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Drying characteristics of grain corn subjected to different drying techniques

*Md Saleh, R., Ahmad Hasan Salahuddin, M., Abd Rahman, F.S., Othman Ghani, M.N.,
Jalani, S.I. and Othman, Z.

Industrial Crop Research Centre, Malaysian Agriculture Research and Development Institute (MARDI), Persiaran MARDI-UPM, 43400 Serdang, Selangor, Malaysia

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Abstract

Grain corn is one of the most important crops for feed production in Malaysia. Freshly harvested grain corn contains a significant amount of moisture content ranging from 25% to 30% (wet basis), which must be reduced to a safe level through the drying process for storage stability. In view of this, whole grain corn was subjected to various drying techniques to evaluate the drying performance and its quality retention. Grain corn was harvested at an optimum maturity of 110 days after planting and dried in ambient, sun and oven at 40°C. Ambient drying of whole grain corn showed the longest drying time, followed by sun drying and oven drying at 40°C. The time taken to reduce moisture content to less than 12% (wet basis) was observed to be 359 hrs for air-dried samples, 292 hrs for sun-dried samples and 55.5 hrs for oven-dried samples. Mathematical modelling for each drying technique demonstrated that Midili's equation displayed the best fitting to describe the drying characteristics of air-dried samples of grain corn, while the diffusion approach's equation was the best mathematical model for sun and oven-dried samples. The concentrations of total carotenoids in the final products for all drying treatments were in the range between 0.290 mg/g to 0.346 mg/g for all drying techniques indicating better stability with low deterioration rates when subjected to low temperature drying.

1. Introduction

Grain corn or maize (*Zea mays* L.*)* is an important cereal crop which is commercially cultivated all over the world. It is one of the most prominent cereal crops providing nutrients to humans as well as a key component in animal feed. The crop can be used as a raw material for fuel production and processed into a variety of industrial products (Anjum *et al*., 2016). Grain corn can be well grown in Malaysia and other Asian countries with tropical climates. In Malaysia, the livestock and the food industry are inevitably linked and play an important role in ensuring the sustainability, security, availability, and sovereignty of the nation's food supply. It was reported that the world production of grain corn was over 1.03 billion metric tonnes in 2017/2018, followed by rice and wheat (Anon, 2018). Malaysia is a net importer of grain corn, with Argentina and Brazil accounting for 93% of total imports, with the remaining 7% coming from the United States, Thailand, Myanmar and Indonesia (United State Department of Agriculture (USDA), 2017). The country's grain maize import trend notably increased from 1.0 million tonnes in 1987 to 2.0 million tonnes in 1996, and then to 4 million tonnes in 2018 (Index Mundi, 2019). In 2018, the trade balance value for feed imports was RM7,309 million, while the value of feed exports was RM2,192 million (Jabatan Perkhidmatan Veterinar, 2019). In view of this, the Malaysian government took the initiative to develop a long-term plan for the grain corn industry by involving all the industry players throughout the entire supply chain, after considering the domestic needs and the country's reliance on grain maize imports. The cross-functional collaboration from government agencies, industrial players and related stakeholders is required to ensure the model development is durable and comprehensive. The primary goal of this current agenda is for the country to be able to produce at least 30% of its grain corn requirements for domestic consumption. According to current projections, the country will need to produce 1.4 million tonnes of grain corn to meet the industry demand until 2032 (Nor Amna A'liah *et al*., 2019). The demand and interest in grain maize continue to rise in tandem with the progressive growth of Malaysia's livestock and food industries. For this reason, the Malaysian Agricultural Research and Development Institute (MARDI) under the Ministry of Agriculture and

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*Corresponding author.
Email: *eizan@mardi.gov.my*

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Food Security has taken the initiative to develop a cost-effective production technology through extensive research activities by evaluating the growth performance of grain corn at multi-locations trials in order to address the current issue of insufficient supply of local production due to low productivity and higher production cost (Mohd Hifzan *et al*., 2019). Adding to that, the current study was undertaken to investigate the drying characteristics of grain corn when subjected to different drying techniques given that most of the animal feeds are sold and marketed in dried form.

Post-harvest operations of grain corn such as drying, and storage are among the critical activities along the production chain for Malaysian small-holder farmers and traders. Drying grain corn prior to seed and feed production is necessary for food preservation, especially in warm and humid countries like Malaysia. Freshly harvested grain corn, with an initial moisture content of 20% to 25%, is highly perishable (Nor Amna A'liah *et al*., 2020), and drying is required to reduce the moisture content to a safe level for safety and storage stability since this commodity is susceptible to fungal infection and contamination (Appell *et al*., 2009). Furthermore, the moisture content of grain corn must be reduced to less than 14% for quality assurance, particularly to prevent aflatoxin production. Many studies have been conducted on the drying of grain corn's kernel, but limited information was documented on the drying of whole grain corn or cobs. Drying of whole grain corn is necessary for seed production due to less injury to the kernels because the dried kernels will be manually separated from the cobs after drying. It is also a common practice for small-holder farmers in Malaysia to dry the grain corn in such a way prior to seed production due to the unavailability of mechanical separators in rural areas. Grain corn was traditionally dried in the field or in the open sun near farmers' homes or farms in most Asian countries, either by hanging it or by placing the crops on cement floors or shelves. This is considered unsanitary and can have a negative impact on the quality of the dried grain corn. In light of this, the current study was initiated to evaluate the drying performance of grain corn when subjected to different drying techniques and its effect on total carotenoid retention will be quantified.

2. Materials and methods

2.1 Harvesting of grain corn

Grain corn at an optimum maturity was harvested 110 days after planting at MARDI's farm in Kluang, Johor. Harvesting was done manually and transported to the Postharvest laboratory on the same day of harvest. The husks were then manually separated from the cobs prior to the drying experiment. Only free-of-defect, healthy-looking cobs with no disease development were chosen for this experiment in order to produce high-quality dried kernels prior to seed production and product development.

2.2 Drying of grain corn

The whole grain corn was dried by various techniques, including hot air oven drying, ambient drying and sun drying. The temperature inside the oven was kept constant at 40°C with an airflow of 2.5 m/s. Drying of grain corn under sun drying was conducted on an open field with an average daily temperature of 21°C to 38°C by placing the crops on a perforated stainless-steel trolley. Air drying of grain corn was carried out in an ambient condition with an average room temperature of 25°C. Moisture content determination for both sun and air drying was performed at 4 hrs intervals. The quality of dried kernels was analysed immediately for all drying techniques.

2.3 Determination of moisture content

The moisture content of grain corn was determined according to AOAC method (Association Official Analytical Chemists, 2019) by drying the sample in an oven at 105°C for 24 hrs (ULM 400, Mermert GmbH, Germany). The initial moisture content of grain corn was estimated to be between 25% and 30% on a wet basis.

2.4 Determination of total carotenoids

The total carotenoid content was determined by extracting 100 mg of dried kernels in 10 mL of a solvent mixture of hexane, acetone, and ethanol, which was a minor modification of the method described by Moscetti *et al*. (2017). To ensure that all of the total carotenoids were fully extracted, the solution mixture was homogenized for 2 mins at 8000 rpm in a laboratory homogenizer (Model T25, IKA, Staufen, Germany) and incubated for 1 h at 4°C in a refrigerator until the sample turned completely white. The extracted sample was then mixed with 5 ml of distilled water to allow for phase separation. The upper layer was separated from the aqueous phase and subsequently assessed for total carotenoids by measuring absorbance at 450 nm with a UV/Vis spectrophotometer (model GenesysTM 10 series, Thermo Electron Co. USA). The total carotenoid content was calculated using an equation (1).

$$\text{Total carotenoids m/L} = \frac{A \times V_1}{A_{1\%}} \times C^{1\%} \qquad (1)$$

Where A is the sample's absorbance reading, V_1 is the dilution factor, $A_{1\%}$ is the extinction coefficient of the 1% solution (i.e. 2500 AU), and $C^{1\%}$ is the concentration of the 1% solution (10 mg/mL). In this study, the total carotenoid content was converted to mg/g_{dm} based on dry matter content, and the concentration was expressed as a retention percentage.

2.5 Calculation of moisture ratio and mathematical modelling

The moisture ratio of the grain corn during drying was determined using the following equation (2) (Botelho *et al*., 2011).

$$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} \quad (2)$$

$$\mathrm{MR} = \frac{M_t}{M_0} \quad (3)$$

Where M (g_w/g_{dm}) represents the moisture content at any given time t, M_o represents the initial moisture content, and M_e represents the equilibrium moisture content. Since M_e values are relatively small when compared to M_t or M_0 for long drying times, the moisture ratio (MR) was simplified to M_t / M_0 as shown in Equation (3) (de Jesus Junqueira, 2017; Doymaz, 2017). The moisture ratio (MR) calculated from equation (3) was fitted to 4 common thin-layer drying models described by previous authors as in Table 1.

2.6 Statistical analysis

A one-way analysis of variance (ANOVA) was performed by Minitab software (Minitab-Release 11.21, Minitab Inc., State College, PA, U.S.A.) in order to determine significant differences in total carotenoid content of grain corn under different drying techniques. Tukey's multiple comparisons test was used to determine whether there were significant differences ($P \leq 0.05$) between average response values.

3. Results and discussion

3.1 Drying characteristics of grain corn

The results from Figure 1 (a-c) showed that the drying time required to achieve the desired level of moisture content, as shown in Table 2, is highly dependent on the drying technique. The time taken to reduce the moisture content to a safe level between 10% - 12% (wet basis) was observed to be 359 h for ambient dried samples, 292 h for sun-dried samples and 55.5 hrs for oven-dried samples. Air drying of whole grain corn showed the longest drying time, followed by sun drying and oven drying at 40°C. These are well-known facts reported by other researchers for agricultural crops which the results vary depending on shape, dimension, drying methods and parameter settings (Koca *et al*., 2007; Zielinska and Markowski, 2012; Eim *et al*., 2013). Both cobs and kernels have different drying performances due to differences in their physical properties, which have a significant impact on the drying kinetics. Corn cob drying characteristics differed from kernel because the large moisture content difference between kernels and cobs causes the time to reach a balance between the two parts (kernel and cob) to be longer due to continuous migration of moisture content from the inside (cellular structure) to the surface of the kernel, resulting in a prolonged total drying time for all treatments particularly drying under ambient conditions (air drying). When compared to ambient drying, open sun drying required less drying time to reduce the moisture content to a safe level for both cobs and kernels

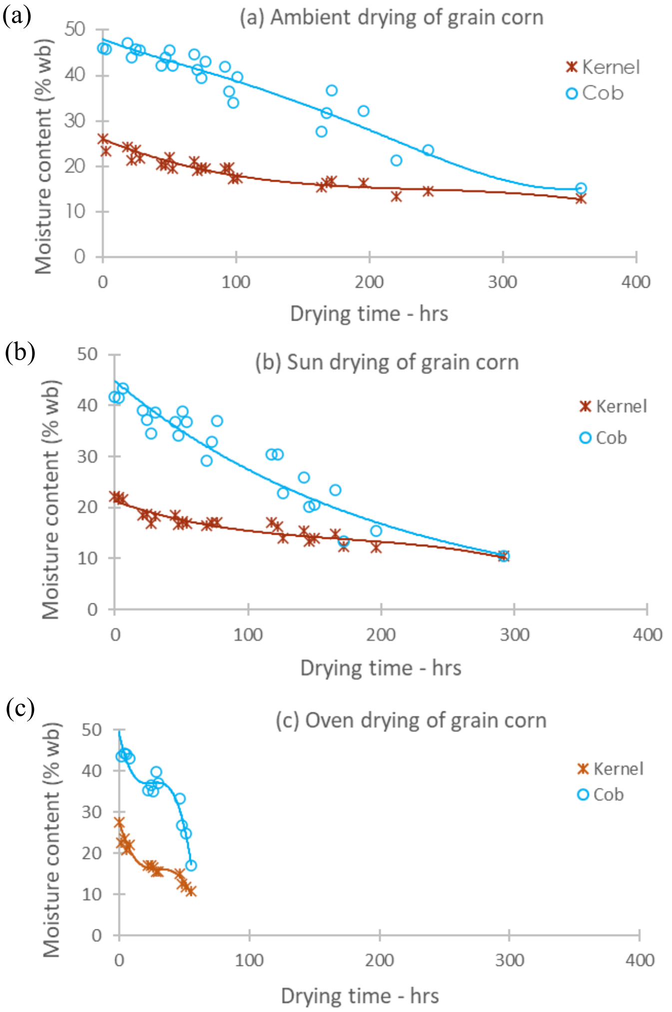

Figure 1. Drying characteristics of grain corn subjected to (a) ambient drying, (b) sun drying and (c) oven drying.

Table 1. Thin layer mathematical modelling of grain corn

Model	Equation	Reference
Exponential decay	$MR = a + \exp(-c)\ (t-b)$	Cuervo and Hensel (2008)
Diffusion approach	$MR = a \times \exp(-k_1 t) + b \times \exp(-k_2 t)$	Kassem (1996)
Page	$MR = a \times \exp(-kt) + (1-a)\ \exp(-kbt)$	Akowuah *et al*. (2021)
Midilli	$MR = a \times \exp(-ktn) + bt$	Akowuah *et al*. (2021)

MR: moisture ratio; k, k_1, k_2: drying constants; a, b, n: model parameters

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due to higher drying temperatures and adequate air movement from the environment causing a shorter effective drying time of 292 hrs.

3.2 Mathematical modelling of drying kinetics of grain corn

Table 2 displays selected mathematical models that have been tested for different drying techniques. The best model was selected based on the statistical parameter of the highest R^2 and the lowest RMSE. The results obtained in Table 2 demonstrated that the Diffusion approach model is suitable for sun drying and oven drying, while the Midili equation is suitable for solar drying of grain corn. The results prove that different drying techniques necessitate different mathematical equations to describe the drying behaviour of grain corn when subjected to various drying modes. This is due to the fact that water vapour migration from the cell to the environment via the diffusion process is influenced by ambient temperature, relative humidity, wind speed and direction, type of crop, and microstructure (Md Saleh *et al*., 2020). Furthermore, different drying techniques influenced the constant values for each model due to varying drying characteristics. The results demonstrated that different drying temperatures for each drying treatment significantly influenced the model's constant values. The same trend was reported by Rafiei *et al*. (2009) when drying soybeans at various temperatures. The authors observed different values of coefficients for the same model when subjected to different drying temperatures.

3.3 Stability of total carotenoids subjected to different drying techniques

Figures 2–4 show the retention of total carotenoids along the drying period when different drying techniques were used. When compared to fresh samples (at 0 hrs), oven and ambient dried grain corn demonstrated high stability with no significant changes in total carotenoid content. At 55 hrs of drying time, the concentration of total carotenoids in oven-dried samples was 0.309 mg/g_{dw}, while it was 0.399 mg/g_{dw} in fresh samples (at 0 hrs). The same trend was observed for ambient drying with the concentration of total carotenoids in fresh and dried grain corn to be observed at 0.303 mg/g_{dw} and 0.296 mg/g_{dw} respectively. Better retention of total carotenoids in ambient dried samples might be due to low temperature and slow drying with less or no

Table 2. Selected mathematical models for different drying techniques of grain corn.

Model	Mathematical formula	Constants	Air-dried	Sun-dried	Oven-dried
Exponential decay	$MR = a+\exp(-c)\ (t-b)$	a	-0.10004316	0.41462938	0.321766949
		b	0.101055361	-106.30074	-17.46866787
		c	0.001874619	0.00609091	0.029837345
		R^2	0.935341355	0.9285317	0.970189729
		λ^2	0.002114294	0.00239487	0.00171398
		RMSE	0.001057147	0.00119744	0.00085699
Page	$MR = e^{-at^b}$	a	0.02276301	0.02508105	0.084390886
		b	0.591767612	0.58076554	0.563591607
		R^2	0.958241134	0.9453204	0.978970883
		λ^2	0.001382412	0.00184904	0.00122506
		RMSE	0.000691206	0.00092452	0.00061253
Diffusion approach	$MR = a \times \exp(-kt) + (1-a)\exp(-kbt)$	a	0.102252063	0.13945812	0.144387295
		b	0.001763649	0.02236192	0.000618107
		k	1.256871463	0.08936999	20.9448512
		R^2	0.953100772	0.95630786	0.984869929
		λ^2	0.001313489	0.00149831	0.000511278
		RMSE	0.000656745	0.00074916	0.000438239
Midili	$MR = a \times \exp(-kt\text{n}) + bt$	a	0.937140336	0.93052719	0.911170244
		b	0.000785093	0.00059673	0.002672327
		k	0.075576696	-0.0606856	0.144818836
		n	0.052996325	-0.0606856	0.144818827
		R^2	0.956241621	0.92703658	0.969460241
		λ^2	0.001439249	0.00244312	0.001755302
		RMSE	0.000504691	0.00122156	0.000877651

exposure to natural sunlight, but the extension of the drying periods may trigger unwanted disease development or infections that could affect the overall quality of the grain corn. Longer drying times, on the other hand, had a negative impact on total carotenoid content in sun-dried samples. The combination of a longer drying period and a higher drying temperature during sun drying significantly reduced total carotenoid concentration from 0.505 mg/g_{dw} to 0.259 mg/g_{dw}, revealing that total carotenoid retention is temperature and exposure time-dependent. A substantial reduction of total carotenoids in sun-dried samples indicated moderate stability of total carotenoids when subjected to open sun drying. This might be due to long exposure time to direct sunlight initiating the degradation of total carotenoids. Ortiz *et al*. (2016) reported a similar trend of total carotenoid degradation on maize drying in an oven at 60°C with an extended drying period of 66 hrs. The results also showed that each piece of grain corn was unique, with high variation in total carotenoids among samples for each drying technique, resulting in inconsistent amounts of total carotenoids throughout the drying periods. The same observation was confirmed by Md Saleh *et al*. (2022) on carrots drying. The authors reported the diversity of total carotenoid concentration for each carrot leading to different levels of quality degradation throughout the drying periods causing inconsistent quality retention of the final product.

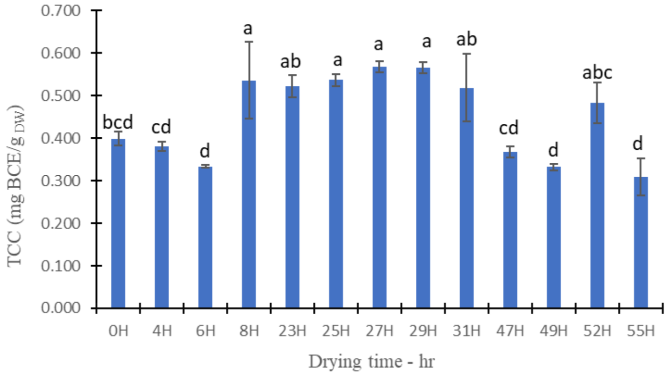

Figure 2. Stability of total carotenoids subjected to oven drying at 40°C. Error lines represent standard deviation of the mean. Bars with different notations are statistically significantly different by Tukey test (p<0.05).

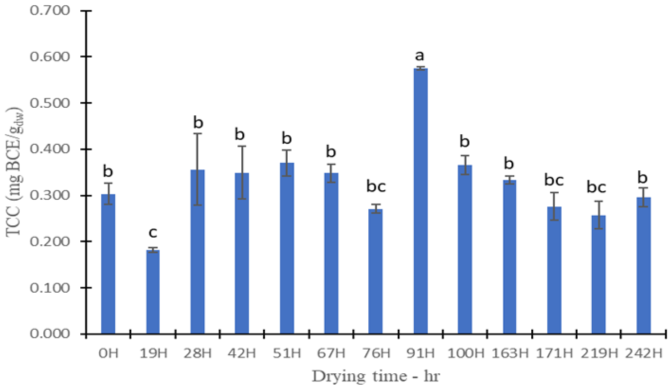

Figure 3. Stability of total carotenoids subjected to ambient drying at 25°C. Error lines represent standard deviation of the mean. Bars with different notations are statistically significantly different by Tukey test (p<0.05).

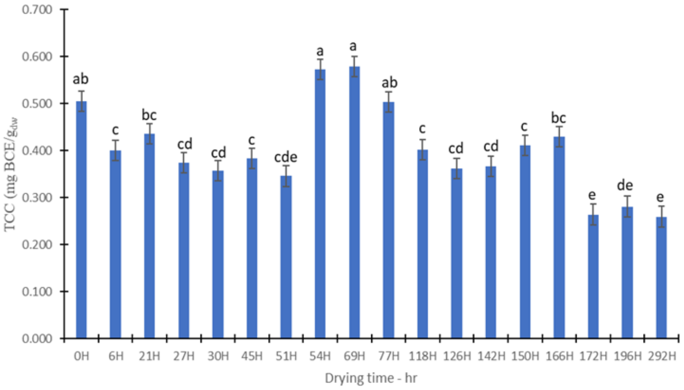

Figure 4. Stability of total carotenoids subjected to sun drying. Error lines represent standard deviation of the mean. Bars with different notations are statistically significantly different by Tukey test (p<0.05).

4. Conclusion

Different drying techniques exhibit different drying characteristics, which have a significant impact on the quality retention of grain corn. Describing and predicting the drying characteristics of grain corn through a mathematical modelling approach is advantageous for process improvement and continuous monitoring for effective control of the drying process. High stability of total carotenoids in grain corn was observed when drying under ambient conditions as well as drying using a mechanical oven due to low temperature with controlled environment drying conditions. The interaction of experimental factors such as (temperature) x (light) x (time) influenced the drying behaviour and retention of total carotenoids in grain corn, which could have a significant impact on the end product's quality. Therefore, both ambient and oven drying with moderate drying periods and low temperatures between 25°C to 40°C is recommended for drying grain corn due to better retention of total carotenoids. Additionally, the current study suggested that an appropriate selection of process parameters is critical during grain corn drying because the quality of the dried product is highly dependent on the process conditions.

Conflict of interest

The authors declare no conflict of interest.

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