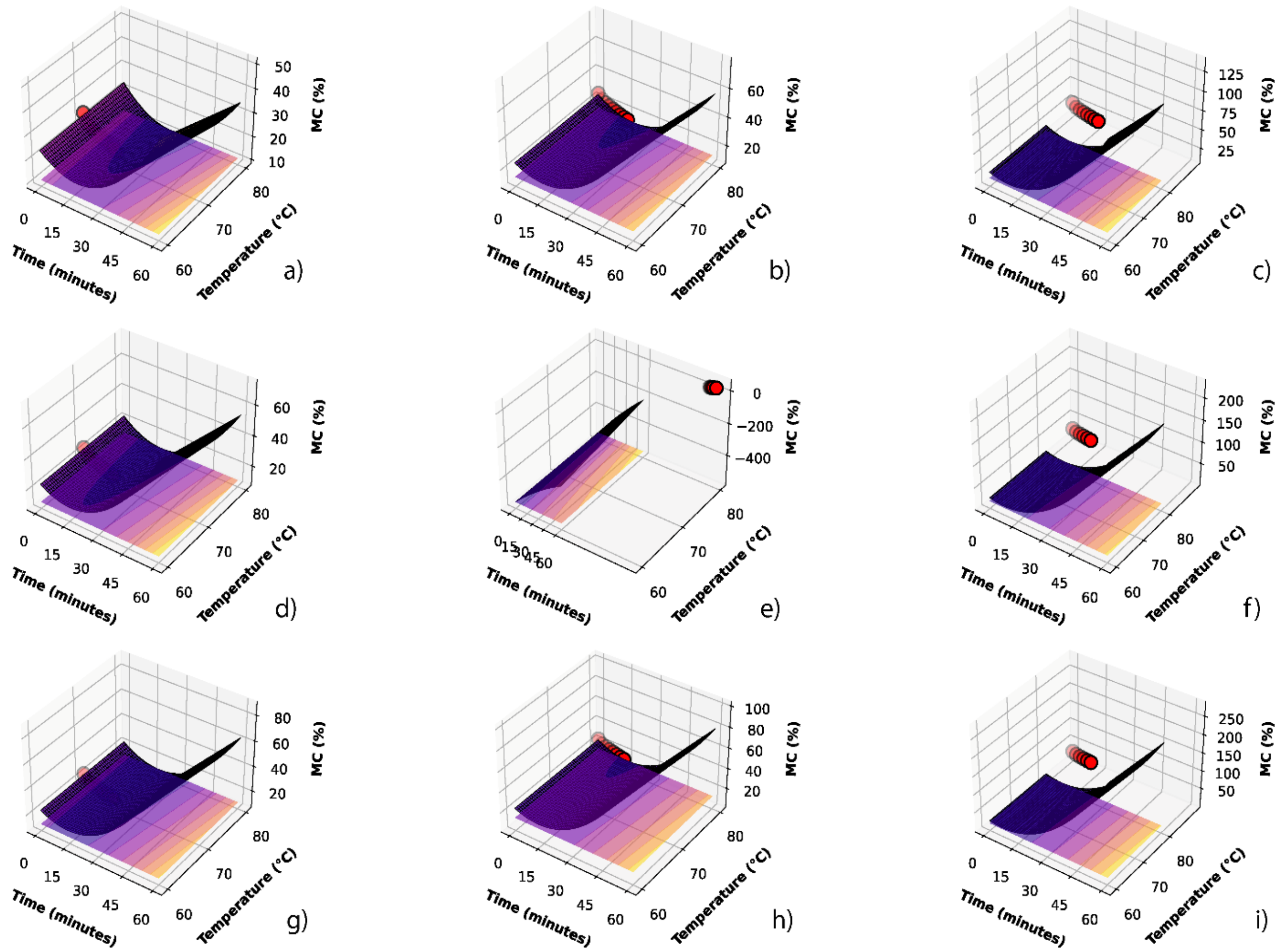

Fig. 2. 3D Surface Plots of Moisture Content Over Time and Temperature for Vacuum Drying Conditions

Table 2. Exponential equations of corn grain water release rate

Sample of corn	Drying	Temperature (°C)	Exponential equation for drying	Coefficiente of determination (R2)
White	Fluid	70	$y = 22{,}909e^{-0{,}016x}$	0,9643
		80	$y = 23{,}526e^{-0{,}025x}$	0,9742
		90	$y = 23{,}526e^{-0{,}025x}$	0,9742
	Vacuum	70	$y = 23{,}031e^{-0{,}028x}$	0,9500
		80	$y = 23{,}425e^{-0{,}033x}$	0,9713
		90	$y = 22{,}990e^{-0{,}039x}$	0,9502
Red	Fluid	70	$y = 22{,}498e^{-0{,}018x}$	0,9741
		80	$y = 22{,}706e^{-0{,}021x}$	0,9788
		90	$y = 22{,}852e^{-0{,}026x}$	0,9774
	Vacuum	70	$y = 22{,}024e^{-0{,}029x}$	0,9328
		80	$y = 22{,}531e^{-0{,}037x}$	0,9628
		90	$y = 22{,}420e^{-0{,}051x}$	0,9437
Hibrid	Fluid	70	$y = 22{,}857e^{-0{,}02x}$	0,9804
		80	$y = 22{,}981e^{-0{,}024x}$	0,9832
		90	$y = 23{,}269e^{-0{,}029x}$	0,9861
	Vacuum	70	$y = 22{,}418e^{-0{,}031x}$	0,9533
		80	$y = 22{,}855e^{-0{,}052x}$	0,9640
		90	$y = 22{,}940e^{-0{,}041x}$	0,9706

CONCLUSION

In this study, the behaviour of different corn varieties during fluidized bed and vacuum drying is analysed, investigating the relationships between moisture content, drying time and temperature. The results showed that the initial moisture content varied significantly between varieties, with the white variety having the highest moisture content and the red variety the lowest. Therefore, rehydration was performed to ensure the reliability of the results. Analysis of the time required to reach equilibrium moisture content showed that drying at higher temperatures resulted in a faster process, with the shortest drying time measured at 90 °C and the longest at 70 °C. A comparison of the different varieties showed that the hybrid variety reached equilibrium moisture content the fastest, while the white variety took the longest to reach the same moisture content. These results are consistent with both vacuum and fluidized bed drying, suggesting that the morphological characteristics of the kernel significantly influence the rate of water release. Polynomial regression models were used to create 3D surface plots to visualize drying trends and allow better interpretation of the results. The analysis of the exponential equations yielded high coefficients of determination (0.9437–0.9861), confirming the reliability and comparability of the results with similar studies in the literature.

In industrial drying processes, different corn varieties are often dried simultaneously despite their different initial moisture content. This study confirms that differences in the rate of water release between hybrids can lead to uneven drying, where some grains can be dried while others retain excess moisture. The results obtained therefore provide important guidelines for the optimization of industrial drying processes to achieve uniform moisture and avoid quality losses.

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