MATHEMATICAL DESCRIPTION OF NORMAL CONVECTIVE AND VACUUM DRYING PROCESS OF RAPESEEDS

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ABSTRACT
Normal convective drying and vacuum drying of rapeseeds were carried out to conduct the comparison between two different drying process at five different drying temperatures and vacuum pressure of 20 kPa. Mathematical model for description of dependency between weight of rapeseeds and drying time for normal convective and vacuum drying process was determined and statistically verified. From the gained drying characteristics imply that vacuum drying has higher efficiency than convective drying.

Key words: *drying; agricultural; normal drying; vacuum drying*

INTRODUCTION
Rapeseed (*Brassica napus* L), which also known as oilseed rape, is a bright-yellow flowering member of the family Brassicaceae. Like any other seeds, rapeseed are easily affected by the moisture content, temperature and the access to oxygen *(Gawrysiak-Witulska et al., 2012)*. Hence, drying process is one of the methods to produce good quality seed.
The drying process is considered as heat transfer into the product and the moisture of the product evaporated out researched by *Akpinar, Midilli & Bicer (2002)*. Drying process has been enhanced from the past to create an effective and efficient way to produce the products. Study *(Akpinar & Bicer, 2005),* the need of a drying process is to meet the quality specifications and conserving energy.
Compared to forced convection, natural convection is a slower heat transfer process as forced convection is help with external force (*Hrabě & Herák, 2015*). Moreover, temperature, moisture content and time are some of the factors that might affect the chemical and physical changes that will happen during the process. Therefore, finding the perfect temperature and moisture distribution of the products with a good estimation of the time for the process can improve the quality of the products (*Mizera, Herák & Hrabě, 2017*).
Moreover, *Orikasa et al. (2014)* mentioned that vacuum drying products will have distinctive characteristics compared to convective drying. When using vacuum drying, it tends to retain the integrity of the original product without damaging it with the usage of the heat *(Parikh, 2015)*. Due to that, researchers had found that vacuum drying is generally used for drying products that are heat sensitive. Meanwhile, convection drying focus on high temperatures to properly accelerate the dehydration and absorption process (*Mizera et al., 2018*).
Drying agricultural products has been and still an ongoing research for a lot of researchers out there for examples with kiwi *(Orikasa et al., 2014),* eggplants *(Akpinar & Bicer, 2005),* pistachio *(Midilli et al., 2002),* tomato *(Sacilik et al., 2005),* apple pomace *(Wang et al., 2006),* and sultana grapes *(Yaldiz et al., 2000).*
Thus the aim of this research is to mathematically describe normal convective and vacuum drying process of rapeseeds and to their mutual comparison.

MATERIALS AND METHODS
Rapeseeds used for the experiments were from Czech Republic. The experiments were carried out in Czech University of Life Sciences Prague (CULS).
For each experiment, the seeds were measure to be 100g initially with precision balance shown in Figure 1 (Kern KB 2000-2N, KERN & Sohn GmbH, Balingen, Germany) and the three samples were run together to get the mean results. The weight of the seeds is recorded with the interval of an hour. The oven used for convective drying is from Memmert UF110, Memmert GmbH + Co.KG, Schwabach, Germany shown in Figure 2 whereas the oven used for vacuum drying is from Goldbrunn l450, Expondo GmbH, Berlin, Germany shown in Figure 3. The settings for the convective drying was set to no fan and no flap for the oven. On the other hand, the setting for the vacuum oven, the vacuum pressure was

set to 20kPa throughout the experiment. The data were not collected at night but the drying process was still carried out overnight and the results is taken on the next day. For both convective drying and vacuum drying, the experiments were run under five different temperatures which are 110˚C, 90 ˚C, 70 ˚C, 50 ˚C, and 30 ˚C. The experiment was terminated once the mean of the weight of the seeds had stabilized.

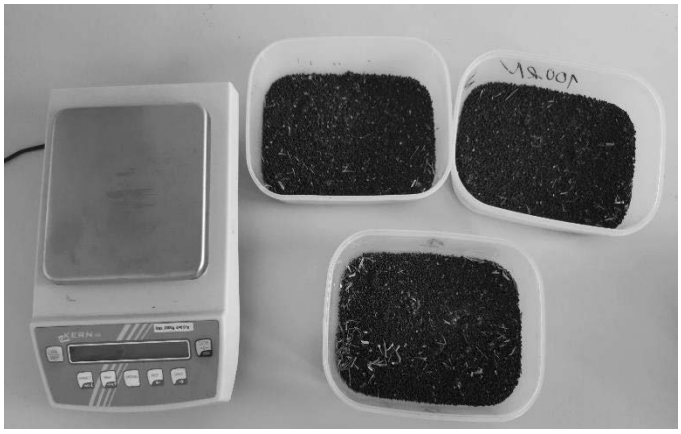


Fig 1: Seeds and precision balance

Fig 2: Memmert UF110 convective dryer for normal drying.

Fig 3: Goldbrunn l450 vacuum dryer for vacuum drying.

RESULTS AND DISCUSSION

In this experiment, rapeseeds were dried under the temperature of 30˚C, 50˚C, 70˚C, 90˚C and 110˚C for both convective drying and vacuum drying. The graphs (Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13) shown is mean weight of the seeds against the heating time. The initial weight of the seeds was measured to be 100g and the data were not collected at night.

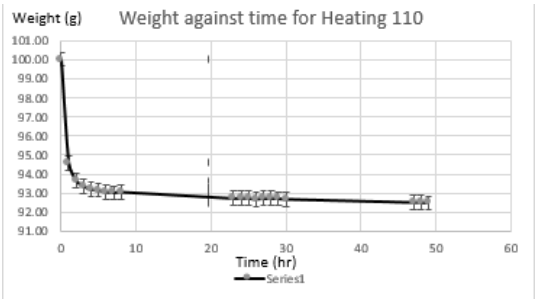


Fig 4: Normal drying 110 ˚C.

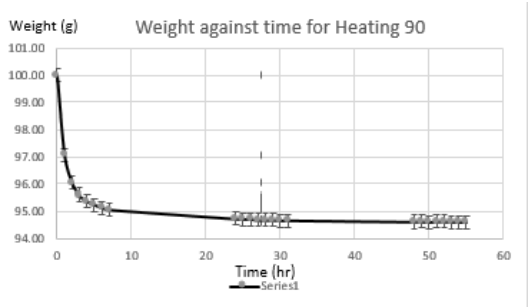


Fig 5: Normal drying 90 ˚C.

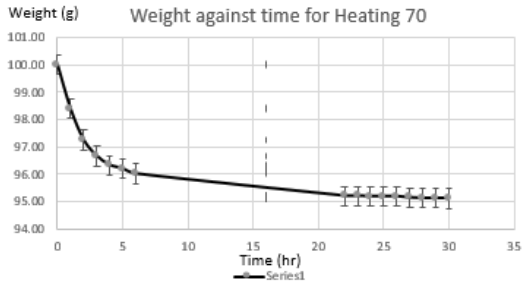


Fig 6: Normal drying 70 ˚C.

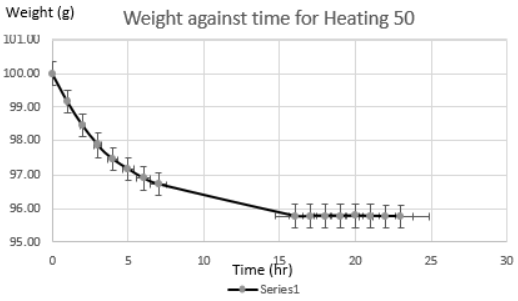


Fig 7: Normal drying 50 ˚C.

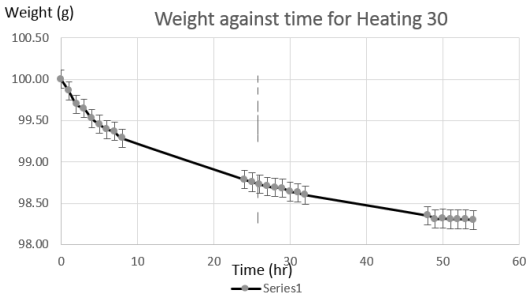


Fig 8: Normal drying 30 ˚C.

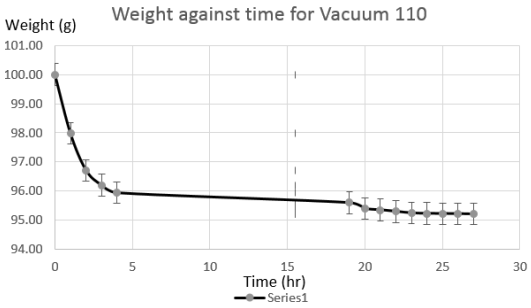


Fig 9: Vacuum drying 110 ˚C.

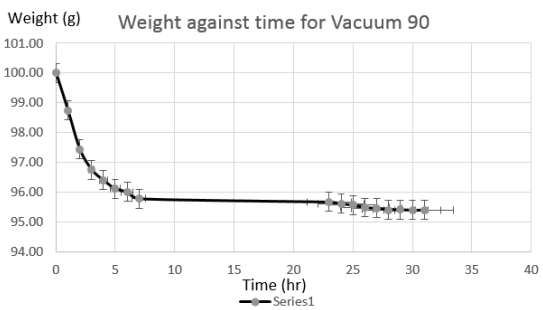


Fig 10: Vacuum drying 90 ˚C.

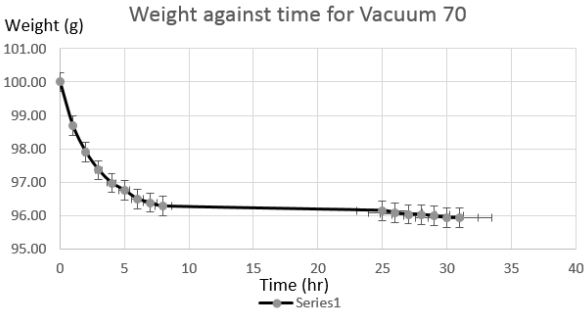
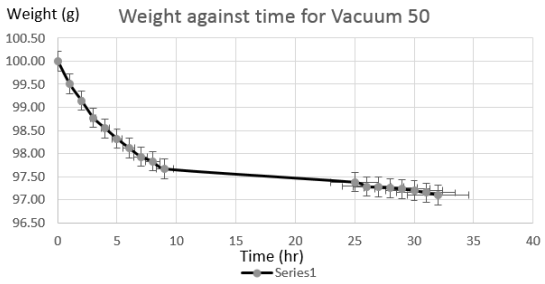


Fig 11: Vacuum drying 70 ˚C.



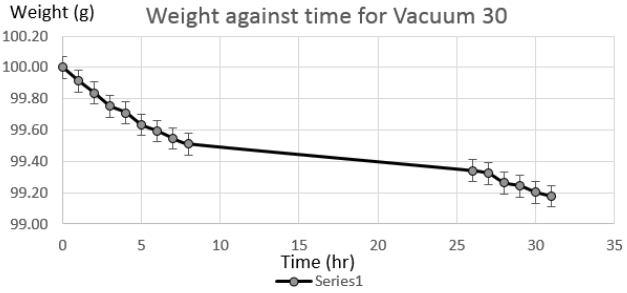


Fig 12: Vacuum drying 50 ˚C.

Fig 13: Vacuum drying 30 ˚C.

The mathematical model to describe this heating process is shown in equation 1.

$$\xi(d,t) := d_0 + d_1 \cdot e^{d2 \cdot t} + d_3 \cdot e^{d4 \cdot t} \qquad (1)$$

Where d_0 – first coefficient of normalized weight
d_1 – second coefficient of normalized weight
d_2 – third coefficient of normalized weight
d_3 – fourth coefficient of normalized weight
d_4 – fifth coefficient of normalized weight
t – Time

Table 1 lists the coefficient values and statistical values for the model obtained with the data for five different temperatures experiment. An ANOVA (Analysis of variance) statistical analysis of the measured and fitted data shows that the measured data could be mathematically described by Eq. 1. The significance of the ANOVA analysis results was based on the values of F_{crit} being higher than Frat values as well as P_{value} greater than 0.05 with high coefficients of determination R^2 (Table 1).

Tab. 1: Coefficient values and statistical values

	d0	d1	d2	d3	d4	F	Fc	Pv	R^2
H 110	92.419	0.934	-0.046	6.671	-1.607	4.173*10^-11	4.098	1	0.999
H 90	94.62	0.995	-0.097	4.378	-1.024	4.173*10^-11	4.052	1	0.999
H 70	94.923	1.469	-0.072	3.634	-0.597	2.894*10^-11	4.171	1	0.999
H 50	95.688	4.017	-0.202	0.306	-0.694	3.045*10^-11	4.171	1	0.999
H 30	97.89	0.392	-0.335	1.722	-0.027	4.625*10^-11	4.043	1	0.999
V 110	95.311	0.171	-1390	4.518	-0.544	1.524*10^-11	4.225	1	0.994
V 90	95.489	0	0	4.573	-0.401	3.381*10^-11	4.149	1	0.994
V 70	96.018	0.261	-1000	3.722	-0.336	3.126*10^-11	4.171	1	0.998
V 50	97.218	0	0	2.785	-0.191	7.367*10^-11	4.131	1	0.996
V30	99.234	8.012 *10^-4	-1000	0.766	-0.125	1.608*10^-9	4.196	1	0.982

Where F - value of the F test
F_c - critical value that compares a pair of models
P_v - hypothesis of the study outcomes significant level
R^2 – coefficient of determination

As expected, the time taken for the drying process of the seeds is longer for normal drying compared to vacuum drying (*Orikasa et al., 2014; Chua et al., 2019; Yaldiz et al., 2001; Akpinar et al., 2003; Wang et al., 2007; Sacilik et al., 2006; Midilli et al., 2003; Akpinar & Bicer, 2005).* From comparison conducted in this study (Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13) of normal drying and vacuum drying,

generally shorter time is required for vacuum drying until the weight of the seeds is stable compared to normal drying. There are some errors during the experiment which caused the time for the vacuum drying at 50 ˚C is longer than the normal drying. Besides, no constant drying rate period is observed in any of the experiments but the drying process happened in decreasing rate based on the observation of the weight of the seeds. This is due to the diffusion of moisture from the centre area of the seeds to the surface is slow and rate limiting mentioned by *Chua et al. (2019).* In already published studies *(Hrabě & Herák, 2015; Mizera et al., 2017; Mizera et al., 2018)* were found that moisture diffusion represents the dominant physical mechanism affecting drying rate decrease during the drying which is a very energy-intensive process and has a significant effect on the quality of the final product.

CONCLUSIONS

- Drying characteristics of rapeseeds under temperature of 30˚C, 50˚C, 70˚C, 90˚C and 110˚C for both convective drying and vacuum drying were determined and described.
- Mathematical model for description of dependency between weight of rapeseeds and drying time for normal convective and vacuum drying process was determined and statistically verified.
- From the determined drying characteristics, it is evident that the time taken for the drying process of the seeds was longer for normal drying compared to vacuum drying
- Vacuum drying has higher efficiency than convective drying.

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