ASM Sc. J., 13, Special Issue 4, 2020 for NCAFM2018, 27-35

Backscattering Imaging as a Monitoring System for Moisture Content and Colour Changes in Pumpkin during Drying Process

D.I. Onwude[1, 3], N. Hashim[1,2*] and A.A. Dana[1]

[1]*Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra, Malaysia, 43400 UPM Serdang, Selangor, Malaysia.*

[2]*SMART Farming Technology Research Center (SFTRC), Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[3]*Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, 52021 Uyo, Nigeria*

In this study, the potential of backscattering imaging system for monitoring moisture content (MC) and colour changes in pumpkins during drying was investigated. Peeled pumpkin slices with 0.4cm thickness were oven dried at temperatures 60°C, 70°C and 80°C. The MC and colour changes were monitored using backscattering imaging at different time interval. ANOVA results revealed that all backscattering imaging parameters were significantly affected by both drying temperature and time at $p<0.05$. The prediction model based on backscattering imaging parameters resulted in high R^2 and low RMSEP values for moisture content, lightness (L*), redness (a*) and yellowness (b*) predictions at 60 ˚C, with $R^2 > 0.7$ and RMSEP < 1.8. The backscattering imaging parameters also resulted in good prediction of MC, L* and b* for pumpkin during drying with $R^2 > 0.8$ and RMSEP < 2.2 at 70 ˚C, and $R^2 > 0.6$ and RMSEP < 3.1 at 80 ˚C, respectively. The findings of this study show that backscattering imaging system has a great potential for monitoring quality changes of pumpkin during drying.

Keywords: Drying; backscattering imaging system; PLS; pumpkin; quality assessment

I. INTRODUCTION

Pumpkins are fruits from genus *Cucurbita* of the *Cucurbitaceae* family, which also includes squash, cucumber, watermelon and gourds. Pumpkin can be found in many shapes, sizes and colours. The colour property of pumpkin pulp is due to the presence of carotenoid which gives the pumpkin flesh a yellow-orange characteristic colour. Carotenoids are natural occurring pigments found in natural food sources and are responsible for the yellow, orange and red colour of such foods. Carotenoids can be supplied through food and human skin, and may drastically reduce the risk of cancer and cardiovascular diseases (Henriques *et al.*, 2012; Onwude *et al.*, 2017). However, due to its high moisture content, pumpkins are highly degradable and must be preserved in order to increase shelf life (Onwude *et al.*, 2017).

Drying is a commonly used method used for the preservation of agricultural crops. The process of drying involves the removal of moisture from a material and it is often used as a unit operation in the production of pharmaceutical, health and premium food products. In the case of carotenoid extraction, drying has also shown to improve the amount of final carotenoid extraction yield (Durante *et al.*, 2014; Onwude *et al.*, 2017). However, during the process of drying physicochemical and structural changes occur which affect the quality of the final dried products (Krokida and Maroulis, 2001). According to Onwude *et al.* (2017), moisture content and colour are two important quality parameters often used for the selection of adequate drying parameters and method, as it affects the appearance, processing, and acceptability of food products.

*Corresponding author's e-mail: norhashila@upm.edu.my

Thus, it is pertinent to monitor the changes of these two quality parameters during drying.

Over the years, destructive methods have often been applied in inspecting the changes in the quality of agricultural crops during drying. These methods (e.g. direct manual measurement and displacement measurement) have been reported to be inadequate in monitoring the quality of agricultural crops during drying (Onwude *et al*., 2017; Romano *et al*., 2008; Udomkun *et al*., 2014). In recent times, backscattering imaging technology has been revealed as a non-destructive machine vision method for inspecting the quality of agricultural crops during post-harvest processes. This technique involves the interaction of light with the product tissue due to photon projection (Romano *et al.* 2012). A backscattering imaging system consist of a charge-coupled device (CCD) camera, laser diodes as a light source and computer to operate the camera, capture images, and store the data. The camera records a fraction of the back scattered light after light has penetrated the object and transfers the data to the computer.

Several researchers have made use of backscattering imaging technique in inspecting the quality of several agricultural crops during postharvest processing. These include the light propagation in kiwifruit (Baranyai and Zude, 2009), estimation of moisture content changes in banana (Romano *et al*., 2008), evaluating the quality attributes of watermelon during storage (Mohd Ali, *et al*., 2017), detection of maturity level and the level of chilling injury in banana (Hashim *et al*., 2018; Adebayo *et al*., 2016; Hashim *et al*., 2013), early decay detection in citrus (Lorente *et al*., 2015), monitoring the shrinkage of sweet potato during drying (Onwude *et al*., 2017) and inspection of quality parameters of apples during drying (Romano *et al*., 2011). In addition, Mollazade *et al*. (2013) also developed a prediction model to evaluate the mechanical properties (fruit flesh or elastic modulus) of apple, plum, tomato and mushroom by using backscattering imaging at 660 nm wavelength. Romano *et al.* (2008) also utilized backscattering images produced with 670 nm laser diode to correlate backscattering image area with changes in moisture content during the drying of banana. In all cases, backscattering imaging technology have been shown to provide a rapid, accurate and reliable evaluation of different quality parameters of agricultural crops during drying. Although there are a few researches on the use of laser light backscattering imaging for monitoring the drying process of food, there is no known study on the application of laser light diode emitting at 658 nm for monitoring and predicting the quality attributes of pumpkin during drying. Besides, for this technology to be widely accepted and commercialise, more experiments on different agricultural crops must be carried out. Hence, the objective of this study is to investigate the potential of backscattering imaging system for use in monitoring the moisture content and colour changes of pumpkin during drying.

II. MATERIALS AND METHODS

A. *Sample Preparation*

Fresh pumpkins were purchased from *Pasar Borong,* Selangor, Malaysia and stored in a refrigerated room at 12°C temperature prior to subsequent drying experiments. A total number of 90 pumpkin samples were used for the drying experiments which was carried out at three different temperatures (60°C, 70°C and 80°C). For each drying temperature, 30 pumpkin samples were used. Before the experiments, pumpkin samples were cut, and the seeds were removed. The samples were then cleaned, peeled and sliced into 2 cm x 2 cm size with the thickness of 0.4 cm. For each of the pumpkin samples, 36 replications were used, 1 slice was taken out from each sample at every one-hour interval for further analysis. The initial moisture content of pumpkin samples was determined using oven moisture content determination standard of ASABE (ASAE, 2005). Five slices of pumpkin samples (2 cm x 2 cm with thickness 0.4cm) were initially weighed using an electronic balance (AND GF-30K, USA) having a sensitivity of 0.001 g and placed in a laboratory oven for 24 hr at 103°C ± 2°C. After 24 hours, the samples were taken out of the oven and re-weighed to determine the final individual weight. The initial moisture content was determined by taking the average values of the initial mass and final mass. The average initial moisture content was found to be 85.4% (wet basis).

B. Drying Experiments

The drying experiments were carried out using WS 30 hot-air Box Dryer in Biomaterial Processing Laboratory, Faculty of Engineering, Universiti Putra Malaysia. Data collection took a total of 3 days by setting the experimental temperature at 60°C, 70°C and 80°C. Before inserting the sliced pumpkin samples, the oven was kept on for 45 minutes to attain constant temperature. After 45 minutes, a steel tray consists of cleaned, peeled and sliced samples (2cm x 2cm with 0.4cm thickness) were placed inside the box dryer to initiate the drying process of the sliced samples. The air velocity (1.2 m/s) was measured using a vane anemometer (Testo 417, Lenzkirch, Germany) with an accuracy of ± 0.03 m/s. The relative humidity during the entire drying experiments ranged from 50 to 60 %.

C. Colour Measurements

Konica Minolta CR-10 colour reader was used to conduct the colour assessment for the pumpkin samples during drying. The CIELAB colour measurement system was used in the determination of the lightness (L*), redness (a*) and yellowness (b*) values of pumpkin slices during drying. Before colour measurements, the colorimeter was calibrated against a standard black and white plate. Replicates readings were taken at three different points on each sample before drying, and samples taken out for every 1hour during drying until no change in the weight of two consecutive measurement.

D. Image Acquisition

An image acquisition system set-up which consists of a charge-coupled device (CCD) camera (QICAM Colour Fast 1394, QImaging, Surrey, BC, Canada), with a zoom lens (F5.6 and focal length of 18 mm), two halogen lamps, computer system and a software (Image-Pro Insight 9 software, Media Cybernetics, Inc., USA) for acquiring RGB images was assembled in the Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia as shown in Figure 1.

The backscattered images were acquired at a distance of 24 cm between the CCD camera and the sample, and at an incident angle of 22° between the laser light beam and the sample. This incidence angle resulted in the best backscattered imaged free from noises. To further reduce the noises due to external light, the image acquisition was done inside a metal frame covered with a black piece of cloth. A total of 5 samples each was used for the image acquisition at different time intervals. Four images (two from each side) were captured per sample.

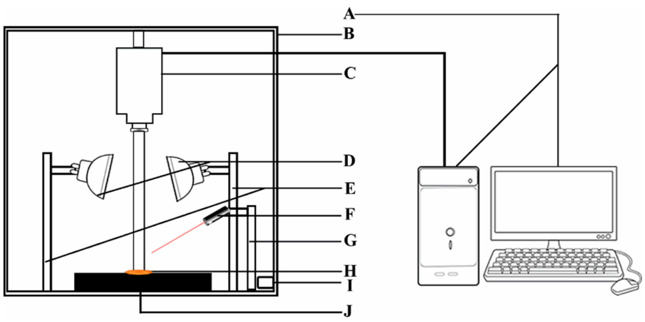

Figure 1. Schematics of backscattering imaging system (A = computer system; B = supporting frame; C = CCD camera; D = halogen lamps; E = Lamp holders; F = laser light emitter; G = laser light emitter's holder; H = pumpkin sample; I = laser diode control box; J= sample capturing platform)

E. Backscattering Optica Analysis

The acquired Backscattering images were analysed using image processing code developed using Matlab programming software (Version R2016a, Mathworks Inc., Natick, MA, USA) based on the required extraction feature. The image processing stages included Image segmentation and image thresholding which are done to divide the acquired images into multiple parts, removing unwanted elements and to correct the non-uniform illumination of the images (Figure 2). Details of the image processing steps used in this study can be found in the literature (Mollazade *et al.*, 2013b). The selected features from backscattering images extraction are Major Axis (MAA), Minor Axis (MIA), Perimeter (P), Area (A) and the Ratio (RA) of Major axis and Minor Axis. The minor axis length represents the length of the minor axis within the scattered light geometry. The major axis length signifies the length of the major axis within the scattered light geometry.

The perimeter calculates the distance between each adjoining pair of pixels around the boundary of the region of interest. Area is the estimated total area of reflected light in pixels. Prior to statistical analysis, all backscattering parameters were normalised (log-scaling) due to the different range of each parameter, and to improve the accuracy of the statistical results.

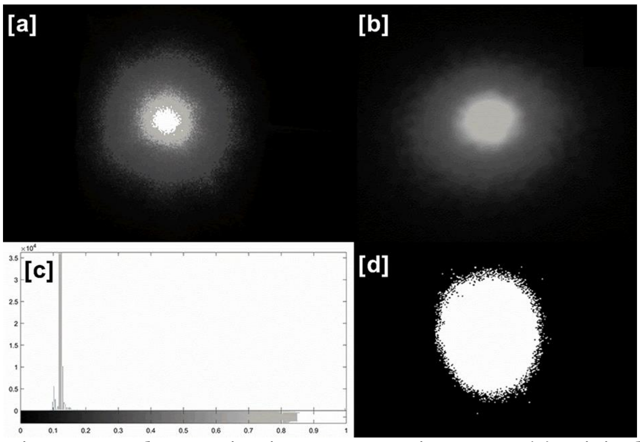

Figure 2. Backscattering image processing steps: (a) original captured backscattered image; (b)image smoothing using Gaussian filter; (c) Histogram showing image pixel distribution; (d) Region of interest for the segmented image

F. Statistical Analysis

Two-way analysis of variance (ANOVA) was applied to determine the statistical differences between pumpkin slices dried at different times and temperature levels. The mean significant difference between quality attributes (moisture content, lightness, redness and yellowness) at different drying time intervals and drying temperature levels were compared using Tukey test at $p \leq 0.05$ significant level, and 95% confidence interval. Triplicate measurements were conducted and mean ± standard error values were reported. This statistical test was carried out using SIGMAPLOT software (Version 12.0, Systat Software Inc. California, USA). Partial least square (PLS) models was developed using Unscrambler software (version 10.3, CAMO AS, Oslo, Norway). The performance evaluation of the PLS models was based latent variables (LV), the coefficient of determination (R^2), root mean square error of calibration (RMSEC), and root mean square error of validation (RMSEV).

III. RESULTS AND DISCUSSION

A. Drying Kinetics

Pumpkin slices were dried under hot-air conditions at 60˚C, 70˚C, and 80˚C respectively. The change in moisture ratio (MR) versus time for the different drying conditions is shown in Figure 3. From the plot, it can be observed that MR decreased rapidly with time. Increase in drying air temperature also resulted in a significant decrease in moisture ratio. Similar findings had been reported for jujube (Chen *et al.*, 2015), sweet potato (Onwude *et al.*, 2018), and pumpkin (Onwude *et al.*, 2016). It took 360min to reach a MR of 0.2 at 60˚C, 300min at 70˚C and 240 minutes at 80˚C. Generally, increased drying temperature resulted in increased moisture transfer rate from the inner layers of the product to its surface (Onwude *et al.*, 2016).

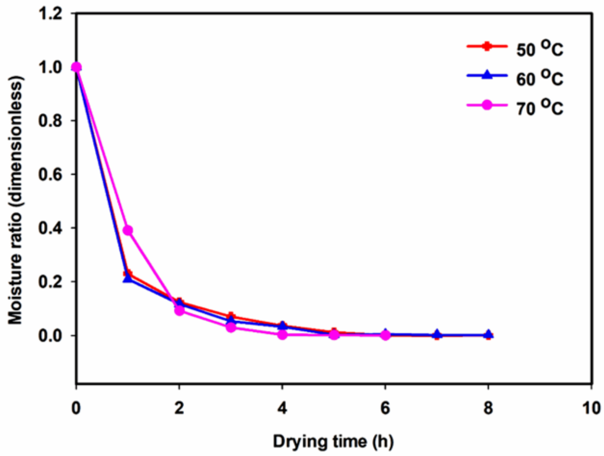

Figure 3. Drying kinetics of pumpkin during hot-air drying

B. Effect of Drying on Colour Parameters

Table 1 illustrates the ANOVA analysis of the colour changes of pumpkin slices during drying at different time intervals and temperature levels. The L* values of pumpkin slices at 60˚C ranges from 77.09 – 59.71, 77.16 – 63.26 at 70˚C and 79.07 – 61.62 at 80˚C, after 8 hours of drying. The a* colour values of pumpkin slices dried at 60, 70 and 80°C ranges from 19.27 – 16.95, 17.15 - 13.90, and 15.52 – 12.05, respectively.

Table 1. Colour changes of pumpkin during drying at different time and temperatures

Drying Hour	L*			a*			b*		
	60 ° C	70 ° C	80 ° C	60 ° C	70 ° C	80 ° C	60 ° C	70 ° C	80 ° C
0	77.09 ± 0.20^{aA}	77.16±0.14^{aB}	79.07±0.23^{aAB}	19.27±0.15^{abA}	17.15±0.15^{aA}	15.52±0.26^{aB}	57.41±0.59^{aA}	59.32±0.41^{aB}	59.06±0.52^{aB}
1	74.70 ± 0.63^{bA}	72.57±0.94^{bB}	70.47±1.25^{bAB}	18.26 ± 0.82^{abcA}	17.49±0.68^{aA}	15.90±0.51^{aB}	58.44 ±0.72^{aA}	63.32±0.80^{aB}	59.92±1.41^{aC}
2	66.70 ± 0.70^{cA}	67.29±0.85^{cA}	68.44±1.17^{cbA}	20.48 ± 0.82^{bA}	15.79±0.50^{abB}	15.00±0.61^{aB}	54.96 ±1.02^{abA}	55.93± 0.79^{bA}	55.74±1.40^{aA}
3	64.10 ±0.94^{dcA}	65.29±0.90^{cA}	65.13±0.91^{cdA}	19.02± 0.74^{abA}	15.58±0.46^{abB}	12.59±0.50^{abC}	51.47 ±1.00^{bcA}	52.61±0.87^{bdA}	49.80±1.38^{bA}
4	61.18 ±0.89^{efA}	65.42±0.89^{cB}	64.89±1.04^{cdB}	17.73 ±0.67^{acA}	13.53±0.43^{bB}	11.77±0.51^{bB}	47.73 ±0.78^{cdA}	48.31±0.91^{cdA}	49.28±1.15^{bA}
5	59.44 ±0.64^{fA}	65.61±0.89^{cB}	62.82±1.29^{dB}	17.20 ±0.69^{acA}	13.36±0.49^{bB}	12.24±0.55^{bB}	46.30 ±0.75^{dA}	47.70±1.14^{cA}	47.80±1.61^{bcA}
6	60.22 ±0.82^{efA}	63.99±1.13^{cB}	61.45±1.32^{dAB}	17.04 ±0.73^{acA}	13.42±0.33^{bB}	12.36±0.53^{bB}	45.42 ±0.93^{dA}	46.04±0.74^{cA}	46.05±1.41^{bcA}
7	60.35 ±0.98^{efA}	64.86±1.05^{cB}	61.32±1.16^{dA}	16.46 ±0.70^{cA}	14.37±0.43^{bB}	12.68±0.47^{abB}	44.50 ±0.80^{dA}	47.10±1.16^{cA}	45.03±1.57 ^{bcA}
8	59.71 ±0.98^{fA}	63.26 ±1.07^{cB}	61.62±0.97^{dAB}	16.95 ±0.58^{acA}	13.90±0.34^{bB}	12.05±0.41^{bB}	43.78 ±0.73^{dA}	44.21±0.94^{cA}	44.05±1.38^{cA}

Data represents the mean and three replicates (±standard error). Different lower letters within the same column indicate statistical difference by the Tukey test, P ≤0.05 for drying time 0 to 8hour, while different upper case across the same row represent statistical difference by the Tukey test, P ≤ 0.05 for each colour parameter based on drying temperatures 60 – 80 °C

These results demonstrated that the lightness (L*) and redness (a*) of pumpkin reduces with increased in drying time. In the same vein, the b* colour values (57.41 – 43.78 for 60°C, 59.32 – 44.21 for 70°C, and 59.06 – 44.05 for 80°C) also demonstrated that the yellowness of pumpkin is affected by drying time.

The ANOVA results at p≤0.05 show significant different between the colour attributes of the fresh sample and those dried at varies times. The ANOVA results also showed that the effect of drying time on the colour properties of pumpkin diminished with a rise in the drying temperature. An increase in the drying temperature from 60 to 70˚C caused a significant change in the L* and a* values of pumpkin. The decrease in the L* value is in line with the decrease in the moisture content at higher temperatures (Dadali *et al.*, 2007; Demirhan & Özbek, 2009, 2010). However, this increase in the drying temperature only affected the b* value at the initial drying stage (after 1hour), the effect becomes less significant as drying continues. A further increase in the drying temperature to 80˚C did not significantly affect the colour properties of pumpkin for most part of the drying period at p≤0.05. As such, there was no significant difference between the effect of drying at 70˚C and drying at 80˚C.

Generally, an increase in drying time and temperature resulted in a decrease in a* values of pumpkin slices during drying. Vega-Gálvez *et al.* (2008) have reported similar changes in a* values during the convective dehydration of red bell pepper and Koca *et al.* (2007) on the dehydrated carrots. The combined effect of drying time and temperature on b* values of agricultural crops has been reported in the literature. (Onwude *et al.*, 2017) observed that the changes in moisture, colour and carotenoid content of pumpkin largely depend on the drying time and temperature. An increase in drying time and temperature resulted in a corresponding decrease in moisture and colour values of pumpkin.

C. Laser Light Backscattering Imaging

The backscattering images of pumpkin slices at different time interval during drying at 70˚C are shown in Figure 4. From the figure, an increase in drying time and a corresponding decrease in the moisture content of pumpkin slices resulted in a reduction in the backscattered image size and an increase in the illuminated portion. On the other hand, a decrease in the diffuse reflectance and backscattered area was observed as a result of a reduction in the moisture content with increased drying time. This behaviour could be explained by the transparent nature of water in-between solids, which causes a reduction in the distance between solids as the water reduces. Romano *et al.* (2011) demonstrated similar result during the drying of apple. Onwude *et al.* (2017) also observed similar trend during the drying of sweet potato.

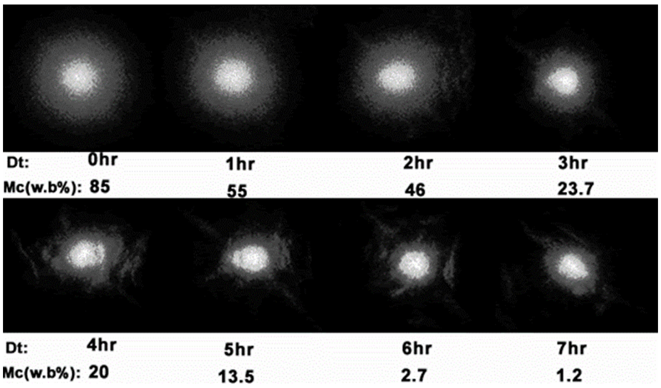

Figure 4. Laser light backscattering imaging of pumpkin slices at different drying time (Dt) and moisture content (Mc) during drying at 70˚C

Figure 5 shows the relationship between normalised laser light backscattering imaging parameters and the physical properties of pumpkin during drying at 70˚C. From the figure, it can be seen that the changes in moisture and colour (L*, a*, b*) properties of pumpkin during drying responded to the different backscattering imaging parameters of major axis, minor axis, perimeter, area and ratio. A decrease in the moisture content of pumpkin during drying resulted to a decrease in the backscattering imaging parameters of area, perimeter, and minor and major axis (Figure 5a). Similar trend was observed with the changes in the lightness index (L*) (Figure 5b) and yellowness index (b*) (Figure 5d) of pumpkin during drying. A reduction in the L* and b* values of pumpkin led to a reduction in the backscattering imaging parameters of area, perimeter, major axis and minor axis. However, the changes in the redness of pumpkin during drying did not result in a corresponding trend for the backscattering imaging parameters (Figure 5c). The backscattering imaging parameters first decreased with decrease in the a* value and then suddenly increase with further decrease in the a* value. This could be as a result of the behaviour of pumpkin colours during drying. Pumpkin contains less red colour as compared with its yellowness.

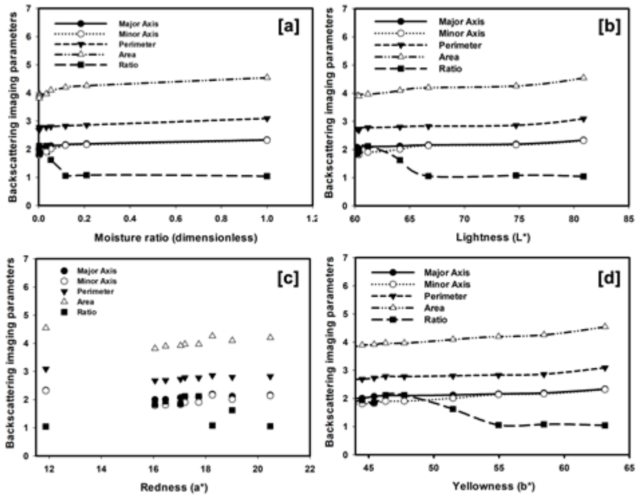

Figure 5. Laser light backscattering imaging parameters vs different physical properties of pumpkin during drying at 60 ˚C: [a] moisture ratio; [b] lightness (L*); [c] redness (a*); [d] yellowness (b*)

To further investigate the potential of applying backscattering imaging parameters in monitoring the drying process of pumpkin at different drying time and temperature conditions, analysis of variance (ANOVA) on the backscattering imaging parameters was conducted.

Table 2 presents the F-values and *p* values (ANOVA) (p<0.05) of backscattering during the drying of pumpkin slices. The effects of drying time, drying temperature and their interactions on the backscattering parameters of major axis length, minor axis length, area, perimeter, and axis ratio were demonstrated. The ANOVA result showed that all the backscattering imaging parameters were significant affected by drying temperature, and drying time at $P < 0.05$. However, the effect of the interaction between drying temperature and time on the backscattering imaging parameters were not statistically different ($P > 0.05$). All the backscattering imaging parameters were significantly affected by drying temperature irrespective of the drying time, and vice versa.

Regarding drying temperature, the major axis length (F-value = 6.188), and axis ratio (F-value = 6.893), were the most significantly affected backscattering imaging parameters. The minor axis length (F-value = 3.812) and perimeter (F-value = 3.949) were the least affected backscattering imaging parameters. On the other hand, the drying time had most effect on area (F-value = 16.126), minor axis (F-value = 10.319), and axis ratio (F-value =

9.501). Major axis length (F-value = 3.376) and perimeter (F-value = 3.941) were found to be the least parameters affected by drying time.

Table 2. Analysis of variance (ANOVA) of backscattering parameters during drying of pumpkin

Factor	Parameter	F-value	P < 0.05
Drying temperature	Major axis length	6.188	0.002^a
	Minor axis length	3.812	0.023^a
	Area	4.192	0.015^a
	perimeter	3.949	0.020^a
	Ratio	6.893	0.001^a
Drying time	Major axis length	3.376	<0.001^a
	Minor axis length	10.319	<0.001^a
	Area	16.126	<0.001^a
	perimeter	3.941	<0.001^a
	Ratio	9.501	<0.001^a
Drying temperature x Drying time	Major axis length	0.614	0.875^{ns}
	Minor axis length	0.969	0.490^{ns}
	Area	0.885	0.587^{ns}
	perimeter	0.564	0.911^{ns}
	Ratio	1.441	0.116^{ns}

^{a} Significant at P < 0.05
^{ns} Non-significant at P<0.05

D. Predicting Moisture Content and Colour Changes of Pumpkin Based on Backscattering Imaging Parameters

The backscattering imaging parameters were used to predict the moisture content, lightness (L*), redness (a*), and yellowness (b*) of pumpkin slices during drying using partial least square (PLS) regression technique. Table 3 presents both the prediction and validation models for the three drying temperature levels. The best predictions were selected based on statistical indicators of R^2, RMSEP, and RMSEV. Based on the results, the backscattering imaging parameters gave good prediction for all the quality parameters of pumpkin undergoing drying at 60˚C with R^2 >0.7 and RMSEP < 1.8. In addition, backscattering imaging parameters resulted in good prediction of MC, L* and b* for pumpkin during drying with R^2 > 0.8 and RMSEP < 2.2 at 70˚C, and R^2 > 0.6 and RMSEP < 3.1 at 80˚C, respectively. Considering drying at 60˚C for instance, the validation models resulted in R^2 values of 0.54, 0.96, 0.51, 0.80 and RMSEV values of 0.39, 1.51, 1.29, and 2.70 for MC, L*, a* and b* quality parameters, respectively. Moreover, it can be observed from Table 3, that backscattering imaging parameters demonstrated the best prediction of lightness (L*) at all drying temperatures.

The relationship between experimental and predicted data for MC (Figure 6a), L* (Figure 6b), a* (Figure 6c) and b* (Figure 6d) is shown in Figure 6. From the plot, it can be seen that the values lie close to the regression line for all the quality parameters. This further validate the application backscattering imaging in predicting the quality attributes of pumpkin during drying. Onwude *et al.* (2017) reported similar findings for sweet potato. Romano *et al.* (2011) demonstrated that backscattering image area can adequately predict the moisture content of bell pepper during drying Romano *et al.* (2012) also observed that area and light intensity were able to predict the moisture content, and soluble solids content of apple, respectively during drying.

Table 3. Calibration and validation models based on the backscattered imaging parameters of pumpkin slices during drying

Drying temperature	Quality parameters	Prediction LV	Prediction R^2	Prediction RMSEP	Validation LV	Validation R^2	Validation RMSEV
60 ˚C	Moisture content (MC)	5	0.775	0.204	5	0.535	0.387
	Lightness (L*)	5	0.976	0.978	5	0.955	1.512
	Redness (a*)	5	0.957	0.337	5	0.507	1.287
	Yellowness (b*)	5	0.901	1.698	5	0.801	2.703
70 ˚C	Moisture content (MC)	5	0.912	0.090	5	0.458	0.277
	Lightness (L*)	5	0.957	0.909	5	0.879	1.707
	Redness (a*) *	5	0.490	0.979	5	0.320	1.353
	Yellowness (b*)	5	0.879	2.161	5	0.462	5.133
80 ˚C	Moisture content (MC)	5	0.945	0.075	5	0.800	0.159
	Lightness (L*)	5	0.963	1.036	5	0.941	1.493
	Redness (a*) *	5	0.462	1.032	5	0.172	2.701
	Yellowness (b*)	5	0.608	3.001	5	0.444	4.021

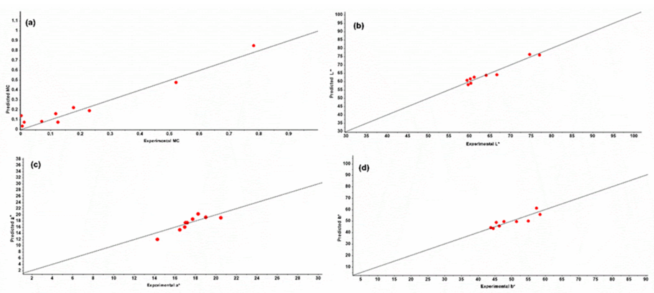

Figure. 6 Relationship between experimental and predicted quality data for pumpkin during drying at 60˚C

IV. CONCLUSION

This study investigated the potential of applying laser-based backscattering imaging technique as a novel and reliable method for the rapid and non-destructive monitoring of moisture content and colour changes of pumpkin during drying. The results obtained in this study demonstrated that the backscattering imaging parameters were affected by both drying temperature and time. The developed prediction models showed that the backscattering imaging parameters gave good prediction for all the quality parameters of pumpkin undergoing drying at 60˚C with R^2 >0.7 and RMSEP < 1.8. The backscattering imaging parameters resulted in good prediction of MC, L* and b* for pumpkin during drying with R^2 > 0.8 and RMSEP < 2.2 at 70˚C, and R^2 > 0.6 and RMSEP < 3.1 at 80˚C. Overall, this quality inspection method could offer a strong basis for the current trends in non-destructive monitoring of the drying process of agricultural crops.

V. ACKNOWLEDGEMENT

The authors are thankful to Universiti Putra Malaysia for the financial support provided under the Geran Putra research funding (GP-IPS/9511600).

VI. REFERENCES

ASAE, 2005, 'Moisture measurement — Unground grain and seeds', *American Society of Agricultural and Biological Engineers*, 1988, pp. 2–4.

Baranyai, L & Zude, M 2009, 'Analysis of laser light propagation in kiwifruit using backscattering imaging and Monte Carlo simulation', *Computers and Electronics in Agriculture*, vol. 69, no. 1, pp. 33–39.

Chen, Q, Bi, J, Xinye, W, Jianyong, Y, Linyan, Z & Yuhan Z 2015, 'Drying kinetics and quality attributes of jujube (Zizyphus jujuba Miller) slices dried by hot-air and short- and medium-wave infrared radiation', *LWT - Food Science and Technology*. vol. 64, no. 2, pp. 759–766.

Dadali, G., Demirhan, E. & Özbek, B 2007, 'Color change kinetics of spinach undergoing microwave drying', *Drying Technology*, vol. 25, no. 10, pp. 1713–1723.

Demirhan, E. and Özbek, B 2009, 'Color change kinetics of microwave-dried basil', *Drying Technology*, vol. 27, no. 1, pp. 156–166.

Demirhan, E. & Özbek, B 2010, 'Microwave-drying characteristics of basil', *Journal of Food Processing and Preservation*, vol. 34, no. 3, pp. 476–494.

Durante, M., Lenucci, M. S. & Mita, G 2014, 'Supercritical carbon dioxide extraction of carotenoids from pumpkin (Cucurbita spp.): A review.', *International Journal of Molecular Sciences*, vol. 15, no. 4, pp. 6725–40.

Hashim, N, Michael P, Christian, R, Rimfiel , JB, Russly, A, Azizah, O, Mahendran, S & Manuela, Z 2013, 'An approach for monitoring the chilling injury appearance in bananas by means of backscattering imaging', *Journal of Food Engineering*. vol. 116, no. 1, pp. 28–36.

Henriques, F, Guiné, RPF & Barroca, MJ 2012, 'Influence of drying treatment on physical properties of pumpkin', *Croatian Journal of Food Technology, Biotechnology and Nutrition*, vol. 7, pp. 53–58.

Koca, N, Burdurlu, HS & Karadeniz, F 2007, 'Kinetics of colour changes in dehydrated carrots', *Journal of Food Engineering*, vol. 78, pp. 449–455.

Krokida, M. & Maroulis, Z 2001, 'Quality changes during drying of food materials', *Drying Technology in Agriculture and Food Sciences*, pp. 61–105.

Lorente, D, Zude, M, Idler, C, Gómez-Sanchis, J & Blasco, J 2015, 'Laser-light backscattering imaging for early decay detection in citrus fruit using both a statistical and a physical model', *Journal of Food Engineering*. vol. 154, pp. 76–85.

Mohd Ali, M, Hashim, N, Bejo, S & Shamsudin, R 2017, 'Quality evaluation of watermelon using laser-induced backscattering imaging during storage', *Postharvest Biology and Technology*, vol. 123, pp. 51–59.

Mollazade, K, Omid, M, Akhlaghian Tab, F, Kalaj, YR, Mohtasebi, SS & Zude, M 2013a 'Analysis of texture-based features for predicting mechanical properties of horticultural products by laser light backscattering imaging', *Computers and Electronics in Agriculture*, vol. 98, pp. 34–45.

Onwude, DI, Hashim, N, Janius, RB, Nawi, N & Abdan, K 2016, 'Modelling effective moisture diffusivity of pumpkin (Cucurbita moschata) slices under convective hot air drying condition', *International Journal of Food Engineering*, vol. 12, no. 5, pp. 481–489.

Onwude, DI, Hashim, N, Janius, RB, Nawi, N & Abdan, K 2017, 'Color change kinetics and total carotenoid content of pumpkin as affected by drying temperature', *Italian Journal of Food Science*, vol. 29, no. 1, pp. 1–18.

Onwude, DI, Hashim, N, Abdan, K, Janius, RB, & Chen, G 2018, 'The potential of computer vision, optical backscattering parameters and artificial neural network modelling in monitoring the shrinkage of sweet potato (Ipomoea Batatas L.) during drying', *Journal of the Science of Food and Agriculture*, vol. 98, pp. 1310–1324.

Romano, G, Baranyai, L, Gottschalk, K & Zude, M 2008, 'An approach for monitoring the moisture content changes of drying banana slices with laser light backscattering imaging', *Food and Bioprocess Technology*, vol. 1, no. 4, pp. 410–414.

Romano, G, Nagle, M, Argyropoulos, D & Müller, J 2011, 'Laser light backscattering to monitor moisture content, soluble solid content and hardness of apple tissue during drying', *Journal of Food Engineering*. vol. 104, no. 4, pp. 657–662.

Romano, G, Argyropoulos, D, Nagle, M, Khan, MT & Müller, J 2012, 'Combination of digital images and laser light to predict moisture content and color of bell pepper simultaneously during drying', *Journal of Food Engineering*. vol. 109, no. 3, pp. 438–448.

Udomkun, P, Nagle M, Mahayothee, B & Müller, J 2014, 'Laser-based imaging system for non-invasive monitoring of quality changes of papaya during drying', *Food Control*. vol. 42, pp. 225–233.

Vega-Gálvez, A, Lemus-Mondaca, R, Bilbao-Sáinz, C, Fito, P & Andrés, A 2008, 'Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo)', *Journal of Food Engineering*, vol. 85, no. 1, pp. 42–50.