Misr J. Ag. Eng., 25(4): 1279-1292 IRRIGATION AND DRAINAGE

DETERMINATION OF POTATO WATER CONTENT USING NIR DIFFUSE REFLECTION METHOD

Elbatawi I. E.,[1] Ebaid M. T. [1] and Hemeda B. E. [2]

ABSTRACT

Spectroscopic techniques with near infrared (NIR) method has been used for the compositional, functional and sensory analysis of food ingredients, process intermediates, and final products all over the world. This study demonstrated a potential way to predict water content in potatoes (Diamant variety) using electric heater, spectroscopy within visible (VIS) and near infrared (NIR) spectral data.The data was selected to establish a prediction models to estimate potato water content (with or without skin). Partial least square regression was used to establish calibration models for predicting the water content in potato samples. Significant wavelength ranges of 750-900, 1000-1150 and 1350-1550 nm was used to predict potato water content without skin. On the other hand, significant wavelength ranges of 750-900, 1000-1250 and 1350-1550 nm was used to predict potato water content with skin according to the experiment results. For potatoes without skin, the R^2 values for prediction of water content was 0.994 and it was 0.997 for potatoes with skin. The residual error was found to be lower for validation set in both test sets using the select wavelength segments. Results also concluded that, spectrometer is accurate, easy and faster than electric heater for the same amount of potato.

INTRODUCTION

Potato is one of the most important agricultural products in Egypt. Cultivated area of potato is about 200.000 fed. producing about 2 million ton/year **(The annual statistics book, 2005).** To maintain good quality for consumers, a fast and objective grading and classification system would reduce the inaccuracy caused by inspector subjectivity and the labor requirement, thus benefiting potato producers and food industry.

1)Senior Res., of Ag. Eng. Res. Inst., Ag. Res. Center. Giza Egypt.
2)Res., Ag. Eng. Res. Inst., Ag. Res. Center. Giza Egypt.

The main characteristics for visual inspection and classification of fruits are color, shape, firmness and water content. The payment system for farmers in the potato industry is based on fresh weight that is mainly due to huge amount of water content (73.8 – 81 %) **(Souci et al 2000).** Thus, estimation of water content in potatoes may help weight evaluations for potatoes. Water content in an object is usually determined using analytical chemical or physical procedures. However, these procedures can be time-consuming, tedious and with poor repeatability **(Yeh et al. 1994). Hecht (1992)** mentioned that the He-Ne laser are considered as low power, which called cold laser. The basic rules for safe use of helium-neon lasers are to avoid into the laser beam and contacting the high voltages that power the discharge. **(Yeh, et al. 1994).** Developed a technique to measure moisture profiles in microwave heated foods using VIS – NIR spectroscopy. They concluded that, oven method to predict water content of vegetables takes long time and sometimes not accurate compared with spectrometer method. **Chen and Ruiz-Altisent (1996)** reported that, correlations of skin color with firmness, sugar content, or other attributes (such as acid and specific gravity) are unreliable and generally low. **Lu et al. (2000)** conducted a study to predict the firmness and sugar content of apples in the spectral region between 800 nm and 1700 nm. They found that the technique gave a good predictions for apple's sugar content with the standard error of prediction (SEP) ranging from 0.5 % to 0.7 % Brix. **El-Raie et al .(2003)** studied the optical properties of tomato maturity stages (A. Piza variety) using Argon laser with wavelengths 448 and 514 nm and He-Ne laser with wavelength 632.8 nm. They concluded that, the wavelength reflected from mature tomato was 514 nm. **Kang et al. (2004).** Developed a NIR sensing technique in interaction mode for a rapid acquisition of spectral information to predict the quality parameters of potato, such as specific gravity and dry matter. **Elbatawi (2008)** developed an acoustical sorting system with NIR to detect hollow heart (cavity) of potato tubers. He mentioned that upon impact with a steel plate, potato tubers with no hollow heart emit sound with higher signal magnitudes than with hollow one. **Elbatawi and Ebaid (2006)** mentioned that sorting and classification of fruits are the main problem specially for Superior and King. They provide a new technique to investigate the applicability of color classification, sugar content and firmness of grape. NIR spectral data were collected from the two varieties of grape in the spectral region between 800 nm and 1700 nm.

The objectives of this study were:

1- To establish calibration models to predict water content of potato samples based on spectral information.

2- To select significant wavelength ranges for developing water-content determination systems.

MATERIAL AND METHODS

The one of the most famous and used in industry and export in Egypt is Diamant. Vegetable like potato tubers (variety of Diamant) were used in this study. The sample of potato tuber was obtained from Horticultural Research Institute (H.R.I), Agricultural Research Center (A.R.C), Giza, Egypt and the measurements were carried out in the same day.

1. Sample preparation

Fifty potato tubers were divided twice to measure water content with and without skin. All samples were weighed before and after drying by electronic balance (its scale ranged from 0 to 5 kg max., with accuracy of 0.2 g, Japan). Samples were handled carefully using plastic gloves against water absorption to avoid any losses of water content measurements for moving slabs to and from the tray. These potatoes (without skin) were cut into identical slabs (5x3x0.2 cm^3) for easy drying. Each slab was weighed and considered as a potato sample. Water content was measured by using the following methods:

1.1. Electric Heater

The potato samples were placed in aluminum dishes and a forced air electric heater (KUMTEL, TS 8943, class 1, Voltage 230, GUC power/1300 W, 50-60 Hz, Turkiye) was used to dry potato samples. The electric heater was set at a temperature of 105 c^o and atmospheric pressure for 24 hours according to **AOAC (2002).** The water content was calculated according to the following equation:

$$\mathbf{Mc} = \frac{M_1 - M_2}{M_1} x\, 100 \quad \% \qquad \mathbf{(1)}$$

Where: Mc = Water content of the samples, %.

M_1 = Weight of the samples before drying, (g). and

M_2 = Weight of dry samples, (g).

1.2. Spectrometer

A portable hyper-spectrometer (Spectronic 21D, MILTON ROY Boulder, Colorado, USA) was located in the lab of Food Technology Research Institute (Agricultural Research Center, Giza, Egypt), was used for spectral measurements. This instrument measured reflectance spectra in a wavelength range of 400-1000 nm. During measurement, the potato samples were placed underneath the fiber bundle of the Spectronic 21D with a distance of 7 cm and a field view of 20^0. A DC regulated fiber-optic illuminator (Fiber-Lite PL 900-A, Dolan-Jenner Industries Inc, MA, USA) was used a light source. Two fiber-optic light-guiding branches were mounted on a test frame to guide light to the potato samples. Light reflected from the sample was led through the fiber-optic bundle to the Spectronic 21D for intensity measurement. A white reference panel with approximately 100 % reflectance across the entire spectrum was used as a reference standard. The ratio of the two measurements was calculated at each wavelength to from a reflectance spectrum. The View Spec Pro Software (Analytical Spectral Devices, Boulder, Colorado, USA) was used for instrument control and computation. All the spectra were recorded and stored in a PC. The spectral range of each spectrum was 400-1000 nm. The reflectance was normalized so that the values were within the range of 0 to 1.

1.3. Spectrometer with image system

Spectrometer of Food Technology Research Institute provides a wavelength ranged from 400 to 1000 nm which is not enough for detecting potato water content. To get extra contrast and more range of wavelengths, NIR diffuse reflectance measurements were performed using an image system attached with the spectrometer (mentioned above).

The system consisted of a DC light source with the control unit, and a thermal electric cooled detector connected to an controlling unit, which in turn was connected to a Lab-Top computer. A 300 W quartz tungsten halogen lamp was used to provide broadband light. The light was delivered and dispersed (according to the wavelength) to the potato tuber through a guide cable to capture the images. The dispersed light at different wavelengths was sensed by the detector and converted into electronic signals to the computer as shown in Fig 1. The potato was positioned with the distal side and facing down towards the light delivery probe. One scanning was performed for each potato tuber between 400 nm and 1750 nm at an interval of 2 nm. NIR was used to detect potato water content and the obtained data was used to compare it with data collected from the electric heater.

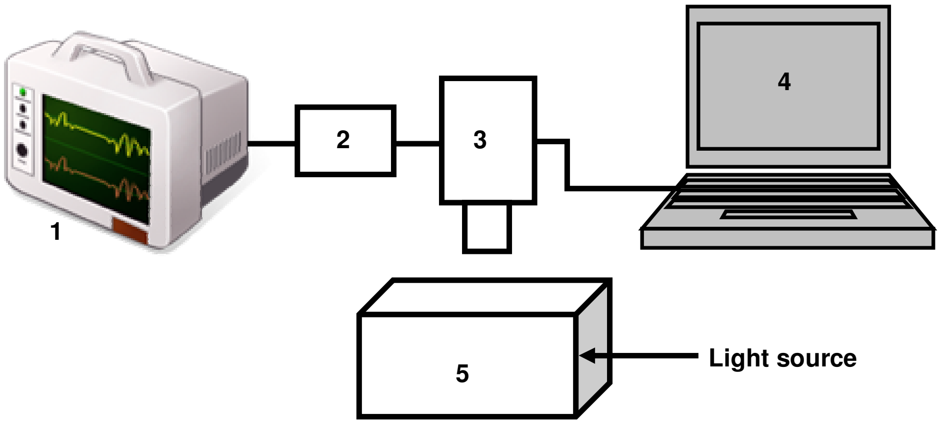

Fig. (1): Schematic diagram of image system connected with spectrometer.
(1) spectrometer, (2) control unit, (3) video camera, (4) lab-top computer and (5) sample box with light source.

2. Data analysis

All the spectra were processed and analyzed using SAS program (comprehensive, spectroscopic, data-processing software). All spectra used for analysis were truncated to a range of 400-1750. The partial least-squares (PLS) calibration method was used to decompose the spectra into a set of variation spectra that represent the changes in reflectance within the spectral range. In this study, water content of the potato samples measured with the electric heater method were used as the constituent data, and the spectra were used as the spectral data. The PLS procedures were: calibration model, optimal number of factors (used in the calibration model), significant wavelength for predicting the constituent (potato water content), and predicted constituent for each sample used in calibration. A calibration model was first established using whole range of the spectra. The optimal number of factors was determined by Predicted Residual Sum of Squares Error (PRESS). The Log (1/R) (relative differences of reflectance between water content and wavelength) was used to find the significant range of wavelength to predict the water content in a potato sample. The best calibration model (with the highest R^2 values) for predicted water content versus actual water content was chosen for the training set. On the other hand, lowest Root-Mean Square Error (RMSE) values were chosen for the validation set. Once the significant wavelength ranges were selected using the PLS Log (1/R), the second calibration model was then established using the spectral reflectance (among the selected wavelength ranges).

3. Calibration and validation sets

In this study, two sets (of tests) were conducted using two types of potato tubers. Four calibration models were developed based on the significant wavelength ranges determined for the two types of samples.

The first set (Test 1) was designed to test the Partial Least Square (PLS) calibration models for the potato tubers without-skin. Fifty potato samples without-skin were used to collect reflectance spectra. For each potato tuber, three spectra were collected at three different locations and were then averaged. Thus, the total number of spectra obtained for this sample was 50. Out of these 50 spectra, 25 were used as training set to develop calibration model and 25 as validation set to test the prediction accuracy of the calibration model. On the other hand, the second set (Test 2) was designed to test the PLS calibration models for the potato tubers with skin. 50 potato samples with skin were used in the test. Out of these 50 spectra, 25 were used for training set and 25 for validation set.

RESULTS AND DISCUSSION

1. Required wavelength for potato samples

The spectrum of potato tubers with skin and potato samples without skin (average water contents were 81.71% and 80.86 % for potatoes with skin and without skin, respectively) was shown in Fig. (2). The major differences between the two spectra were observed in the wavelength region of 400-700 nm, which mainly due to the skin color of the potato sample. From 700-1600 nm, the spectrum potato with skin was slightly higher than spectrum without skin. In general, the two spectra showed similar trends in the remaining portion within the NIR region. This similarity indicated that the significant wavelength ranges for potato samples with and without skin may be very similar over the spectral range of 700-1600 nm.

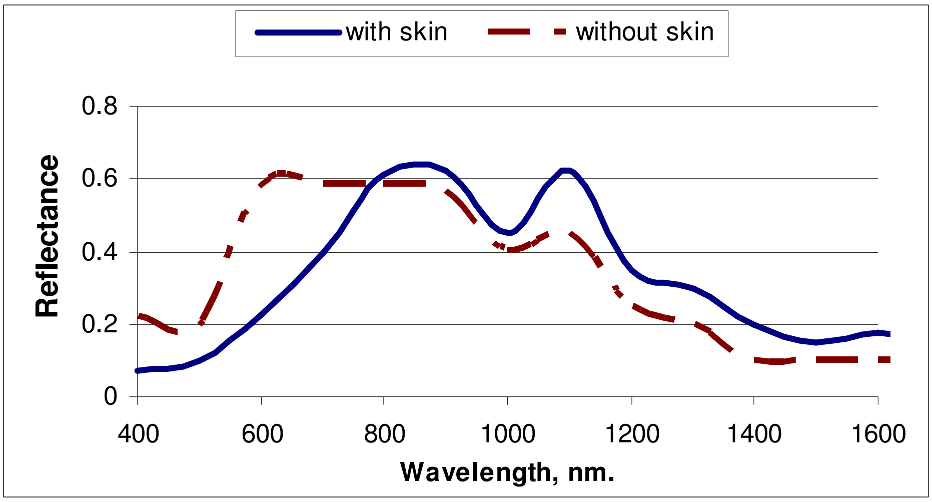

Fig. (2): Wavelength reflectance spectra of potato tubers with and without skin.

2. Potato samples without skin (Test set 1)

The first set (Test 1) was designed to test the Partial Least Square (PLS) calibration models for the potato tubers without-skin. The reflectance of the wavelength range of 400-1750 nm was chosen. From the test set 1, optimal number of factors 5, for the first PLS calibration model established. As shown in Fig. (3), peaks in the wavelength segments of

750-900, 1000-1150 and 1350-1550 nm were found to correspond to the change of water content in potato samples.

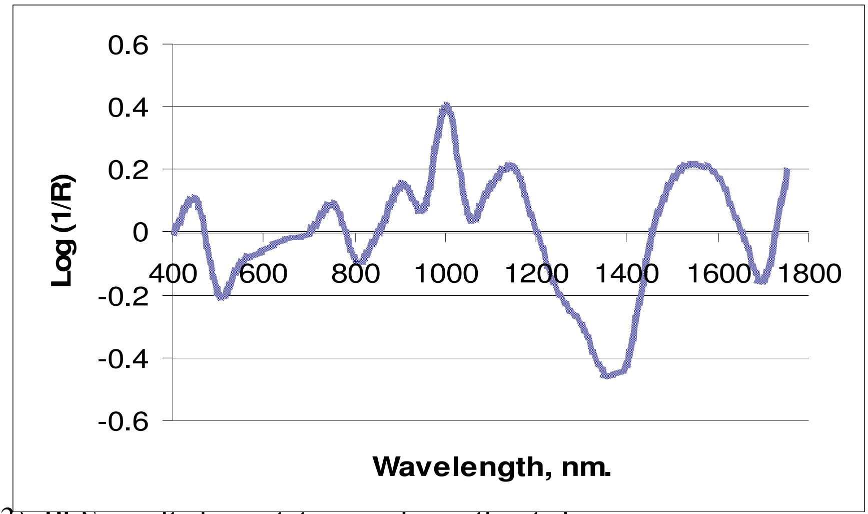

Fig. (3): PLS results for potato samples without skin.

The predicted water content for training and validation set of potato samples without skin using the calibration model established using a wavelength range of 400-1750 nm shown in Fig. (4). The Root Mean Square Error (RMSE) between the actual and predicted water content was found 0.89 and 7.52 for training set and validation set, respectively. The water content in the training set was predicted with R^2 of 0.99 by using the established calibration model.

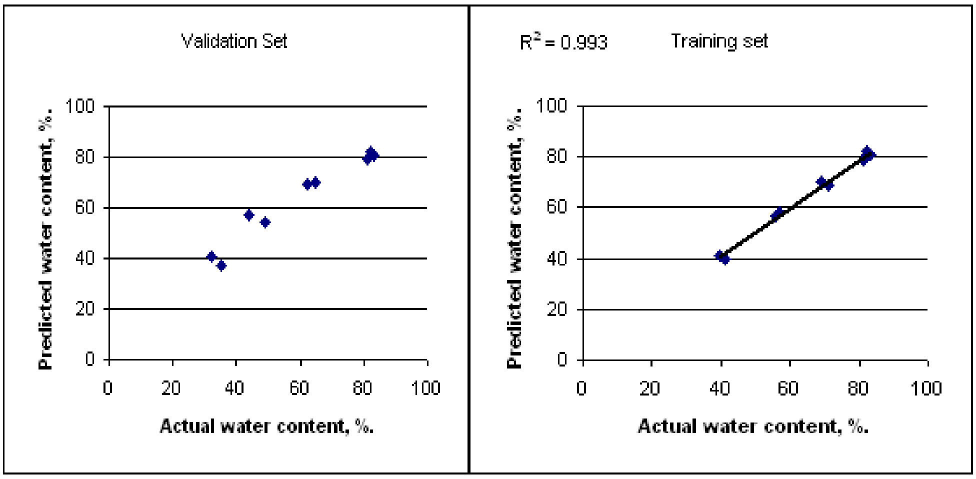

Fig. (4): Predicted water content, actual water content for training and validation set of potato samples without skin (wavelength ranged from 400 to 1750 nm).

On the other hand, Fig. (5). shows the predicted water content for training and validation set of potato samples without skin using the calibration model established based on the reflectance in the wavelength range of 750-900, 1000-1150 and 1350-1550 nm. The RMSE between the actual and predicted water content was found to be 0.925 and 5.893 for training and validation set, respectively. The water content in the training set was predicted with a R^2 of 0.994 by using the established calibration models.

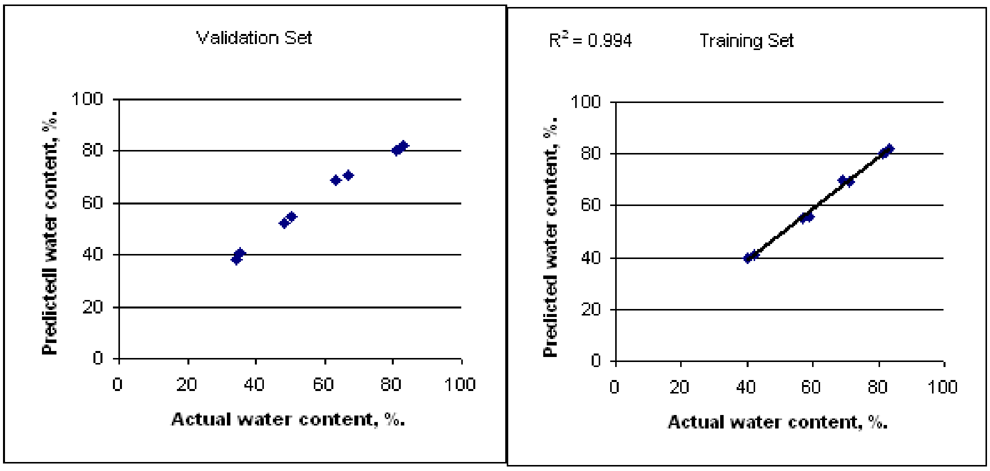

Fig. (5): Predicted water content, actual water content for training and validation set of potato samples without skin (wavelength ranged from 750 to 1550 nm).

3. Potato samples with skin (Test set 2)

The second set (Test 2) was designed to test the PLS calibration models for the potato tubers with skin. Fig**.** (6) shows the Log (1/R) over the wavelength range of 400-1750 nm. From the test set 2, a PLS calibration model was established with the optimal number of factors 10 based on the lowest PRESS value. From Fig. (6) peaks in the wavelength segments of 850-900, 1000-1250 and 1350-1490 nm indicated strong responses to change in water content in potato tubers.

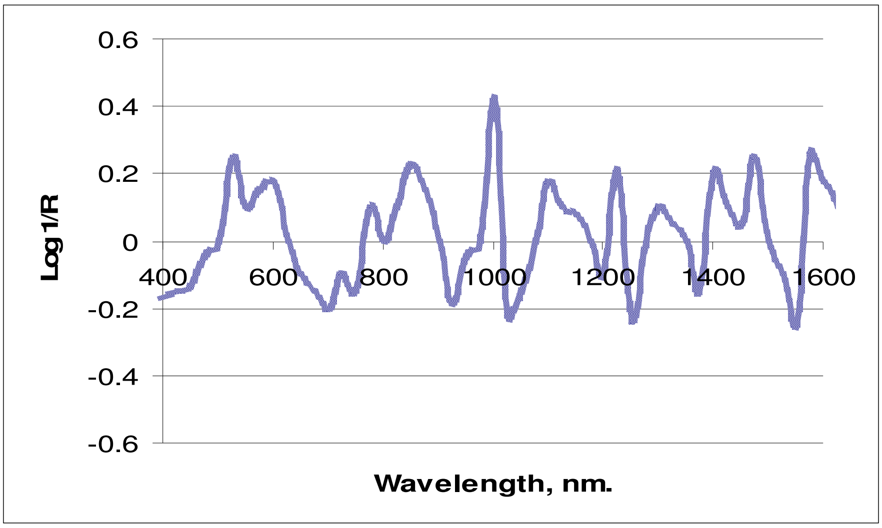

Fig. (6): PLS results for potato tubers with skin.

Fig. (7) shows the predicted water content for training and validation set of potato samples with skin using the calibration model established using a wavelength range of 400-1750 nm and the number of factors of ten. The RMSE between the actual and predicted water content was found to be 0.57 and 2.02 for training set and validation set, respectively. The water content in the training set was predicted with R^2 of 0.99.

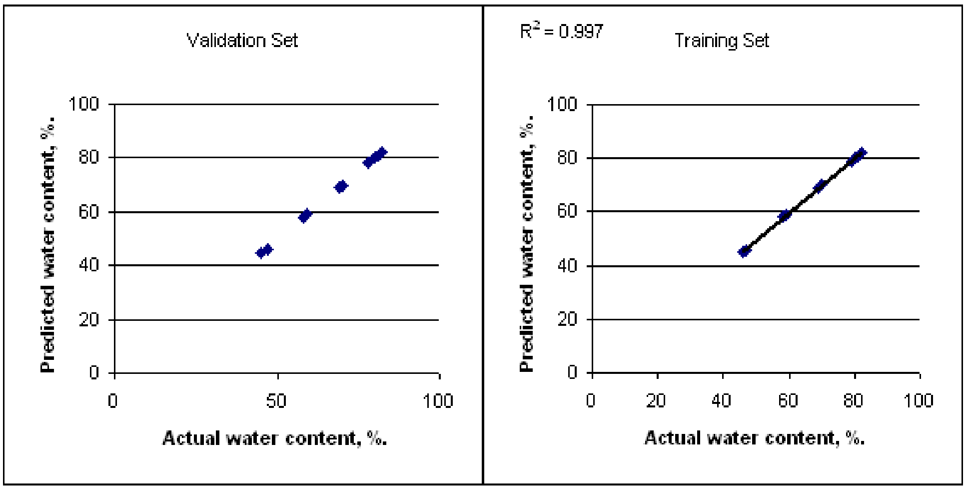

Fig.(7): Predicted water content, actual water content for training and validation set of potato tubers with skin (wavelength ranged from 400 to 1750 nm).

On the other hand, Fig. (8). shows the predicted water content for training and validation set of potato tubers with skin using the calibration model established based on the reflectance in the wavelength range of 750-900, 1000-1250 and 1350-1550 nm. The RMSE between the actual and predicted water content was found to be 0.469 and 0.441 for training and validation set, respectively. The water content in the training set was predicted with a R^2 of 0.997.

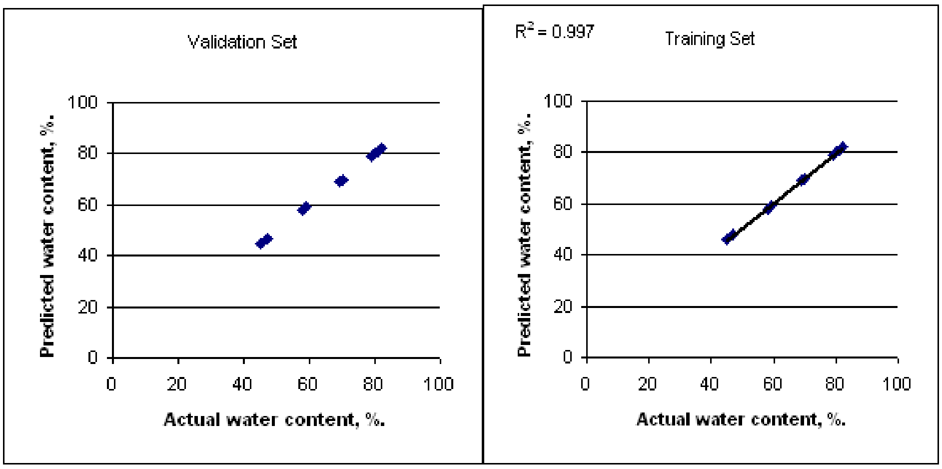

Fig.(8): Predicted water content, actual water content for training and validation sets of potato tubers with skin (wavelength ranged from 750 to 1550 nm).

The prediction capability of four established calibration models and the average water content of potato tubers are summarized in Table (1). For the potato sample without skin, the first two models gave good prediction on training set with small RMSE, while large RMSE for validation set.

Table (1): Summarized results of four calibration models.

Average of potato water content (%)		Wavelength, (nm)	No. of factors	Training set (R^2)	RMSE (%)	
Electric heater	Spectrometer with NIR				Training set (R^2)	Validation set (R^2)
80.13	80.217	Without skin (400-1750)	5	0.993	0.899	7.522
80.32	80.293	Without skin (750-1550)	5	0.994	0.925	5.893
81.35	81.698	With skin (400-1750)	10	0.997	0.576	2.025
82.12	82.348	With skin (750 -1550)	10	0.997	0.469	0.441

For the potato samples with skin, the last two models gave good prediction for both training set and validation set with small RMSE. Fine tuning of these calibration models is needed to reduce RMSE to achieve high accuracy on evaluating water content in potatoes. Both models give almost same results of potato water content. That means, the potato water content can be pridected using either electric heater or spectrometer. On the other hand the only different between the two instruments that, spectrometer is accurate, easy and faster than electric heater.

CONCLUSIONS

In this study, a spectroscopic technique was developed to determine water content in potato. The study demonstrated high accuracy in water content prediction. Partial least squares regression was used to establish calibration models for predicting the water content in potato samples.

The RMSE was found to be lower for validation set in both the experimental test sets using the select wavelength segments, thus giving an indication of higher reliability on the calibration models that used selected wavelength segments. Both models give almost same results of potato water content. That means, the potato water content can be predicted using either electric heater or spectrometer. On the other hand the only different between the two instruments that, spectrometer is accurate, easy and faster than electric heater. For the same amount of potato, the NIR method is easier and faster compared with other methods.

REFERENCES

AOAC, Association of Official Analytical Chemists (2002). Official Methods of Analysis, 17th ed. Association of Official Analytical Chemists, Gaithersburg, Maryland, U.S.A.

Chen, P. and M. Ruiz-Altisent (1996). Assessment of Impact Sensor for High Speed Firmness Sensing of Fruits. Paper No. 96F-003. AgEng96, Madrid, Spain.

Elbatawi I. E. A. and M. T. Ebaid (2006). A New Technique for Grape Inspection and Sorting Classification. Arab Univ. J. Agric. Sci., Ain Shams Univ., Cairo, 14(2) 2006: 555-573.

Elbatawi, I. E. (2008). An Acoustic Impact Method to Detect Hollow Heart of Potato Tubers. Journal of Biosystems Engineering, 100(2)206-213.

El-Raie A. E., H. E. Hassan and A. A. Abd El-Rahman (2003). Optical properties for Tomatoes maturity stages using visible lasers. The 11th Annual Conference of Misr Society of Agr. Eng. 20(4) Oct. 2003 :13-26.

Hecht, J. (1992). The laser guidebook. 2nd ed. McGraw-hill, Inc. N. Y. ISBN O-07-027737-0.:31-37.

Kang, S., K.J. Lee, W. Choi, L. R. Son, D. S. Choi, and G. Kim (2004). A near infrared sensing technique for measuring the quality of potatoes. ASAE Paper. No: 033137. St. Joseph, Michigan, USA.

Lu, R.; D. E. Guyer and R. M. Beaudry (2000). Determination of Firmness and Sugar Content of Apples Using NIR Diffuse Reflectance. J. Texture Studies 31(6): 615-630.

Souci, S. W., W.Fachmann, and H. Kraut, (2000). Food composition and nutrition tables. Medpharm, Scientific Publishers, Stuttgart, Germany. ISBN: 3887630769. pp:639 – 640.

The annual statistics book (2005). Ministry of Agriculture, Agricultural Research Center, Egypt. :1-4.

Yeh, R. S., R. C. Anantheswaran, J. Shenk, and V. M. Puri. (1994). Determination of moisture profiles in food during microwave heating using VIS/NIR spectroscopy. Lebensm. – Wiss. U. – Technol., 27 :358 – 362.

الملخص العربى

تقدير المحتوى المائى للبطاطس باستخدام خاصية انعكاس الاشعة

ابراهيم السيد البطاوي[1] **محمد طه عبيد**[1] **بهاء الدين حميدة**[2]

تحتل البطاطس مركزا هاما بين المحاصيل الغذائية فى كثير من دول العالم، كما انها من ناحية القيمة الغذائية تعتبر البديل الاول لمحاصيل الحبوب فى حل مشكلة الغذاء. وفى مصر يعتبر محصول البطاطس من محاصيل الخضر الرئيسية لما لها من أهمية تصديرية وكذلك لما لها من استخدامات عديدة فى كثير من الصناعات الغذائية، حيث يزرع منها سنويا حوالى 200.000 فدان تعطى أنتاجية كلية تقدر بحوالى 2 مليون طن/سنة (كتاب الاحصائيات السنوية، 2005).

وفى هذة الدراسة تم محاولة التوصل للمحتوى المائى فى محصول البطاطس (صنف ديامونت) بالقشرة وبدون قشرة باستخدام طريقتى الفرن الكهربائى وخاصية انعكاس الاشعة تحت الحمراء (spectroscopy with NIR) بطول موجى يتراوح مابين 400-1750 nm .

ومجاميع الطول الموجى الهامة هى 750-900، 1000-1150، 1350-1550 nm للاختبار الاول (درنة البطاطس بدون قشرة) و 750-900، 1000-1250، 1350-1550 nm، للاختبار الثانى (درنة البطاطس بالقشرة)، كما أختيرت هذه الاطوال الموجية لعمل نموذج معايرة للتنبؤ بالمحتوى المائى فى عينات البطاطس.

وقد وجد أن قيم R^2 للمحتوى المائى المتوقع، والمحتوى المائى الحقيقى المقاس لـ Training set باستخدام مجاميع الطول الموجى الهامة 750-900، 1000-1150، 1350-1550 nm للاختبار 1 (بدون قشرة) كان 0.994 ، وللاختبار 2 (بالقشرة) ووجد ان قيم R^2 للمحتوى المائى المتوقع، والمحتوى المائى الحقيقى المقاس لـ Training set باستخدام مجاميع الطول الموجى الهامة 750-900، 1000-1250، 1350-1550 nm هو 0.997.

كما وجد أيضا أن الخطأ المتوسط اقل فى حالة مجموعة المقارنة (Validation set) والتى تستعمل الطول الموجى المناسب (أوالمؤثر)، وهذا يعطى الاشارة للثقة فى نموذج المعايرة للتنبؤ بالمحتوى المائى فى عينات البطاطس الذى تم اختياره واستعمل فيه مجموعات الطول الموجى المختارة سابقا.

وقد اوضحت الدراسة انه ليس هناك فروق معنوية كبيرة واضحة فى احدى الطريقتين ولكن الفرق فقط فى وقت وطريقة ودقة قياس المحتوى المائى. حيث وجد أنه لنفس كمية البطاطس المطلوب قياس محتواها المائى باستخدام طريقة انعكاس الاشعة تحت الحمراء (spectroscopy & NIR) فانها تستغرق دقائق معدودة مقارنة بالطريقة التقليدية (الفرن الكهربائى).

---

(1)باحث أول بمعهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – الجيزة – مصر.

(2) باحث بمعهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – الجيزة – مصر.