Convective Drying of Rapeseed Hybrids' Seeds

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Summary

The aim of this study was to investigate the water release from seeds of three rape hybrids, ('Artus', 'Baldur' and 'Titan'), during the convection drying of the seeds at three different drying temperature (40, 60 and 80 °C). The drying was conducted in laboratory scale drier which can simulate the conditions of large drier. The air velocity in the drier was maintained at 1.0 m/s. Activation energy needed for starting the process of water release during the convective drying of oil seed rape seeds was also studied.

According to the obtained values, the mathematical models (equations and curves) of kinematic drying were determined. By comparing the exponential equations and the constants of water release from seeds it was observed that drying of hybrid Artus was the slowest and the one of hybrid Titan the fastest. Results showed that there was a significant difference between all investigated hybrids in water release rate and that within the same drying conditions, hybrids showed different behaviour. Moreover, air temperature increase caused significant increase in water release from the seeds. The highest activation energy needed for starting the process of water release from the seeds had the hybrid Artus and the lowest one hybrid Titan. Due to this, it can be concluded that the activation energy was reversely proportional to the water release rate from the seeds.

Key words

convective drying, oil seed rape, hybrids, activation energy

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Introduction

The speed and quality of seed drying depend on physical characteristics of the drying environment, physical and chemical characteristics of the material to be dried, and thickness of the layer through which the water is diffused in the drying regime. In natural drying process air temperature is approximately the same as that of the seed and, thus, drying is slower. With increasing the air temperature, the drying process is accelerated (Kričcka et al., 2007).

Relevant for drying rate is the rate of water flow through the seed towards the surface. The performance of the material during the drying process is essentially influenced by its composition, i.e., by characteristics of different parts of the seed. In relation to wheat and corn, rape seed has different structure and shape. The spherical shape of seed reduces the porosity of the pile to minimum which increases air resistance during the drying process.

Exposing wet seeds to higher temperatures for a longer period of time may lead to a too fast drying and thus to cracking, which potentially affects safe storage (Krič-ka et al., 2007).

It is already known that different lots of rape seed, with different initial moisture, perform differently in the drying process. After the drying procedure, the seeds at the dryer 's exit have different moisture content, which may represent a problem during storage. One part of the seed is overdried, which is not rational, either in terms of energy consumption or in terms of preservation of nutritive substances of the seed (excessive drying of grain or seed increases the protein content because of dry matter concentration which reduces digestibility, i.e., it leads to protein denaturation and lower solubility), while the seed's parts with moister higher than needed for safe storage provide the ground for development of microorganisms (Katić, 1997; BIOEN, 2001).

The researchers present the mathematical modeling of the drying process (moisture loss from seeds) with polynomial, exponential and logarithmic equations.

Thus, Page (1949) proposes exponential equation of the thin layer drying model with characteristic seed constants and moisture ratios, while Thompson (1967) proposes exponential equation with variant valued and dry air temperature. Noomhorm and Vermal (1986) also use second order exponential equations in studying the thin layer and shaping its curve. They also compared their own studies with the results of the Thompson model, after which they concluded that the Thompson model gives satisfactory results in thin layer drying. Theory of application of the thin layer drying procedure on thick layer was not acceptable until the mid 1960-ties, when according to Mujumdar (2000), Hukill in 1954 was the first who started to develop the thick layer simulation model on the basis of the results obtained by studying the thin layer drying process. This development resulted in introduction of computer-based models for monitoring and simulation of the process.

However, in order to give full description of the drying kinetics it is necessary to know a large number of parameters (Mujumdar, 2000). Among them are type of dryer, dryer's geometry, heating method, but also the properties of the drying material. It is important to know geometrical particles of the material such as size of particles, distribution of particle size, distribution of capillary size and particle shape (Kričcka et al., 2005). It is particularly important to know transfer capacities of the material. When mass transfer is concerned, these capacities consist of activation energy for water release from seed and drying constant (Voća et al., 2007). It is necessary to know the variations of these capacities during the drying. Since all these capacities vary with changing working environment, it is clear that the modeling of the drying process is a complex task. Especially so, if we keep in mind that during the drying process the parallel processes of mass transfer and heat transfer happen.

Thus, the specific aim of a large number of studies is to find a simple mathematical model that will successfully describe the drying kinetics. These are mainly exponential models with only few parameters.

The main shortcoming of such models is that physical significance of their parameters has not been determined yet. What is known about these parameters at present is the influence of specific conditions and of some properties of the material on their values (Sander and Glasnović, 2004). It was determined that the drying process can be described using mathematical modeling by exponential, logarithmic or polynomial equations, regardless of the variety in question. The comparison of the obtained polynomial equations, or interrelation of incline can be shown by use of derivation dw/dτ (Martins and Stroshine, 1987; Kričcka et al., 1999). The moisture content of drying material can be at any moment anticipated by use of any of these drying equations, especially if the drying constant "k" is calculated.

The drying constant is normally in function of drying air temperature calculation. Henderson and Pabis (1961) proposed the equation for calculating the drying constant following the Arrhenius equation. This equation allows to calculate the energy required for initiating the water release process. The Arrhenius equation puts in relation the drying temperature, water release constant and activation energy for initiating the water release process. The activation energy can be determined by means of drying temperature (T), water release constant (k), or, by using the incline ln k and 1/T. Consequently, the activation energy is calculated by multiplying the incline of the said direction and universal gas constant 8.314 J/mol K.

Bala (1997) defined the activation energy or reaction's activation energy (E_a) of water release from seed, which must be brought to the water molecules to stir their inter-reactions. In order to incite chemical reaction in the water molecules, they must collide, but molecules can interact only if their energy charge is above the required activation energy. In chemical kinetics, activation energy is the level of potential barrier separating the product from reactant. The molecules gain activation energy by transforming their kinetic energy into potential energy. Therefore, if water molecules' kinetic energy in the seeds is not high enough, it can be fully transformed in to potential energy by their collision, but it will not set on the activation complex.

The molecules become distant from each other as soon as potential energy decreases. If energy is brought in the seed's molecule system, e.g., heat energy (by raising temperature), a larger number of molecules per second will cross the potential energy barrier.

In other words, reaction rate in molecule transformation rises with temperature increase. With increasing the potential energy barrier i.e., reaction activation energy, a smaller number of reacting molecules can cross the peak of energy barriers and the reaction becomes slower (Voća et al., 2007).

The aim of this study was to investigate the water release from seeds of three rape hybrids ('Artus', 'Baldur' and 'Titan'), during the convection drying of the seeds at three different drying temperatures (40, 60 and 80 °C). Since it has been assumed that the mentioned hybrids were dried in different ways, the differences in water release rate between the studied rape hybrids were determined, as well as the influence of drying temperature on main parameters of the convection drying.

Materials and methods

The research was carried out in the laboratory of the Department of Agricultural Technology, Storage and Transport of the Faculty of Agriculture of the University of Zagreb on three "00" rape hybrids: 'Artus', 'Baldur' and 'Titan', grown in experimental fields in Bjelovar-Bilogorska County during 2004, with application of efficient plant growing measures. Since the samples of rapeseeds had different initial moisture and these values had to be equalized in order to make the samples comparable for further studies. For this reason, the samples were rehydrated up to about 18% of moisture content. Before drying, the samples were cleared of impurities and foreign matters. The rehydration was carried out by direct action on seed mass with precisely determined quantity of distilled water. The quantity of water needed for desired moisture level (18%) was determined following the expression from the Measurement Instructions of the State Office of Metrology (Pliestić and Varga, 1995).

Then, the samples were stored in glass vessels and put in the cooling chamber at temperatures from 3 to 5 °C, in duration of 72 hours, during which time they were frequently stirred. After conditioning, the moisture content in the samples was determined again, and the rehydrated samples were positioned as the initial ones and were used in further work.

The drying was performed in the laboratory scale dryer of small capacity but with capacity to simulate the conditions present in large dryer. The airflow rate in the dryer was maintained at 1.0 m/s, and the samples were dried at three different temperatures, i.e., 40 °C, 60 °C and 80 °C, that were chosen because of their practical value.

Before drying the water content in the seed sample was determined. After that the seed mass at the end of the drying process was mathematically determined. A digital balance was placed next to the laboratory scale dryer. Before each start of the drying process, temperature and relative humidity were determined by use of a psychrometer placed in the space of the dryer. Also, before starting the drying process in the drying space (vessel with perforated bottom) temperature of the seeds was determined. Every five minutes the vessel was weighted.

The airflow rate, or fan regulation was also controlled manually, by use of regulation transformer. Measurement of the preset air temperature was performed by means of probe PT 100 immediately before the air flowed through the sample. The airflow rate after exiting the sample layer was determined by means of digital anemometer made by "Edra Five" from United Kingdom. The reading area of the digital anemometer was in a range of 0.3 to 30 m/s, with accuracy of ± 0.1 m/s.

The moisture was determined by use of the oven method of drying in a dryer at 105 °C for three hours up to constant mass with assumption that the sample, beside moisture, does not contain any other evaporative ingredients or products that may cause variances in the mass of the studied sample (Šuko and Petek, 1970). The drying of the sample was performed in the laboratory oven dryer (INKO ST-40) with a facility to regulate temperature between 40 and 240 °C. The accuracy of measurement is ±0.1 °C, and working space volume was 20 liters.

On the basis of the mass losses measurements, every five minutes the exponential equations were calculated in required temperature values for each studied hybrid up to moisture equilibrium (6%). Mathematical modeling will give the value of water release rate up to moisture equilibrium, in order to be able to exactly compare the variances in water release rate of specific hybrids. In all obtained exponential equations it was necessary to find the determination coefficient that shows the comparability of the results of water release from the seeds.

The data was analyzed following GLM procedure in the SAS system package in version 8.0 (SAS Institute, 1997). The results were subject to variance analysis, while the variances of mean values were compared by use of LSD test for $p=0.05$.

Results and discussion

The Figures 1, 2 and 3 show the drying curves specifically for all three drying temperatures for the studied hybrids, for the purpose of determining the relations between the hybrids and water release rate.

Kinetics of convection drying was studied for three hybrids at three drying temperature variances. The drying curve within individual hybrids have a normal course. When kinetic drying curves were determined in different drying conditions, geometrically similar curves were obtained that are characteristic for the studied material.

It can be determined that, independently of temperature, hybrid Artus had the longest drying time, and Titan had the shortest one, by 31% in average. At 40 °C this percentage was 28%, at 60 °C 38%, and 25% at 80 °C. At air temperature of 40 °C, it took hybrid Artus 95 minutes to dry, while at the

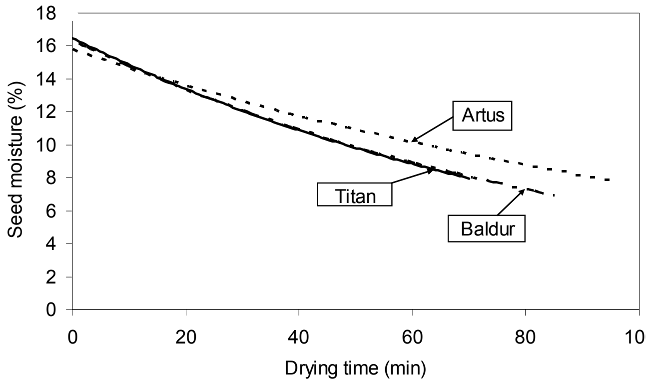

Figure 1. Drying curves for investigated hybrids at air temperature of 40 °C

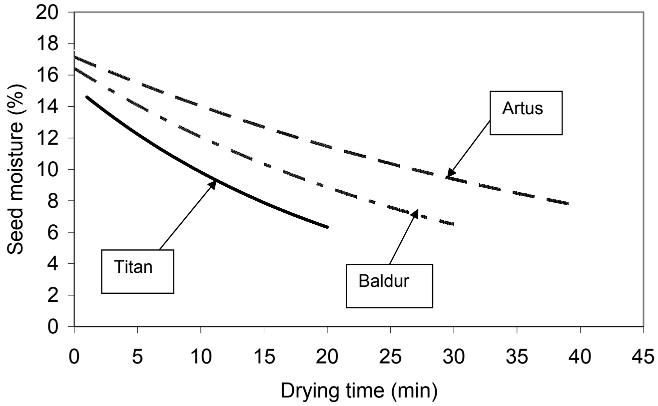

Figure 2. Drying curves for investigated hybrids at air temperature of 60 °C

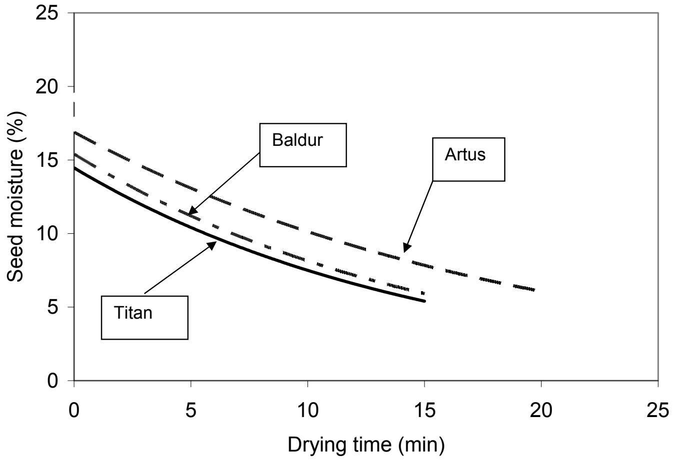

Figure 3. Drying curves for investigated hybrids at air temperature of 80 °C

air temperature of 60 °C the drying time was 56% shorter. With the air temperature in the drying process of 80 °C, the drying time of hybrid Artus was 79% shorter in relation to the first air temperature.

At air temperature of 40 °C, it took hybrid Baldur 85 minutes to dry, while at 60 °C this time was 65% shorter. At drying air temperature of 80 °C, the drying time for hybrid Baldur was 83% shorter than with the first air temperature.

Hybrid Titan, at temperature of 40 °C was dried after 70 minutes, while at 60 °C it took 66% shorter time to dry. The drying time of hybrid Titan at temperature of 80 °C was 79% shorter than at 40 °C.

In order to make the drying curves of the observed hybrids comparable, the mathematical modeling of equation of water release rate was applied. A similar method was also used by Martins and Stroshine (1987), and Krička (1993). Table 1 gives the exponential equations of drying of the observed hybrids up to moisture equilibrium (6%). The analysis of the drying equations makes it evident that the exponential coefficient of variables has a negative sign, which means that the curve falls. Namely, it shows the tendency of the water release rate (Table 1). With higher absolute value of the coefficient, the drying rate was higher.

After formulating the exponential equations the determination coefficient was found in the range between 0.86 and 0.97.

Such high coefficients show that the research of water release from the seeds was carried out with precision and that the obtained results can be compared with each other. The calculation of the water release coefficient allows to precisely determine which hybrid has the shortest and which one has the longest water release time.

Table 2 presents the reaction rate constant values in water release from the seed up to constant moisture for all studied hybrids. The above Table shows that at all temperature levels, hybrid Titan had the fastest drying rate, while hybrid Artus had the slowest one. Therefore, it can be determined that the rapeseed hybrids perform differently in the drying process, pending on drying temperature. Similar conclusions were reached by Krička et al. (1999). Their researches also showed the variations between the cultivars but also the variations between the years of cultivation. Moreover, in this research one of the hybrids ('Titan') had a higher drying rate than others, regardless of temperature level, which is very valuable for drawing conclusions. Given the fact that convection drying of the observed hybrids was carried out in one year only, it is not possible to claim with a great accuracy that the 'Titan' seeds would always have the highest draying rate among this group of hybrids, should the research be carried out over a several year period. The seed drying coefficients showed that the highest value was observed in hybrid Titan, with 0.236 s^{-1}, and the lowest one in hybrid Artus, where the coefficient was 0.101 s^{-1}. In accordance with the Table above it can be concluded that the seed drying constant (k) significantly grows with increasing air temperature, and it varies with each studied hybrid.

Using the Arrhenius equation the curves were defined for interdependence between seed drying rate constant and drying temperatures (Henderson and Pabis, 1961; Bala 1997). The incline of the direction was the basis for determining the activation energy of the rapeseed hybrids. By calculating the value of activation energy, it is possible to determine

Table 1. Exponential equations of seed drying up to constant moisture (6%) for the studied hybrids at three different drying temperature

Hybrid	Drying temperature (°C)	Exponential equation	R^2
Artus	40	$y = 18.972e^{-0.0097x}$	0.97
	60	$y = 19.564e^{-0.0246x}$	0.95
	80	$y = 16.89e^{-0.0512x}$	0.96
Baldur	40	$y = 16.49e^{-0.0104x}$	0.95
	60	$y = 16.465e^{-0.0313x}$	0.93
	80	$y = 15.397e^{-0.0637x}$	0.96
Titan	40	$y = 16.344e^{-0.0101x}$	0.97
	60	$y = 16.045e^{-0.0323x}$	0.91
	80	$y = 14.461e^{-0.0657x}$	0.86

y – seed moisture (%), x – drying period (min)

Table 2. Values of reaction rate constant in drying (k) of seeds up to constant moisture (6%) of studied hybrids at three drying temperature levels

	Coefficient of seed drying, k (s^{-1})		
Drying temperature (°C)	Artus	Baldur	Titan
40	0.082a	0.097b	0.171b
60	0.090a	0.100ab	0.239ab
80	0.128a	0.169a	0.299a
Mean value	0.100	0.122	0.235
LSD	NS	**	***
Hybrid (H)		**	
Artus		0.101b	
Baldur		0.122b	
Titan		0.236a	
Drying temperature (T)		***	
40°C		0.116c	
60°C		0.143b	
80°C		0.199a	
H x T		NS	

, * - significance at the 0.01 and 0.001 probability level, NS – not significant The differences between the values with the same letters are statistically insignificant at P=0.05

Table 3. Mean values of activation energy of the studied hybrids

Hybrid	Artus	Baldur	Titan
Activation energy (kJ/kg)	27.13a	12.93c	8.01b

the energy that must be introduced in the seed by thermal procedure of convection drying in order to stir molecules to interact and to start the drying process.

As activation energy value is higher, the reaction slows down, i.e., the drying process is slower. The Table 3 presents the activation energy values for all studied hybrids, obtained from the analysis of water release rates at three drying temperatures.

The largest amount of energy required to start the drying process was observed in the hybrid Artus, 27.13 kJ/mol. It is significantly above the values observed in other hybrids. The lowest activation energy value was observed in hybrid Titan, 8.01 kJ/mol, while in hybrid Baldur it was 12.93 kJ/mol. It can be determined that the variations in activation energy values among the studied hybrids exist. Since the drying times also showed the same tendency it can be determined that the activation energy directly depends on water release rate. The same conclusion was also drawn by Bala (1997).

Conclusions

On the basis of this research, the results of drying of the seed of rape hybrids 'Artus', 'Baldur' and 'Titan' the following conclusions can be drawn:

1. Exponential equations of drying are comparable for specific drying temperatures and showed the variations in water release rates in seed of all studied hybrids.
2. In all exponential equations high determination coefficients were found showing that the selected model was appropriate and the results were comparable. By comparing the exponential equations and seed drying constants it was observed that hybrid Artus had the slowest drying, and 'Titan' performed the fastest drying.
3. The study showed statistically significant (P = 0.01) difference between water release rates in the studied hybrids in convection drying of seeds. The hybrids show different performance under the same drying conditions. By increasing the air temperature, the seed water release rate increase becomes statistically significant (P = 0.001).
4. The highest activation energy required for starting the water release from seed was found in hybrid Artus, and the lowest one in 'Titan'. Accordingly, it can be concluded that activation energy is in inverse proportion to seed water release rate.

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