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REGULAR ARTICLE

Non-destructive measurement of total soluble solid (TSS) content of dates using near infrared (NIR) imaging

A. Manickavasagan[1]*, K. Ganeshmoorthy[1], M. R. Claereboudt[2], R. Al-Yahyai[3] and L. Khriji[4]

[1]*Department of Soils, Water and Agricultural Engineering, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud, P.O. No. 34, PC 123, Muscat, Sultanate of Oman*
[2]*Department of Marine Science and Fisheries, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud, P.O. No. 34, PC 123, Muscat, Sultanate of Oman*
[3]*Department of Crop Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud, P.O. No. 34, PC 123, Muscat, Sultanate of Oman*
[4]*Department of Electrical and Computer Engineering, College of Engineering, Sultan Qaboos University, Al-Khoud, P.O. No. 34, PC 123, Muscat, Sultanate of Oman*

Abstract

The total soluble solid (TSS) content is one of the important quality attributes that determines the commercial value of dates. At present, TSS content in dates is measured using destructive techniques that are laborious and time consuming. In this study, the potential of a near infrared (NIR) imaging technique to determine TSS content of dates was evaluated. Date samples of three cultivars (Fardh, Khalas and Naghal) at tamar stage (n=400 fruits) and two ripening stages (tamar and khalal) of Khalas cv. (n=400 fruits) were used in this study. The area scan NIR camera which covers the full spectrum range of 900−1,700 nm was used to capture the images of individual date fruits. Immediately following image acquisition, the TSS content (ºBrix) of each sample was measured using a digital refractometer. The TSS content of dates was in the range of 34−63° Brix and 14−37°Brix for tamar and khalal stages, respectively. Similarly, the percentage of NIR reflectance was 12−38 and 39−64 for tamar and khalal stages, respectively. A multiple linear regression (MLR) prediction model along with a dummy variable concept was established between measured TSS and NIR reflectance. NIR reflectance was inversely proportional to the TSS content of dates. The correlation coefficient (r) between TSS content and NIR reflectance was 0.62 and 0.98 for three cultivars and two ripening stages, respectively. The high correlation among ripening stages indicates the opportunities of NIR technique for potential applications in influencing ripening stages. However, further work is warranted to determine the correlation between TSS and NIR reflectance in different ripening stages of other cultivars.

Key words: Dates, Multiple linear regression, NIR imaging, reflectance, TSS

Introduction

In Oman, around 50% of the cultivable area is occupied by date palms (Al-Yahyai, 2007) which produce about 268,011 mt of dates every year and the country ranks eighth in date production globally (FAO, 2010). Dates are also considered to be a healthy and nutritious fruit rich in fibers and in antioxidants (Ali et al., 2012; Manickavasagan et al., 2013). The developmental phases of date fruit can be broadly classified into four ripening stages: kimri (unripe), khalal (fully ripe), rutab (partially overripe) and tamar (fully overripe) (Al-Yahyai and Al-Kharusi, 2012; Mireei et al., 2010). The three stages of ripe dates are available in the market in different seasons depending on the cultivar and demand.

In general, consumer preference of dates is mainly based on appearance, texture and sweetness. About 60% of the fresh weight of the date fruit consists of sugar (Salunkhe and Desai, 1984). Fadel (2002) reported that relatively high sugar content is the most important commercial attribute of the date fruit. During storage, even unripe dates would ripen

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*Corresponding Author

A. Manickavasagan
Department of Soils, Water and Agricultural Engineering, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud, P.O. No. 34, PC 123, Muscat, Sultanate of Oman

Email: manick@squ.edu.om

completely based on total sugar content in fruits (Schmilovitch et al., 1999). Therefore, it is important to measure quality parameters of dates motivated by various postharvest handling activities.

The sugar content in dates is monitored by measuring the total soluble solid (TSS) content as sugar forms a major constituent of the soluble solid content. Also most of the TSS in dates consists of different types of sugars and it is a good estimate of total sugar content (Farag and Al-Masri, 1999). Total soluble solid of dates is normally measured using a hand-held refractometer using the fresh juice of dates. However, it is a difficult process as there is little extractable juice even when the moisture content of date fruit is more than 80% (Mireei et al., 2010). Given that the traditional TSS measurement process is time-consuming and laborious, we set out to develop a non-contact, non-destructive and fast technique with reasonable accuracy for this application which might be highly beneficial to the date industry.

Computer vision techniques with different imaging systems have been successfully used to determine the surface and internal qualities of various food products, and near infrared based imaging techniques are popular due to their ability to predict some internal qualities of the product. NIR spectroscopy was used to predict the TSS content in peach (Sumio et al., 1992), cherry and apricot (Paolo et al., 2000), apple (Liu and Ying, 2004), watermelon (Abebe, 2006) and orange (Cayuela, 2008). However, there is no published work available on the use of the NIR technique to determine TSS content in dates.

The objective of this study was to determine the correlation between TSS content of dates and NIR reflectance among: i) three cultivars (Khalas, Fardh and Naghal) of dates at tamar stage; ii) two ripening stages (khalal and tamar) of dates of the Khalas cv.

Materials and Methods

Sample collection

Date samples of Fardh, Naghal and Khalas cvs. were purchased from Bright Sun Dates Factory (Barka, Oman), farmers (Samail, Oman) and the Agricultural Experimental Station (Sultan Qaboos University, Oman). A sample of 400 dates per category was randomly chosen across sources. In similar imaging applications with dates, around 100–600 replications (images per category) had been taken (Al-Rahbi et al., 2013; Manickavasagan et al., 2013; Thomas et al. 2012). In this study, as the TSS had to be measured manually for all imaged samples individually, a reasonable replication size of 400 per category was fixed.

NIR image acquisition system

The NIR imaging system consisted of a NIR InGaAs camera (Model No.SU320, Goodrich Sensors Unlimited, Inc. USA) with a 25 mm F/1.4 C-mount lens, sample platform, illumination (a pair of 20 W halogen lamps, Royal Philips Electronics, Germany) and a data acquisition computer (Figure 1). The camera had a spatial resolution of 320×256 pixels with 25 µm pitch and uniform sensitivity to the NIR waveband between 900–1,700 nm. The camera and the sample were placed inside a closed box (35×25× 35 cm) to avoid backscattering distraction from other light sources. Indirect light was used in which the light was directed to the white back plates of the enclosure and diffuses light. A digital cable was connected to the connector of the camera and to the camera link digital port on the frame grabber card (PCI 1428, National Instruments Corp., Austin, TX, USA) for capturing NIR reflectance images in the computer. These images were acquired through SUI image analysis 4.0.1 software (Goodrich Sensors Unlimited, Inc. USA). The distance between the lens and the sample was maintained constantly at 30 cm throughout the experiment. A total of 1,600 date images (3 cultivars in tamar stage and 1 cultivar in khalal stage) were acquired and stored for further analysis.

Total soluble solid (TSS) measurement

Immediately after image acquisition, the collective date fruit samples were subjected to TSS measurement using a digital refractometer (model: PR-32α, Palette digital refractometer, ATAGO, CO., LTD. Tokyo, Japan) which provided the ºBrix value with an accuracy of +/- 0.1%. The TSS content of date samples was measured using the procedure described by Dadzie and Orchard (1997). Juice of date fruit was prepared by thoroughly mixing 3 g of tissue pulp in 9 ml distilled water for 2 min and then passing it through a filter paper. Then one drop of filtrate was placed on the prism of the refractometer and ºBrix value was recorded. The recorded value was multiplied by '3' as the dilution factor.

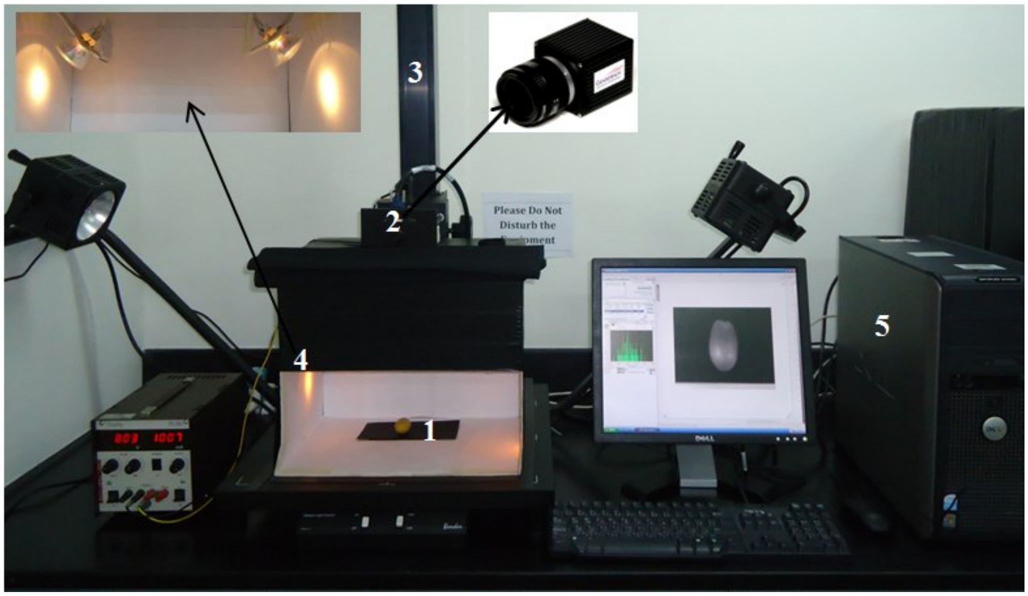


Figure 1. Experimental setup for NIR imaging system: 1. Sample platform, 2. NIR camera, 3. Camera mounting stand, 4. Illumination, and 5. Image acquisition system.

Image analysis

The acquired NIR images were processed using the MATLAB (Version 7.6.0, Mathworks Inc., Natick, MA, USA). In each image, the region pertaining to the date sample was segmented from the background using Otsu threshold method (Figure 2) followed by a binary erosion, dilation process to remove the unwanted holes in the image. After segmentation, the relative NIR reflectance of individual sample was extracted using the approach described by Lu and Chen (1998) and Wang et al. (2012) following Eqn. 1:

$$I = 100 \times (T-D)/(W-D) \qquad \text{[Eqn. 1]}$$

where,
I = Calculated % reflectance value of the object
T = Gray level of the object pixels of the NIR image
D = Gray level of the black reference image
W = Gray level of white reference image

Black and white reference images were taken using a white sheet (approximately 99% reflectance) and black sheet (approximately 0% reflectance).

Data analysis

Difference in mean TSS and IR reflectance between cultivars of dates and maturation stages was tested using single factor ANOVA. Post-hoc comparisons were carried out using Least Significant Difference (LSD) on SPSS software (IBM SPSS Statistics, NY, USA).

A multiple linear regression (MLR) model was developed for the prediction of TSS in dates using SPSS software. Regression relationship was established between measured TSS and NIR reflectance acquired from individual date samples. MLR was accomplished with the dummy variable concept for prediction for different cultivars and ripening stages of dates. Since cultivars and stages are not continuous variables, they could not be included directly in a model. Those categorical variables were included in the model as dummy variables (Palomares and Pauly, 1989; Wu et al., 2008); the TSS prediction equation for used for evaluating three cultivars of dates is:

$$Y = \beta 0 + \beta 1\, X + \beta 2 D1 + \beta 3\, D2 + \varepsilon t \qquad \text{[Eqn. 2]}$$

where,
Y – TSS (ºBrix)
$\beta 0$ – Regression intercept
$\beta 1$ – $\beta 2$, $\beta 3$; Regression coefficients
X – IR Reflectance (%)
D1 , D2– Dummy variables
εt – Error term

The regression was performed with the measured as well as dummy variables to obtain a relationship between the measured TSS and percentage reflectance. The number of dummy variables was calculated as: number of categorical variables minus one.

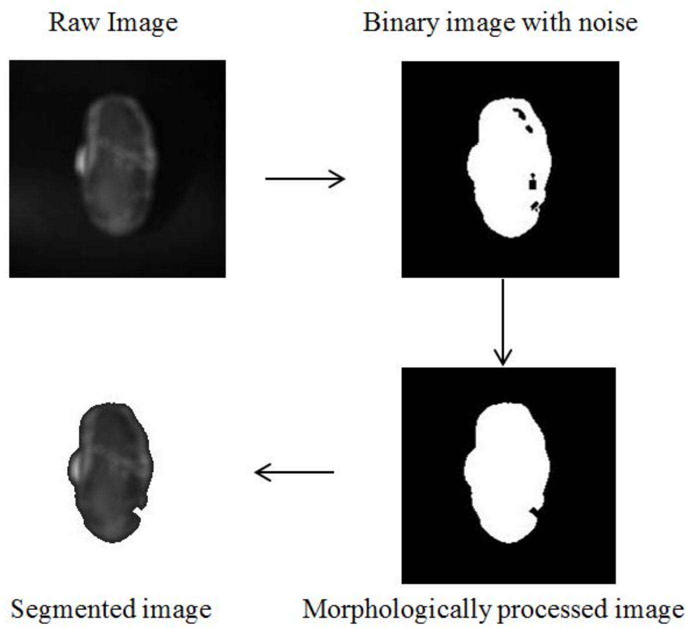


Figure 2. Steps involved in the segmentation of dates from the background region of the image.

Table 1. TSS and NIR reflectance of dates (n=400) in three cultivars at tamar stage.

Cultivar	TSS (^{0}Brix)			NIR reflectance (%)		
	Mean	SD*	Range	Mean	SD	Range
Khalas	٥٣,٩^{a**}	2.8	46.5-63.3	18.2^{a}	2.4	11.9-25.3
Fardh	49.7^{b}	2.7	43.5-57.6	23.4^{b}	3.7	12.1-34.2
Naghal	48.6^{c}	3.2	33.9-56.7	23.2^{b}	4.2	12.0-38.4

*SD = Standard Deviation (n=400 fruits)

** same letters in the same mean column are not significantly different at α=0.05, LSD post-hoc test.

Results and Discussion

The NIR images of individual sample were taken for 400 dates in each cultivar and ripening stage. Immediately after imaging the TSS of each date sample was instrumentally measured. Then the % of NIR reflectance was correlated with measured TSS.

TSS prediction for different varieties of dates

The measured TSS values of date samples and their corresponding NIR reflectance are given in Table 1. Although measured TSS of each cultivar was significantly different (ANOVA, LSD post-hoc test), there was no significant difference in reflectance between Fardh and Naghal cvs. The dates in Naghal cv. produced the widest range in both TSS and Reflectance. Dates from the Khalas cv. formed a distinct cluster, whereas the other 2 cultivars overlapped strongly (Figure 3).

In addition to TSS content, the skin characteristics of the fruit also play a vital role in determining the reflectance pattern (Cavaco et al., 2009). In dates, at tamar maturation stage, the skin tends to delaminate, and therefore increase the scattering effect of light and alter the reflectance (Lee et al., 2008). As indicated by Fraser et al. (2003) skin acts as a barrier for light penetration and reduces the effectiveness of NIR imaging system for this application. The apparition of delamination areas on our samples may have contributed to the relatively poor correlation between NIR absorption/reflectance and TSS content. Although significant ($F(3,1196)=252.2$, $p<0.05$), our regression model linking date variety and IR reflectance to TSS was only able to predict 39% of the variability in TSS variability.

The regression coefficients indicated a negative slope of the relationship between TSS and IR reflectance of the dates. The least square multiple regression equation for TSS (ºBrix) prediction of the three date cultivars was calculated based on Eqn. 3:

TSS = 51.002 - 0.102 IR Reflectance +4.705 D1+1.067 D2 [Eqn. 3]

where, D1 and D2 are dummy variables for Khalas and Fardh cvs. respectively. The coefficient for D1 (β2=4.7) indicates that mean values of TSS for Khalas were 4.7 units higher than Naghal. Similarly, for Fardth, the mean TSS values were 1.06 units higher than that for Naghal dates.

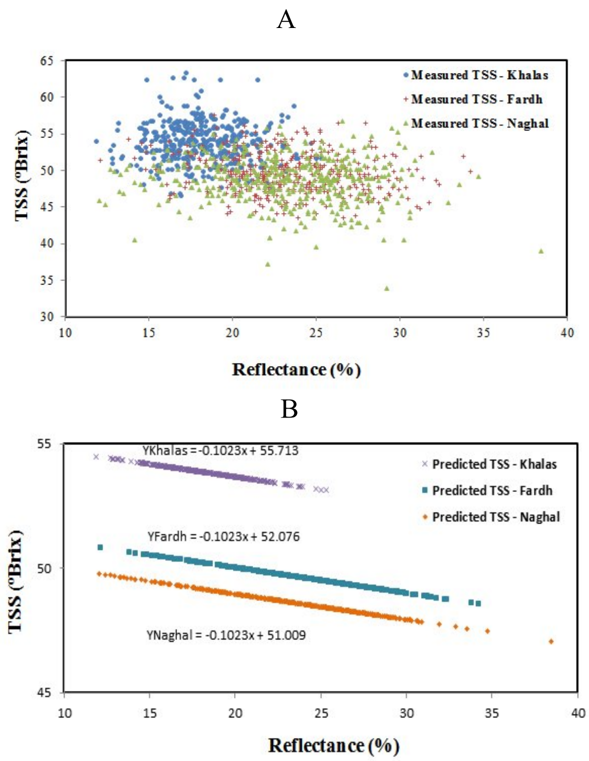


Figure 3. Percent NIR reflectance vs TSS of dates in three cultivars: (a) Scatter plot of three cultivars at tamar stage, (b) Expected values of TSS, using the regression equations linking NIR and TSS values for three cultivars.

TSS prediction for ripening stages of dates

The TSS and reflectance values of both ripening stages were significantly different (Table 2; Figure 4). The observed differences in NIR reflectance between two stages may be due to differences in chemical composition, including TSS, (Grzegorz et al., 2010) but also to moisture content. Al-Yahyai and Al-Kharusi (2012) reported that the moisture content was 78−84% and 33−36% for khalal and tamar stages of Khalas cv., respectively. The dates in khalal stage have high moisture content with golden yellow color and a smooth skin, whereas dates in tamar stage are much drier with thick, often wrinkled and delaminating skin. Although there was a wide range in both TSS and reflectance between two stages, there were no overlaps between the two stages of dates on the plot. The higher NIR reflectance values were related to date samples with relatively lower TSS contents and vice versa. This NIR reflectance property of the fruit may have been related not only to its TSS content but also to the characteristics of the fruit surface.

The regression model linking date maturity stage and IR reflectance to TSS had a high coefficient of determination (r^2=0.95) and was highly significant ($F_{(2,797)}$ =7836.1, $p < 0.05$) but this predictive success was mostly due to a complete separation between the two groups of dates both in terms of TSS and reflectance.

Figure 4b shows prediction equations for khalal and tamar stages of Khalas cv. There were two separate identical trend lines for each ripening stage. For convenience in using the model, these two equations have been combined as one prediction model with the use of the dummy variable.

The least square multiple regression equation for TSS (ºBrix) prediction of the two date maturation stages was:

TSS= 55.052 - 0.066 (IR Reflectance) - 31.318 D [Eqn. 4]

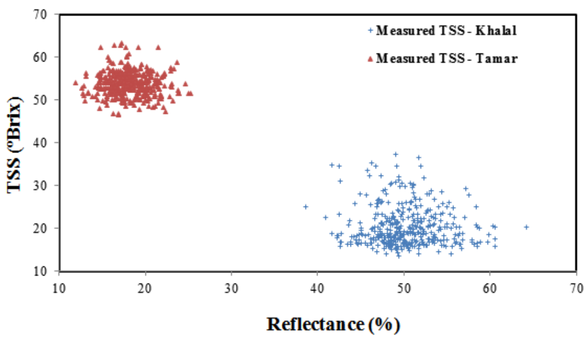
where, D is a dummy variable with value 1 for khalal and 0 for tamar. The dummy variable (khalal stage) with negative coefficient (-31.318) indicated that TSS of khalal was approximately 33 lower than tamar stage. Eqn. 4 can be used to predict the TSS content of dates in khalal and tamar stages of Khalas cv.

Table 2. TSS and NIR reflectance of dates (n=400) in two ripening stages of Khalas cultivar.

Stage	TSS (^{0}Brix)			NIR reflectance (%)		
	Mean	SD*	Range	Mean	SD	Range
Khalal	20.4[a]	4.6	13.6-37.4	50.1[a]	3.8	38.6-64.3
Tamar	53.9[b]	2.8	46.5-63.3	18.1[b]	2.4	11.8-25.2

*SD = Standard Deviation (n=400 fruits)

** same letters in the same mean column are not significantly different at α=0.05, LSD post-hoc test



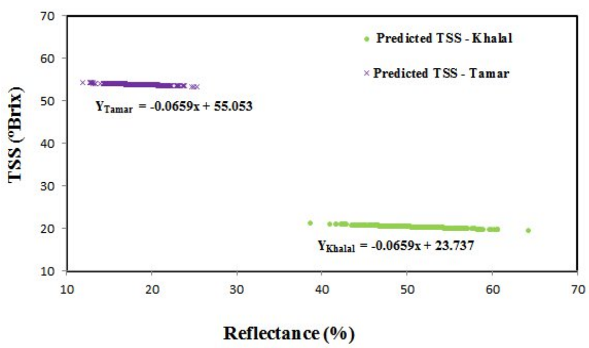


Figure 4. Percent NIR reflectance vs TSS of dates in two ripening stages: (a) Scatter plot of Khalas dates at two maturity stages, (b) Expected values of TSS of Khalas dates using the regression equations linking NIR and TSS values for two maturity stages.

Conclusions

Measured NIR reflectance was inversely correlated with TSS and to some extend predictable. Prediction was poor at the most advanced maturation stages, likely due to variability in the skin characteristics of the dates between cultivars. The intensity of illumination played a vital role in NIR reflectance pattern and eventually TSS prediction. Therefore, the effect of other illuminations with various light sources on TSS prediction using NIR imaging should be studied.

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