Differences in water release rate of hulled and hull-less pumpkin seed

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Unterschiede der Wasserfreisetzung von Kürbiskernen mit und ohne Schale

1 Introduction

Curcubita pepo L. is the best-known pumpkin species in Europe. In the immature phase its fruit can be used as vegetable and as ripe fruit it can be used as human food and livestock feed. Young fruits are green, and the mature fruits become ones are yellow-orange. Shape, size and color of the fruits vary. In Croatia, Slovenia, Austria and Hungary, pumpkins are grown primarily for the production of edible pumpkin seeds and for salad oil production (DUBRAVEC, 1996; MURKOVIC and PFANNHAUSER, 2000).

Natural conditions in Croatia allow an extraordinary successful cultivation of pumpkins used for edible oil production. It is possible to achieve a yield of fruit as high as 80 t/ha. The pumpkins contain about 2 % of seed and the 1000-seed weight is about 200 g. Hull seeded pumpkin seeds contain about 31 % of oil whereas the hull-less pumpkin seeds contain 52 % of oil. Pumpkin oil is famous for its specific taste and bouquet and is traditional local specialty. Pumpkin oil is not suitable for cooking and frying because of its dark green color and high content of unsaturated fatty acids (up to 78 %). Heating decreases the content of linoleic (C 18:2) acid while increasing the stearic (C 18:0) acid content. Pumpkin seed oil may contain 40–57 % of linoleic acid. It is an important source of nutritional plant sterols and vitamin E (ŠTRUCELJ, 1984; LAZOS et al., 1995; MURKOVIC and PFANNHAUSER, 2000).

In Central Europe, pumpkin seeds were medically used

Zusammenfassung

Ziel dieser Arbeit war es, den Einfluss der Luftgeschwindigkeit auf den Trockungsprozess für drei verschiedene Kürbissorten (Ölkürbisse bzw. Speisekürbisse) zu untersuchen. Die Trocknung der Kürbiskerne wurde bei vier unterschiedlichen Temperaturen und zwei unterschiedlichen Luftgeschwindigkeiten durchgeführt. Eine Expontentialfunktion für den Trockungsprozess wurde erstellt und die Werte für die Wasseraktivierungsenergie der untersuchten Sorte berechnet. Die Ergebnisse deuten darauf hin, dass die optimale Temperatur für die Trocknung bei 60 °C liegt, dies gilt für alle untersuchten Sorten. Bei einer Trocknungstemperatur von 60 °C war der Ölgehalt am höchsten. Überdies garantierte dies eine gute Qualität des getrockneten Kernes/Samens, wie auch einen optimalen Energieeinsatz während der Trocknung.

Schlagworte: Kürbiskerne, Trocknung, Temperatur, Luftgeschwindigkeit.

Summary

Aim of this paper was to determine the effect of air velocity during the drying process of three of pumpkin varieties used for human nutrition and edible oil. Drying of pumpkin seed was conducted at four different temperatures and two different air velocities. Hence, exponential equations of drying process were calculated together with related determination coefficients and water activation energy values for every variety and every year. Results indicated that the optimum drying process for the seed of each pumpkin variety is to be conducted at temperature of 60 °C. This drying temperature ensures the highest oil content in comparison to other drying temperatures. Furthermore, it ensures high quality of dried seed along with rational energy consumption.

Key words: Pumpkin seed, drying, energy activation, temperature, air velocity.

for centuries in treating problems regarding kidney and urinary tract problems and also against worms (especially tapeworms). For the latter therapeutic doses of about 100 g of pumpkin seeds were prescribed followed by a spoonful of ricinus oil about 2 h later. Moreover, it is reported that dry pumpkin seeds are traditionally eaten on an empty stomach to tart tapeworms, sometimes several doses daily in Africa. Furthermore, because of its high vitamin E content, consumption of pumpkin seed oil showed a beneficial effect in treating benign prostate hyperplasia (BRANDT and WASICKY, 1931; YOUNIS and GHIRMANY, 1998).

Due to their high moisture content, pumpkin seeds have to be dried to 8–10 % moisture latest than 24 hours after harvest to prerent fungi contamination that leads to a loss of chlorophyll seed sheath. Adequate drying facilities are one of the most important prerequisites for an intensive pumpkin seed production (WEIDENBÖRNER, 2001).

Technological drying is the continuation and completion of the natural ripening process of pumpkin seeds, which has not been conducted naturally due to unfavorable climate conditions. In order to ensure long preservation, the drying process is to be aimed towards preserving the quality of the seed. After the drying has been completed, the remaining, quantity of water should be sufficient only for latent life of the seed while decreasing biological activity of the present microorganisms to the very minimum (LAZOS, 1986; KRIČKA et al., 2001).

The drying process type is determined by the duration and quality of the drying process. In the case of natural drying, air temperature is very similar to seed temperature, which prolongs the drying process. If heated air is used, the drying process is subsequently faster. Increasing of the air temperature decreases seeds' relative humidity, which ensures greater difference in air and seed moisture in order to accelerate the drying process. Drying process efficiency depends on the heating intensity, relative humidity and air velocity as well as on the construction of the dryer (PUTIER, 1993).

Varieties of hull-less seeded pumpkins are becoming increasingly interesting for the modern production. They are in great demand in the field of domestic oil, chemical and pharmaceutical industry as well as in export. The hull-less seeds yield with more oil on the same acreage also enables a more efficient organization of the oil production process (PARIS, 2001).

The aim of this paper is to determine the influence of air temperature and air velocity on the drying of the seeds and on the energy of water activation in three pumpkin varieties (Gleißdorf hull-less seeded pumpkin, Maik hull-less seeded pumpkin and Dubrava, a variety with hulled seeds) that are used in Croatia for human nutrition and for production of salad oil.

2 Research methodology

The research materials were pumpkin *Curcubita pepo L.* varieties Gleißdorf hull-less seeded pumpkin, Maik hull-less seeded pumpkin and Dubrava, an indigenous Croatian variety with hulled seeds. The varieties in research were grown during a two-year period (1999 and 2000) in Djakovo area (Eastern Slavonia) on 2 ha experimental fields. Due to the fact that July and August of both research years were distinctly dry, fruit dimensions of each of the three varieties were smaller than in average years. However, number of the fruits per hectare approximately matched each variety's average. It has to be noted that samples were taken randomly for a 3-replication analysis.

After the seeds were machine-picked, their moisture content was determined (standard etalon method) before and after the washing. Namely, the surface of the seeds, both hulled and hull-less, was covered with sticky slime, which had to be removed for the purpose of efficient drying process. Drying was conducted in a laboratory with dryers at air temperatures of 40, 60, 80 and 100 °C and air velocities of 0.8 and 1.2 m/s with the targeted 6 % moisture.

The process of drying began when the targeted input temperature and air velocity through the layer of seeds were achieved. Seed mass was measured in the intervals of 5 minutes from the beginning to the end of the drying process. The dryer consisted of a power-generating part, an operating part and a control part. The power-generating part consisted of an electric motor (it supplied air by means of a ventilator), electric heaters and a copper hull. The operating part comprised a borosilicate cylinder and two separator grids tasked with the optimum division of air for drying through the layer of drying material. The control part facilitated change of electric potential by means of an autotransformer, namely regulation of the number of electric motor rotations. The working area of the regulator ranged from 40 °C to 150 °C. Air temperature was measured by means of a PT100 probe with accuracy ±0.35 °C. Air velocity was measured by a digital anemometer with the working span ranging from 0.3–30 m/s.

After the drying had been finished, i.e. the water had been released from the seed, mathematical modelling of the drying curve was conducted by means of exponential equation, which resulted in determination coefficient. Additionally, by determining the kinetics of water release from the seeds at different air temperatures, the diagrams of activation energy were made in order to determine the values of water activation energy in seeds during the process of drying. The energy of water activation in seeds was calculated by means of the Arrhenius equation $E_a = -2.303\ R\ tg\ \beta\ [Jmol^{-1}]$, with R being the gas constant, and tg β being the slant of the activation energy straight line. The slant was calculated from the value of the algorithm of constant speed of water release from the seeds (k) and temperature (T) (MATTHEWS, 1985; GUPTA et al., 2002).

Oil content in pumpkin seeds was determined by extraction in solvent according to Soxhlet (AOCS, 1990). The amount of raw oil was measured in clean, undamaged and healthy seeds, seeds with mechanical impurities, broken, sick or damaged seeds were sorted out.

3 Results and discussion

Average moisture of the hull-less seeded pumpkin seeds after the harvest was 38 %. After the washing, moisture of the hull-less seeded pumpkin seeds increased to approximately 58 % whereas the moisture of the hull-seeded pumpkin seeds increased from approximately 47 % to 65 % after washing. The drying process was conducted until the level of 6 % of average moisture had been obtained.

The above mentioned, exponential equations of the drying process together with the determination coefficients were calculated for each research year with the specific temperature values and the specific air velocities; all with the purpose of tracking the drying process. Tables 1 and 2 display the resulting equations.

Drying at 40 °C and air velocity of 0.8 and 1.2 m/s of hulled pumpkin seed in both research years lasted considerably longer in comparison to the hull-less seeds. Between hull-less seeds there was practically no difference in the drying process time. Speaking of the organoleptic characteristics, the seeds of all of the three pumpkin varieties were unchanged with their natural color and pleasant smell. The average oil content for the hulled seeded pumpkin was about 32.11 % and for the hull-less seeded pumpkin about 45.60 %.

Drying at 60 °C clearly indicated that the drying rate was considerably faster than at 40 °C with no changes in organoleptic properties of the pumpkin seeds. The oil content in hulled seeded pumpkin increased to about 33.08 % and in the hull-less seeded pumpkin to about 46.18 %.

Table 1: Exponential equations of water release speed from the seeds of pumpkin varieties Gleißdorf, Maik and Dubrava at various temperatures (40, 60, 80 and 100 °C) and air velocities (0.8 and 1.2 m/s) in the first research year

Tabelle 1: Exp. f. d. Wasserfreisetzung aus Kürbiskernen (Vari. Gleißdorf, Maik und Dubrava) bei unteschiedlichen Temperaturen (40, 60, 80 und 100 °C und Luftgeschwindigkeiten (0,8 und 1,2 m/s) im ersten Versuchsjahr

Variety	Drying temperature (° C)	Air velocity (m/s)	Exponential equation for drying	r^2
Gleißdorf	40	0.8	$w = 44.191e^{-0.0132t}$	0.9942
	60		$w = 41.615e^{-0.0269t}$	0.9844
	80		$w = 40.405e^{-0.0421t}$	0.9709
	100		$w = 41.18e^{-0.0647t}$	0.9557
	40	1.2	$w = 37.905e^{-0.0242t}$	0.9704
	60		$w = 47.362e^{-0.0354t}$	0.9962
	80		$w = 39.698e^{-0.0483t}$	0.9604
	100		$w = 43.522e^{-0.0792t}$	0.9564
Maik	40	0.8	$w = 46.686e^{-0.0142t}$	0.9940
	60		$w = 40.617e^{-0.025t}$	0.9717
	80		$w = 44.694e^{-0.0424t}$	0.9857
	100		$w = 45.179e^{-0.0653t}$	0.9721
	40	1.2	$w = 41.093e^{-0.0247t}$	0.9789
	60		$w = 49.314e^{-0.034t}$	0.9904
	80		$w = 43.379e^{-0.0473t}$	0.9761
	100		$w = 47.363e^{-0.0813t}$	0.9668
Dubrava	40	0.8	$w = 52.545e^{-0.0123t}$	0.9924
	60		$w = 54.207e^{-0.0216t}$	0.9886
	80		$w = 48.075e^{-0.0337t}$	0.9616
	100		$w = 51.031e^{-0.0511t}$	0.9754
	40	1.2	$w = 59.335e^{-0.0214t}$	0.9975
	60		$w = 58.348e^{-0.0218t}$	0.9942
	80		$w = 50.813e^{-0.0436t}$	0.9664
	100		$w = 54.292e^{-0.0729t}$	0.9735

Key: w – pumpkin seed moisture (%), t – drying period (min)

Drying process at 80 °C showed further shortening of the drying period. However, part of the dried hull-less seeds clearly displayed traces of burning, cracking, dark brown discoloration and slightly bitter taste. This did not happen with the hulled seeds. Oil content in hull-less seeded pumpkin was about 45.92 %, and in hull-seeded pumpkin about 32.92 %.

The drying period of hull-less seeds at 100 °C (Gleißdorf and Maik) showed an average decrease of a fifths times, while drying of hulled seeds decreased to a forth times in

Table 2: Exponential equations of water release speed from the seeds of pumpkin varieties Gleißdorf, Maik and Dubrava at various temperatures (40, 60, 80 and 100 °C) and air velocities (0.8 and 1.2 m/s) in the second year of the research

Tabelle 2: Exp. d. für die Wasserfreisetzungsrate der Kürbisarten Gleißdorf, Maik und Dubrava bei unterschiedlichen Temperaturen (40, 60, 80 und 100 °C) und unterschiedlichen Lufttemperaturen (0,8 und 1,2 m/s)

Variety	Drying temperature (° C)	Air velocity (m/s)	Exponential equation for drying	r^2
Gleißdorf	40	0.8	$w = 43.607e^{-0.0137t}$	0.9956
	60		$w = 40.583e^{-0.0262t}$	0.9847
	80		$w = 38.985e^{-0.0418t}$	0.9667
	100		$w = 39.851e^{-0.0564t}$	0.9482
	40	1.2	$w = 37.061e^{-0.0239t}$	0.9672
	60		$w = 44.489e^{-0.0346t}$	0.9821
	80		$w = 39.891e^{-0.047t}$	0.9752
	100		$w = 41.821e^{-0.0768t}$	0.9424
Maik	40	0.8	$w = 43.606e^{-0.0137t}$	0.9956
	60		$w = 36.746e^{-0.0255t}$	0.9530
	80		$w = 38.98e^{-0.0418t}$	0.9670
	100		$w = 39.842e^{-0.0564t}$	0.9482
	40	1.2	$w = 37.061e^{-0.0239t}$	0.9672
	60		$w = 46.724e^{-0.0346t}$	0.9970
	80		$w = 39.891e^{-0.047t}$	0.9752
	100		$w = 41.821e^{-0.0768t}$	0.9424
Dubrava	40	0.8	$w = 50.04e^{-0.034t}$	0.9918
	60		$w = 52.815e^{-0.0215t}$	0.9898
	80		$w = 46.07e^{-0.033t}$	0.9596
	100		$w = 52.24e^{-0.0496t}$	0.9823
	40	1.2	$w = 59.148e^{-0.0215t}$	0.9983
	60		$w = 46.282e^{-0.0256t}$	0.9711
	80		$w = 48.707e^{-0.0418t}$	0.9667
	100		$w = 53.385e^{-0.0699t}$	0.9815

im 2. Versuchsjahr, w = Feuchtigkeitsgehalt, +/– Trocknungsdauer des Samens

Table 3: Water release rate in seeds from varieties Gleißdorf, Maik and Dubrava in the first year of the research

Tabelle 3: Wasserfreisetzungsrate für die Sorten Gleißdorf, Maik und Dubrava im ersten Versuchsjahr

Variety	Air temperature (° C)	Air velocity (m/s)	Constant of water release rate (k/min^{-1})	Water activation energy (J/mol)	r^2
Gleißdorf	40	0.8	0.03416	535.73	0.5240
	60		0.03820		
	80		0.04128		
	100		0.04819		
	40	1.2	0.03382	6,210.80	0.9716
	60		0.05343		
	80		0.04275		
	100		0.05536		
Maik	40	0.8	0.03703	5,870.59	0.9180
	60		0.03832		
	80		0.04519		
	100		0.05272		
	40	1.2	0.03572	6,799.54	0.6422
	60		0.05520		
	80		0.04729		
	100		0.05951		
Dubrava	40	0.8	0.02895	5,411.59	0.5964
	60		0.03679		
	80		0.03708		
	100		0.04167		
	40	1.2	0.03901	2,128.71	0.8845
	60		0.04405		
	80		0.04129		
	100		0.04611		

comparison to the drying at 40 °C. The hull-less seeded pumpkin seeds were mostly burned, cracked and almost unsuitable for further processing. However, hulled seeds hardly showed any damage caused by temperature, which could be attributed to the hull's protective role. Furthermore, oil content in hull-less seeds was decreased to 44.26 %, whereas hulled seeds did not display the same feature and the oil content was 32.22 %.

Based on the results of water release from the seed, the constants of water release speed were calculated as well as the values of activation energy for each pumpkin varieties in both research years. Tables 3 and 4 display the constants of water release reaction and the values of activation energy calculated from the straight lines shown in Figure 1, 2 and 3.

Drying kinetics deals with the changes in seed water content in relation to the dry matter depending on the time. It also investigates the speed at which the above-mentioned system components tend to reach a state of equilibrium. The speed of this reaction is often proportional to the concentration of one single component (as in the case of pumpkin seed). This kind of reaction is defined first level reaction. However, based on the correlation coefficient (in the first year r^2 ranged from 0.524 to 0.972; in the second year r^2 ranged from 0.509 to 0.910) it can be concluded that it varies from being significant to being highly significant.

Table 4: Water release rate in seeds in seeds from varieties Gleißdorf, Maik and Dubrava in the second year of the research
Tabelle 4: Wasserfreisetzungsrate in Samen der Variationen Gleißdorf, Maik und Dubrava im zweiten Versuchsjahr

Variety	Air temperature (° C)	Air velocity (m/s)	Constant of water release rate (k/min^{-1})	Water activation energy (J/mol)	r^2
Gleißdorf	40	0.8	0.03416	4,747.53	0.5510
	60		0.03820		
	80		0.04128		
	100		0.04819		
	40	1.2	0.03382	6,470.58	0.8492
	60		0.05343		
	80		0.04275		
	100		0.05536		
Maik	40	0.8	0.03703	4,949.20	0.5090
	60		0.03832		
	80		0.04519		
	100		0.05272		
	40	1.2	0.03572	6,370.56	0.9101
	60		0.05520		
	80		0.04729		
	100		0.05951		
Dubrava	40	0.8	0.02895	7,258.43	0.8004
	60		0.03679		
	80		0.03708		
	100		0.04167		
	40	1.2	0.03901	792.46	0.8561
	60		0.04405		
	80		0.04129		
	100		0.04611		

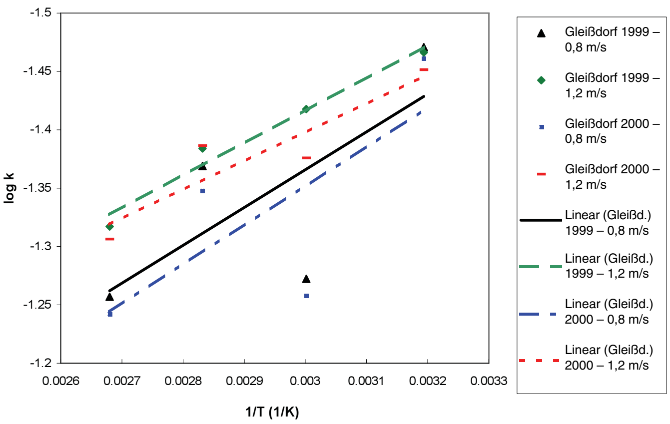

Figure 1: Energy of water activation for variety Gleißdorf
Abbildung 1: Wasseraktivierungsenergie der Variation für die Sorte Gleißdorf

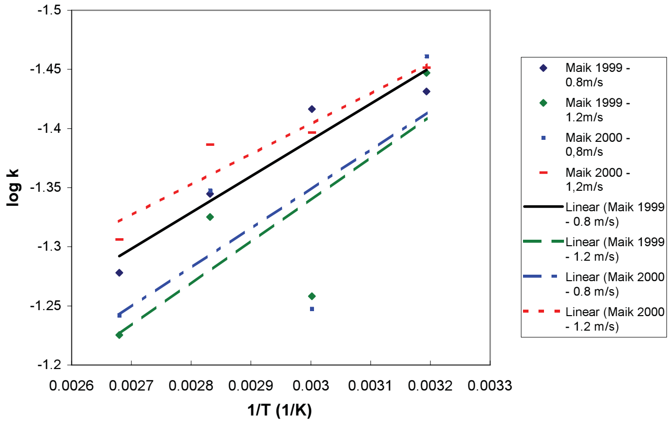

Figure 2: Energy of water activation for variety Maik
Abbildung 2: Wasseraktivierungsenergie der Variation für die Sorte Maik

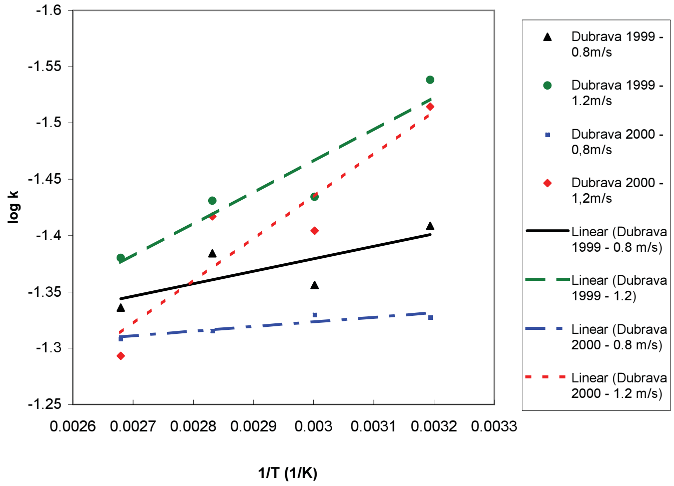

Figure 3: Energy of water activation for variety Dubrava
Abbildung 2: Wasseraktivierungsenergie der Variation für die Sorte Dubrava

The Constant of the chemical reaction speed was (as mentioned before presented) acquired experimentally. It can be stated that the reaction was faster at 60 °C in comparison to 40 °C in both research years whereas the reaction was mostly slower at 80 °C in comparison to 60 °C. Since the constant of the chemical reaction speed was inversely proportional to the reactants' concentration after a certain period of time, it can be concluded that a reaction between oil and water, as the main reactants, occurred due to the decrease of oil content in the seed. Moreover, the constant of the water release rate increased again at the temperature of 100 °C, which the authors attribute to rapid evaporation of water from the seeds. However, another consequence is a severely damaged surface of the seed.

Activation energy was calculated for each variety based on the determined constant of the reaction rate at four different drying temperatures (40, 60, 80 and 100 °C). It can be stated that the activation energy is a feature inherent to each variety, which also depends on the agro technology applied during the production. It can also be stated that the activation energy and the water release rate in the seed were directly related to the drying rate. Namely, straight lines, which resulted from the calculations, indicated a slower reaction energy in hull seeded pumpkin when compared to hull-less seeded pumpkin, not deponding on the applied air velocity.

When speaking of the effects weather conditions have on drying velocity, none of the three researched pumpkin varieties showed any significant difference between years, namely the drying process was affected solely on the species.

4 Conclusion

Based on the research of processing three pumpkin *Cucurbita pepo L.* varieties, hull-less seeded pumpkin Gleißdorf, hull-less seeded pumpkin Maik and Dubrava, a hull seeded variety, it can be concluded that the moisture levels are different due to the differing structure of the hull-less seeded pumpkin seeds compared to the hull seeded pumpkin seeds. Thus, the hull-less seeded pumpkin seed contains about 38 % water after harvest and about 52 % after washing. A hulled seed on average contains 47 % water after harvest and 65 % after washing. Subsequently, these differences, as well as a different seed structure, have different impact on the drying process period and the activation energy. It is notable that the hulled pumpkin seed samples, dried at 40 °C and at air velocities of 0.8 and 1.2 m/s, indicates that the process is considerably longer compared to the hull-less seeded pumpkin seeds, whereas there is practically no difference between the varieties of hull-less seeded pumpkins. If samples are dried at 60 °C under above mentioned air velocities, drying rate is notiably faster than it is at 40 °C. When seeds are dried at 80 °C, drying rate gets even faster. At the air temperature of 100 °C, drying period is averagely shortened to a fifth when speaking of hull-less seeded pumpkin seeds, and to a forth times when speaking of hulled seeds in comparison to the drying at 40 °C.

Furthermore, it was determined that the water activation energy is a feature inherent to each variety. Additionally, when comparing the straight lines of water activation energy with different drying rates in one year, it can be noted that the straight line's angle of ascent is practically the same. It points to the fact that drying should be conducted at lower air velocities because this ensures better air exploitability and lower energy consumption.

Chemical analyses regarding oil content in seeds showed that oil content ranged from 32.11 % to 33.08 % in common hulled seed, and from 44.26 % to 46.18 % in hull-less seed. Consequently, it is better to dry hull-less pumpkin seeds at 60 °C, whereas common hull seeded pumpkin seeds can endure higher temperatures. Drying air velocity did not have a significant influence on drying period, except at 40 °C. Therefore, it is advisable to dry seeds at lower air velocity (0.8 m/s) because this lowers energy consumption in the same drier capacity.

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