Non-destructive approaches for quality evaluation of eggplant (*Solanum melongena* L. cv. Traviata)

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A thesis submitted to the Graduate and Postdoctoral Office
in partial fulfillment of the requirements for the
degree of Master of Science

December 2013

Abstract

The goal of this study was to examine the use of non-destructive compression tests, and hyperspectral imaging for determining physical quality attributes of eggplant (*Solanum melongena* L. cv. Traviata). The effects of source (farms where samples came from), light and temperature conditions during storage were studied. Non-destructive compression tests were conducted to obtain surface stiffness (S) parameter whereas the hyperspectral-imaging technique was used in the near infrared (NIR) spectral range (900-1,700 nm), to indicate the peel gloss (G) of fresh and stored eggplants. Eggplant density (D) was computed by dividing its weight (W) by its volume (V). Laboratory tests were carried out to develop a freshness index for an American variety of eggplant fruit (*Solanum melongena* L. cv. Traviata). It was determined that source (farm) was a highly significant factor on quantitative and qualitative quality parameters. Light and temperature conditions had as well significant impact on such parameters, and their respective ratios, at different storage periods. Surface stiffness and peel gloss decreased during postharvest storage. On the contrary, density increased significantly over time. Based on this, a freshness index (I_f) of eggplant was defined as the product of surface stiffness and peel gloss ratios divided by the density ratio.

I_f was then plotted vs. mass, density, surface stiffness, and peel gloss ratios, and storage period (h) in order to apply kinetic approaches to fit models with which it was possible to predict such index. The values of correlation coefficient (CC) and Mean Square Error (MSE) were assessed to see how well the curves fitted. I_f as a function of surface stiffness loss (SL) was the best model; it showed the highest CC (0.99) and the lowest MSE values (0.0014). The least accurate predictor was I_f as a function of peel gloss loss (GL). Stepwise regressions were performed to determine which wavelengths were significant for I_f. The models built with such wavelengths for fruits stored at 10 and 27°C showed CC values of about 0.73 and 0.90, respectively. Freshness index is a concept that may be helpful to avoid over or underestimations of eggplant quality and, hence, to fix fair prices. Nevertheless, more varieties of eggplant should be studied to validate this concept. More temperature conditions should be studied in the future in order to apply the Arrhenius' equation.

Résumé

Des essais en laboratoire ont été effectués pour développer un indice de fraîcheur pour une variété américaine d'aubergine (*Solanum melongena* L. cv. Traviata). Des essais de compression non destructifs et d'imagerie hyperspectrale dans le proche infrarouge (NIR, 900 à 1 700 nm), ont été réalisées pour mesurer la fermeté (S) et la brillance de la peau des aubergines fraîches et entreposées sous différentes conditions de luminosité et de température). La densité de fruit (D) a été calculée en divisant la masse (W) par le volume (V). Il a été démontré que la provenance des fruits (ferme) a été un facteur important qui a affecté les paramètres quantitatifs et qualitatifs. La lumière et la température ont aussi eu un impact sur ces paramètres et de leurs rapports respectifs, à des périodes d'entreposage différentes. Les paramètres S et G ont diminué au cours de l'entreposage post-récolte, tandis que le paramètre D a augmenté de façon significative au cours de la période d'entreposage. Sur cette base, un nouvel indice de fraîcheur (I_f) de l'aubergine a été défini comme étant le produit du rapport de fermeté de la surface (S_r) et le rapport de pelage brillant (G_r), divisé par le rapport de densité (D_r).

Par la suite, les relations entre I_f et les paramètres W_r, D_r, S_r, et G_r, et la période de stockage (*t*) ont été établies en tenant compte de la cinétique (loi d'Arrhenius) ont permis d'établir des modèles permettant de prédire cet indice. Les valeurs du coefficient de corrélation (CC) et l'erreur quadratique moyenne (MSE) ont été évalués pour identifier les meilleurs modèles. Le modèle exprimant I_f en fonction de la perte de rigidité de la surface (SL; 1 – Sr) était le meilleur modèle avec la plus haute valeur de CC (0,99) et la plus basse valeur de MSE (0,0014). Le modèle le moins précis était lorsqu'on exprimait I_f en fonction de la perte de brillance de la peau (GL; 1 - G_r). Régressions par étapes ont permis d'identifier les longueurs d'onde les mieux corrélées à l'I_f. Les modèles construits avec de ces longueurs d'onde pour les fruits entreposés à 10 et 27°C étaient caractérisés par des valeurs de CC 0,73 et 0,90, respectivement. Indice de fraîcheur est un concept qui peut être utile pour éviter de sous-estimer la qualité des aubergines et, par conséquent, de fixer des prix équitables. Néanmoins, plusieurs variétés d'aubergines doivent être étudiés afin de valider ce concept. De plus, plus de températures doivent être étudiées afin d'accroître la précision des modèles prédicatifs basés sur la loi d'Arrhenius.

Acknowledgements

I want to thank my supervisor, Professor Michael Ngadi, for offering me the space and equipment from his lab that were essential to conduct my experiments for this work. I also want to thank him for his guidance throughout this research.

It is my pleasure to thank the Consejo Nacional de Ciencia y Tecnología (CONACYT), the Mexican institution that sponsored my University fees and my expenses in Montreal. Without them, none of this would have been possible.

I want to express my heartfelt gratitude to Timothy Schwinghamer, who spent hours on the statistical analyses, and Dr. Akinbode Adedeji for correcting and editing this piece of work. My dear friend, Hui Huang, thank you very much for teaching me part of what you knew about the hyperspectral-imaging technique. Yvan Gariepy, thanks a lot for helping me with respect to the use of the Instron machine, and for writing my French Abstract. Dr. Leroy Phillip, thank you for providing the funds needed to carry out this project. I also like to thank Lauren Rathmell, from LUFA farms, for giving me (for free!), during the winter, fresh eggplant fruits that were used in the preliminary work of my experiments.

My parents, Alicia Martínez and Arturo Mayorga; it is because of you that I could get to where I am now. You provided the resources for me to get all the previous education required to accomplish this degree. Thank you so very much! I dedicate this to you. ¡Los amo!

A.A. Mayorga

Contribution of Authors

This thesis comprises of two manuscripts, both of which I am the primary author. I conducted the research work, collected data, analyzed the data and wrote the manuscripts. My supervisor, Dr. Michael Ngadi is also an author in both manuscripts. He provided overall guidance and concepts for the work as well as reviewed the manuscripts. In the first manuscript, Timothy Schwinghamer (PhD candidate from Plant Science Department at McGill University) had direct participation in the statistical analyses of the results during my thesis research work. His contribution was not merely technical, because his analysis required decision-making regarding the better fitting models, and interpreting the meaning and significance of the model parameters. Dr. A. Adedeji assisted in editing my writing.

An abstract of chapter 5 has been accepted for presentation at the 2014 American Society of Agricultural and Biological Engineers (ASABE) Annual International Meeting. Chapters 4 and 5 will be submitted for publication on a scientific publication in food engineering area in 2014.

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Nomenclature

°C	— Celsius degrees
1-MCP	— 1-Mthylcyclopropene
B	— Dark Image
CC	— Correlation Coefficient
cm	— Centimeter
cv.	— Cultivar
d	— Day
D	— Density (in $kg \cdot m^{-3}$)
D_{max}	— Maximum Diameter (in mm)
D_r	— Density Ratio
DRMO	— Density Ratio Minus One
Eq.	— Equation
FAO	— Food and Agriculture Organization of the United Nations
ft	— Foot/Feet
g	— Gram
G	— Gloss (dimensionless)
G_0	— Initial gloss (dimensionless)
GL	— Peel Gloss Loss
G_r	— Gloss ratio
h	— Hour
Ha	— Hectare
HPLC	— High Performance Liquid Chromatography
I_0	— Original spectral image
I_f	— Freshness index (dimensionless)
IS	— International System of Units
I_s	— Peel gloss
kg	— Kilogram
kPa	— Kilopascal
L	— Lightness
m	— Meter

MD	— Modulus of Deformability (in $N \cdot mm^{-1}$)
mg	— Milligram
min	— Minute
mL	— Milliliter
mm	— Millimeter
MSE	— Mean Square Error
N	— Newton
NIR	— Near Infrared
nm	— Nanometer
ORAC	— Oxygen Radical Absorbance Capacity
p	— p-Value
PHL	— Postharvest Losses
ppm	— Parts per Million
PVC	— Polyvinyl Chloride
RH	— Relative Humidity
ROI	— Region of Interest
s	— Second
S	— Stiffness (in N·m-1)
S_0	— Initial Stiffness (in N·mm-1)
SC	— Storage Condition
SL	— Surface Stiffness Loss
S_r	— Stiffness Ratio
t	— Time (in h)
USD	— American dollars
vs.	— Versus
W	— White Image
WL	— Water Loss or Weight Loss
α	— Confidence Limit
λ	— Wavelength (in nm)
µm	— Micrometer
µmol	— Micromole
ρ	— Density (in $kg \cdot m^{-3}$)
ρ_0	— Initial Density (in $kg \cdot m^{-3}$)

I. General Introduction

1.1. Overview

Eggplant (*Solanum melongena* L.) is an economically important vegetable crop that is usually grown in the tropics and subtropics. It is of South Asian origin and belongs to the Solanaceae family (Alam et al., 2006). Its world production was estimated to be 46.8 million tons in 2011, with China and India as the largest producers (FAOSTAT, 2013).

Eggplant is an inexpensive but major food component of the human diet in many developing countries (Naujeer, 2009). Its close relatives, the Gnoma (*Solanum macrocarpon* L.), and Scarlet African (*Solanum aethiopicum* L.) eggplants, are the most popular native traditional vegetables in West and Central Africa (Sekara et al., 2007). Eggplant is a source of vitamins and minerals, but its growing reputation in many countries is due to the fact that it is a good source of antioxidants (anthocyanins and phenolic acids), which have beneficial effects on human health (Gajewski et al., 2009). Eggplant is among the top vegetables in terms of oxygen radical absorbance capacity (ORAC) (Cao et al., 1996). This is why it has been employed in traditional medicine for treatment of many diseases (Khan, 1979; Kashyap et al., 2003).

Fruit shape, size, colour, and taste are the most noticeable features that differ among the related species and wild types of eggplant (Frary et al., 2007). The violet or dark purple varieties are the most popular in the market (Sadilova et al., 2006). The fruit should be harvested for consumption at a physiological non-mature stage — when they are already developed, but the seeds are still soft (Gajewski and Arasimowicz, 2004). Over matured fruit on the plant is related to the development of unattractive attributes in eggplant, such as bitter flavours, opaque skin, and floppy flesh (Maynard, 1987; Mohammed and Brecht, 2003).

Quality, as determined by proper physical, biochemical, and edible conditions, cannot be improved after harvest, but its maintenance may be attempted (Prusky, 2011). The higher the standard set by the consumer, the greater the potential for quality losses will be (Boxall, 2001). For the producer, quality includes disease resistance, high yield, uniform maturity, desirable size, and ease of harvest (Kader, 1996); thus harvesting crops at the optimal stage of development is very important. For instance, it is recommended for eggplant to be harvested when it reaches 80% of its total size on the plant, because at this stage it reaches its maximum concentrations of sugars, ascorbic acid, and phenolic compounds (Maynard, 1987). Besides, undesirable changes, as mentioned above, such as bitterness, opaque colour, soft texture, and decay, begin to occur.

Eggplant is highly perishable. It is not good for it to be stored for long periods. It is a non-climacteric fruit, which means that ethylene is not crucial for its ripening control. However, calyx abscission and increased deterioration could be a problem if eggplants are exposed to > 1 ppm ethylene during distribution and short-term storage (Cantwell and Suslow, 1997). The shelf life of eggplant is between 2 and 4 days when held at temperatures above 25°C (Mohammed and Sealy, 1986; Jha and Matsuoka, 2002). In order to make agriculture feasible, it is necessary to develop appropriate postharvest technologies to increase the shelf life of fruits, vegetables, and other horticultural crops. For example, the application of cool temperatures can increase the shelf life of eggplant up to 2-3 weeks, although, since this crop is very susceptible to chilling injury, refrigeration is not recommended. Eggplant should not be stored for long periods at temperatures below 7-10°C (Concellón et al., 2007). In addition to postharvest technologies, there are studies proving that by wrapping eggplant with films of different materials and/or by applying thin layers of wax on the peel, moisture losses during storage can be reduced. By preventing eggplants from losing water, the rate of other deterioration signs (e.g. fruit shrivelling, flesh softening, gloss losses) decreases significantly. By developing appropriate postharvest technologies, not only postharvest losses (PHL) will be reduced; the fluctuation of prices would as well decrease (Antunes et al., 2007).

PHL is a term that refers to the loss in measurable attributes of quantity and quality of foods in the postharvest system (De Lucia and Assennato, 1994). Both quantitative (weight or volume) and qualitative (changes in colour, firmness, and/or other physical characteristics) losses can occur at any point in the postharvest distribution chain (Hodges et al., 2011). A postharvest distribution chain differs from one country (or even region) to another. Crops may go from farmers (producers) to farmers' markets, and/or from farmers' markets directly to the consumer. However, crops may also follow other pathways that can be more complicated. For instance, since there is globalization of the markets, crops may go from produce farms to shippers, and these shippers may take the produce to a foreign country and/or to a national integrated wholesale — retailer. The magnitude of PHL is different in each link of the postharvest distribution chain. Hodges et al., (2011) illustrate an example of how the magnitude of weight and quality losses varies along the postharvest chain for rice in South Asia. The losses accumulated until the stage of consumption for rice in South Asia ranges from 10 to 30% (loss in value). High PHL mean low profit and high prices, which obviously lead to lower consumption (Antunes et al., 2007).

In order to reduce PHL, it is essential, first, to map PHL along the postharvest distribution chain; then, to develop proper techniques to be able to measure them; and finally, to develop appropriate techniques to increase the shelf life of the horticultural crops. The PHL in developing countries can be as high as 50% (FAO, 1997). Mazaud (1997), in Prusky (2011), stated that, although rough estimations of PHL exist, there are no universal techniques to measure them objectively.

Decisions concerning time of harvest, maturity, ripeness, and quality are based mostly on subjective and visual inspection of the fruit's external appearance. Kader (2010) suggests a general rating scale (that goes from 1 to 9, 9 being the best) to determine the overall quality of horticultural crops. It is stated that 5 is the minimum value for any crop to be accepted in a marketing system. The quality of horticultural crops is mostly based on size, shape, colour, gloss, flavour, firmness, texture, taste, and freedom from external and internal defects (Jha and Matsuoka, 2000). So, a high quality eggplant should be dark purple, glossy, and firm; besides, it should have a dark green calyx and stem. An eggplant with these characteristics would receive a 9 in the scale that Kader proposed. Nevertheless, for being subjective, Kader's scale depends on the perception of each individual; therefore, there are chances for the quality and, hence, the price of eggplant to be under or overestimated. For this reason, it is beneficial to develop objective techniques to assess quality. In this study, a non-subjective freshness index of an American variety of eggplant was developed, and predicted with kinetic approaches and with spectral data collected from hyperspectral images in the near infrared (NIR) range of the fruits. An American variety was chosen not only because it is the most consumed variety of this crop in the Americas (Lawande and Chavan, 1998), but also because objective freshness indexes have not been developed for this type of eggplant.

1.2. Thesis Structure

This thesis report has six chapters. The first chapter elucidates the present scenario of eggplant economic importance in the world, the existing problems in determining its quality during postharvest stages, and the importance of developing objective methods to measure its quality losses. The second chapter states the hypothesis, and the general goal with emphasis on specific objectives of the study. A brief history of eggplant, as well as a detailed description of its quality changes during the postharvest distribution chain, and review of earlier work in this area of research are presented in Chapter 3. An evaluation of quality and quantity losses of eggplant from different farms (by carrying out non-destructive experiments) at various storage conditions is reported in Chapter 4. The fifth chapter describes the development of a non-subjective freshness index that could be a useful tool for producers and consumers to avoid under or overestimations of quality and, hence the price of eggplant fruit. Finally, Chapter 6 abridges the conclusions derived from this work.

1.3. Scope of the Study

The present research aims at exploring the use of non-destructive compression tests, and hyperspectral imaging as tools to determine physical quality features of eggplant (e.g. surface stiffness and peel gloss). It was also envisioned to study the effect of source (farms where *S. melongena* come from), and light and temperature conditions on both qualitative and quantitative losses of eggplant during postharvest storage.

The results from this study are expected to be beneficial for both producers and consumers because the freshness index that was developed is objective (the chances of either under — or over — estimations of quality are reduced), and it may be used for fixing fair prices. By doing so, wastes of eggplant can be reduced, too. Similar methodologies could be applied on other fruit or vegetable crops.

References

Alam, S.N., Hossain, M.I., Rouf, F.M.A., Jhala, R.C., Patel, M.G., Rath, L.K., Sengupta, A., Baral, K., Shylesha, A.N., Satpathy, T.M., Shivalingaswamy, T.M., Cork, A., and Talekar. N.S. 2006. Implementation and promotion of an IMP strategy for control of eggplant fruit and shoot borer in South Asia. Technical bulletin No. 36. AVRDC publication number 06-672. AVRDC — The World Vegetable Center, Shanhua, Taiwan. 74 pp.

Boxal, R.A. 2001. Postharvest losses to insects — a world overview. International Biodeterioration & Biodegradation. 48: 137-152

Cantwell, M., and Suslow, T.V. 1997. Eggplant: recommendations for maintaining postharvest quality. Available online at:

http://postharvest.ucdavis.edu/pfvegetable/Eggplant/. Accessed on November 16th, 2012.

Cao, G., Sofic, E., and Prior, R.L. 1996. Antioxidant capacity of tea and common vegetables. J. Agric. Food Chem. 44: 3426–3431.

Concellón, A., Añón, M.C., and Chaves, A.R. 2007. Effect of low temperature storage on physical and physiological characteristics of eggplant fruit (Solanum melongena L.). LWT 40: 389-396

De Lucia, M., and Assennato, D. 1994. Agricultural Engineering in Development: post-harvest operations and management of foodgrains. FAO Agricultural Services Bulletin No. 93. Rome: FAO

FAO (Food and Agriculture Organization of the United Nations). 1997. Estimated postharvest losses of rice in Southeast Asia. Available online at: http://www.fao.org/News/FACTFILE/FF9712-E.HTM. (July 16, 1997).

FAOSTAT (Food and Agriculture Organization of the United Nations). Accessed June 2013. http://faostat.fao.org.

Frary, A., Doganlar, S., and Daunay, M.C. 2007. Eggplant. In: Genome mapping and molecular breeding in plants. Volume 5 Vegetables. C. Kole Edition. Editor: Shreck, S. Germany. Springer Berlin Heidelberg New York. 287-313. 408 pp.

Gajewski, M., and Arasimowicz, D. 2004. Sensory quality of eggplant fruits (Solanum melongena L.) as affected by cultivar and maturity stage. Pol. J. Food Nutri. Sci. 13/54, No 3: 249-254

Gajewski, M., Katarzyna, K., and Bajer, M. 2009. The influence of postharvest storage on quality characteristics of fruit of eggplant cultivars. Not. Bot. Hort. Agrobot. Cluj 37: 200-205.

Hodges, R.J. Buzby, J.C. & Bennett B. 2011. Foresight Project on global food and farming futures Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. Jouran of Agricultural Science. 149: 37-45

Jha, S.N., and Matsuoka, T. 2000. Review: Non-destructive techniques for quality evaluation of intact fruits and vegetables. Food Sci. Technol. Res. 6(4): 248-251

Kader, A.A. 1996. Maturity, ripening, and quality relationships of fruit-vegetables. Strategies for Mark. Orient. Greenhouse Production. Eds. A.F. Abou-Hadid, R.A. Jones. Acta Hort. 434.

Kader, A.A. 2010. Produce quality rating scales and color charts. Postharvest

Horticulture Series No. 23-CD. Second Edition. Postharvest and Technology Research and Information Center, UC Davis.

Kashyap, V., Kumar, S., Collonier, C., Fusari, F., Haircour, R., Rotino, G.L., Sihackak, R.D., and Rajam, M.V. 2003. Biotechnology of eggplant. Scientia Hort. 97(1): 1-25.

Khan, R. 1979. Solanum melongena and its ancestral forms. In Hawkes J.C., Lester J.G., and Skelding, A.D. (ed.) The biology and taxonomy of the Solanaceae: 629-638. Linnean Society of London academic Press, London, UK.

Lawande, K.E., and Chavan, J.K. 1998. Eggplant (Brinjal). In: Handbook of vegetable science and technology. Production, composition, storage, and processing. Salunkhe, D.K., and Kadam, S.S. Eds, New York: 225-244.

Maynard, D. N. 1987 Commercial vegetable cultivars for Florida. Univ. Of Florida Coop. Ext. Serv., IFAS, Circular 530.

Mazaud, F. 1997. Food and Agriculture Organization of the United Nations (FAO), Agro-Industires and Postharvest Management Service, Rome.

Mohammed, M., and Brecht, J.K. 2003. Immature Fruit Vegetables. In: Postharvest Physiology and Pathology of Vegetables. Second Edition. Editors: Bartz, J.A. and Brecht J.K. New York Basel. Marcel Dekker, Inc. 671-690. 773 pp.

Mohammed, M., and Sealy. 1986. Extending the shelf life of melongene using polymeric films. Trop. Agr. 63:36-40.

Naujeer, H.B. 2009. Morphological diversity in eggplant (Solanum melongena L.), their related species and wild types conserved at the National gene bank in Mauritius. MA thesis, Swedish Biodiversity Centre. (Publication No. 57).

Prusky, D. 2011. Reduction of the incidence of postharvest quality losses, and future prospects. Food Sec. 3: 463-474.

Sadilova, E., Stintzing, F.C., and Carle, R. 2006. Anthocyanins, colour and antioxidant properties of eggplant (Solanum melongena L.) and violet pepper (Capsicum annuum L.) peel extracts. Z. Naturforsch. 61c: 527-535

Sekara, A., Cebula, S., and Kunicki, E. 2007. Cultivated eggplants – origin, breeding objectives and genetic resources, a review. Fol. Hort. 19 (1): 97-114.

II. Experimental Design, Hypotheses and Objectives

2.1. Experimental Design and Statistical Analysis

Generalized linear mixed models, with covariance structure based on time, were produce in SAS to analyze the data because the experiments that were carried out had repeated measures. Mixed linear models are used with repeated measures data to accommodate the fixed effects of treatment and time and the covariation between observations on the same subject at different times (Littell et al., 2000). Cnaan et al., (1997) extensively discussed the use of the general linear mixed model for analysis of repeated measures and longitudinal data.

In the experiments, three factors, with two levels each, as shown in section 4.3.2 of this thesis, were taken into consideration. This gives a total of 6 treatments. The number of replicates per treatment was chosen to be 6. Jha and Matsuoka (2002a and 2002b) and Jha and Matsuoka et al., (2002) carried out their experiments with 5 eggplants per treatment. However, we decided to use 6 replicates in case there were outliers. Since it was an experiment with repeated measures, as mentioned above, storage period was also a factor that was taken into account.

Kinetic models were used to describe the changes in the freshness index when plotted versus different parameters, such as mass, density, peel gloss and surface stiffness ratios, and storage period. Stepwise regressions were carried out to find the significant wavelengths from the near infrared range (NIR) to build a predictive model for the freshness index of eggplant that was developed.

2.2. Hypotheses

The first hypothesis of this work was that the changes in mass, volume, density, peel gloss, and surface stiffness of eggplant, during different storage conditions, could be used to develop an index with which it was possible to measure objectively the overall quality of the fruit.

Another hypothesis was that factors, such as light and temperature conditions, and source of the fruit, were going to have a significant effect on the freshness index over storage period.

A third hypothesis was that kinetic models (freshness index as a function of mass, density, surface stiffness and peel gloss ratios, and storage period; as well as hyperspectral data) could be significant to describe and predict such index.

2.3. General Objectives

The general objective of this research was to evaluate the quantity (mass, volume, and density) and quality (peel gloss and surface stiffness) losses of eggplant from different farms, during postharvest storage, at different light and temperature conditions, by conducting efficient and non-invasive methods (mass, volume, and density recording, non-destructive compression tests, and hyperspectral imaging technique in the NIR range) in order to develop a freshness index.

Specific objectives were stated as follows:

1. To study the effects of light and temperature conditions during storage on water and volume losses, and density changes of eggplants.
2. To study the influence of light and temperature conditions on quality namely surface stiffness and surface gloss of eggplant during storage.
3. To assess the use of hyperspectral imaging in the NIR range as a technique for measuring surface gloss of eggplant.
4. To develop a freshness index as an objective method of defining quality of eggplants.
5. To establish hyperspectral-imaging technique in the NIR range and kinetic approaches as methods to predict the freshness index of eggplant.

The freshness index developed in this study —which is based on parameters such as surface stiffness, peel gloss, and density of the fruit— is an objective measure of the general eggplant quality. The main advantage of the freshness index is that wastes of this extremely perishable crop could be reduced, because fruits that are still edible would not be discarded as much. However, in order to succeed in reducing wastes, the prices of eggplants should be adjusted according to its freshness index, which can be easily predicted with the models that were developed in this research.

References

Cnaan, A., Laird, N.M., and Slasor, P. 1997. Using general linear mixed model to analyze unbalanced repeated measures and longitudinal data. Statistics in Medicine. 16: 2349-2380.

Jha, S.N. and Matsuoka, T. 2002a. Surface stiffness and density of eggplant during storage. Journal of Food Engineering. 54: 23-26.

Jha, S.N., and Matsuoka, T. 2002b. Development of freshness index of eggplant. Applied Engineering in Agriculture. 18(5): 555-558.

Jha, S.N., Matsuoka, T., and Miyauchi, K. 2002. Surface gloss and weight of eggplant during storage. Biosystems Engineering. 81(4): 407-412.

Littell, R.C., Pendergast, J., and Natarajan R. 2000. Tutorial in Biostatistics: modelling covariance structure in the analysis of repeated measures data. Statistics in Medicine. 19: 1793-1819.

III. General Literature Review

3.1. A Brief History of Eggplant

Eggplant (*Solanum melongena* L.) is a native plant species of South Asian origin (Alam et al., 2006). It is indigenous to a vast area stretching from northeast India and Burma, to Northern Thailand, Laos, Vietnam and Southwest China (Fig. 3.1) (Daunay and Janick, 2007; Naujeer, 2009). The wild *Solanum* species of eggplant fruit types are round green berries, 3-5 cm in diameter (Frary et al., 2007). Eggplant fruit was domesticated in the Indo-Burma region with indications that it was cultivated in antiquity (Daunay and Janick, 2007). Early agricultural, botanical, and medicinal documents described not only the morphology of eggplant, but also its uses and properties. The domestication of this crop involved dramatic expansion of fruit size, shape, and colour diversity, and also decreases in plant prickliness and fruit bitterness (Frary et al., 2007). Wild eggplant can still be found in the area formerly known as Indo-China. Some modern cultivars from this region have fruits that are reminiscent of wild *Solanum* species fruit types.

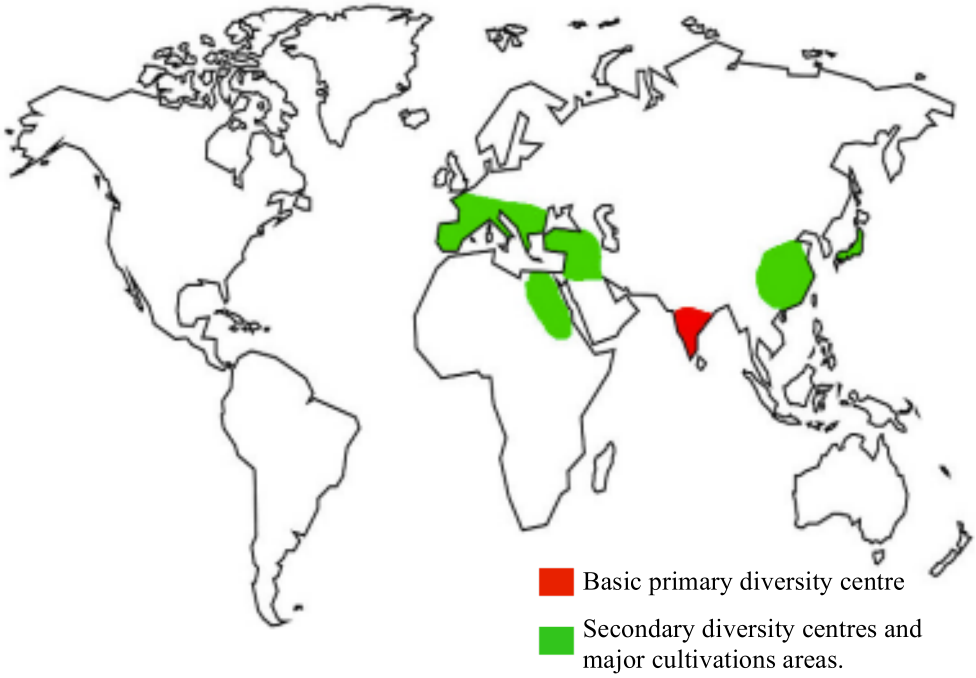

Fig. 3.1 Primary and secondary diversity centres of eggplant (*Solanum melongena* L.) (Naujeer, 2009)

From its Indo-Burma origin and domestication, eggplant spread further east to Japan, and west, probably at the time of Muslin conquests (Frary et al., 2007). Arab traders took it to Spain; the Spaniards took it to the Americas; and the Persians to Africa (FAO, 2013).

Both the plant and the fruit are commonly called eggplant, although the fruit receives many other names, such as *brinjal* in India, and aubergine in England. The word 'eggplant' in English dates to the British occupation of India, where white egg-shaped fruits were very popular in some areas (Daunay and Janick, 2007). Common names usually relate to the resemblance of the fruits with eggs, such as *Eierfrucht* (German), and *plante aux oeufs* (French). Plenty of other vernacular names are just transliterations from Sanskrit, to Persian, Arabic and Turkish, and later to European languages.

3.2. Botanical Description of Eggplant

S. melongena is commonly known as a vegetable, but, botanically, it is categorized as a fruit (Luthria, 2012). Eggplant belongs to the nightshade family, Solanaceae. This family is ranked as third in economic importance; it comprises many morphologically different domesticated crop species that are beneficial to human health, diet, beauty and ornamental use (Mueller et al., 2005; Sekara et al., 2007). Eggplant belongs to the tribe Solaneae, which includes cultivated species such as potato (tuberous *Solanum* sp.), tomato (*Solanum Lycopersicum* sp.), *Physalis* and *Cyphomandra* species, and pepper (*Capsicum* sp.) (Daunay et al., 2001). Eggplant and its related species belong to subgenus *Leptostemonum*, which includes almost one third of the species within the genus *Solanum* (Frary et al., 2007).

The plant is woody and develops several branches according to a roughly dichotomic ramification pattern. Anthocyanins, prickles and hairiness on vegetative parts vary significantly. The flowers may be single or multiple with five calyx-lobes and purple-violet corollas. Inflorescences are 1 to 5 andromonoecious cymes, although most modern cultivars display solitary hermaphrodite flowers. The basic flower type is 5-merous (5 sepals, 5 petals, 5 stamens) but 6, 7 and 8-merous flowers are commonly found in globosely and round fruited types (Frary et al., 2007).

The fruits are berries of highly variable shape (round, intermediate, long, snake-like) and size (fruit may vary from 4 to 45 cm, and thickness between 3 and 35 cm in diameter, with a weight ranging from 0.5 to 1500 g) (Frary et al., 2007; Swarup, 1995). The absence or presence, as well as the distribution pattern of two kinds of pigments, chlorophylls and anthocyanins, control a wide diversity of fruit colours (Daunay et al., 2004). The colour ranges from shiny purple to white, green, yellow and black, often with stripes and patches on the skin.

3.3. Economic Importance of Eggplant

Eggplant is cultivated worldwide today, and it is available in street markets of less developed nations and supermarkets of developed countries. In 2011, 1.8 million hectares (Ha) of land were used, worldwide, to produce 46.8 million tons of eggplant fruit, obtaining a yield of about 26,000 kilograms per hectare ($kg \cdot Ha^{-1}$) (FAOSTAT, 2013). But the average yield is extremely variable, depending on climate, cultural system, crop duration, and grower technology (Frary et al., 2007). China is the lead producer of eggplant in the world (refer to Table 3.1), followed by India, where it is one of the essential vegetables; *S. melongena* is the most popular and economically important vegetable crop in Bangladesh (Rashid et al., 2003).

Table 3.1 World lead producers of eggplant in 2011 (FAOSTAT, 2013)

Country	Production (ton)	Area harvested (Ha)	Yield ($kg \cdot Ha^{-1}$)
China	27,700,000.00	787,000.00	35,196.95
India	11,896,000.00	680,000.00	17,494.12
Egypt	1,166,430.00	45,020.00	25,909.15
Turkey	821,770.00	25,355.00	32,410.57
Japan	322,400.00	10,000.00	32,240.00
Italy	243,319.00	9,423.00	25,821.82
Spain	202,245.00	3,268.00	61,886.48

The European production of *Solanum melongena* is concentrated in Southern Europe (Table 3.1). Other important eggplant producers from Europe are Greece, France and Netherlands. In countries from Southern Europe, the fruits, produced all year round in greenhouses or open field, are consumed locally and also exported to northern Europe (EGGNET, 2005).

3.3.1. Eggplant in the American Continent

According to data from FAOSTAT (2013), Mexico and the United States are the lead producers of eggplant in the Americas, with 62,500 and 62,300 tons in 2011, respectively. The Caribbean, as a whole, is another important eggplant producer.

Although the nutritional energy value of eggplant is limited, consumption of this crop has increased in the last few years, in part, because of its good phenolic and other antioxidants content. Eggplant is also a good source of alkaloids, which have several beneficial biological and pharmaceutical properties (Aubert et al., 1989). Although alkaloids have negative effects, as excessive levels result in extremely bitter fruit, cultivated species of eggplant do not contain such high levels of alkaloids, unless the plants have been subjected to extreme stress (e.g. high temperatures) (Frary et al., 2007). Cao et al., (1996) conducted an experiment in which the Oxygen Radical Absorbance Capacity (ORAC) of 22 vegetables (such as kale, garlic, spinach, broccoli flowers, red bell pepper, etc.) was studied. They determined that eggplant (with an antioxidant score of 5.1 μmol of Trolox-equivalent$\cdot g^{-1}$) is among the top vegetables in terms of ORAC. The antioxidant capacity of eggplant is owing to its content of anthocyanins and phenolic compounds. For this reason, the Caribbean countries and the southern states in United States are some of the regions where eggplant has gained a very good reputation over the years (Mohammed and Brecht, 2003).

In the Caribbean region, according to FAOSTAT (2013), in 1990, a total of 1,397 Ha of land were used to produce 7,116 tons of eggplant, obtaining a harvest yield of about 5,082 $kg\cdot Ha^{-1}$. From 1994 to 2000, the total production of eggplant fluctuated between 9,600 and 13,500 tons. From 2010 to 2011, there was an increase in the yield, from 5,732.9 to 7,234.2 $kg\cdot Ha^{-1}$, the latter being the highest yield recorded in the Caribbean since 2003.

Some Caribbean countries export large amounts of eggplant fruit. Dominican Republic is the country that has exported eggplant the most from all the Caribbean nations. In 1998, Dominican Republic exported a total of 3,600 tons, which was translated into a USD value of 1.26 millions (FAOSTAT, 2013). It is interesting that from 2006 to 2007 Dominican Republic increased exportations of eggplant from 4,013 to only 5,079 tons, but the USD value increased from 1.35 to 4.09 millions, a little bit more than 300%. So, eggplant is not only an important vegetable for the local consumption in Caribbean countries; it is also important economically, due to its large exportations. Some Caribbean countries import moderate or low amounts of this crop.

Barbados is the country that imports eggplant the most from the Caribbean. In 2008, Barbados imported a total of 569 tons, which was translated into a USD value of 452,000. In 2009, their importations increased to 753 tons of eggplant, but the USD value decreased to 391,000 (FAOSTATS, 2013).

The price of eggplant (for the producers) differs from one country to another. Out of the Caribbean nations, Barbados is where eggplant has the highest price. In 2000, the price of eggplant in Barbados was 1,095 USD·ton^{-1}, while in the Dominican Republic and Trinidad & Tobago the prices were, respectively, 212.2 and 354 USD·ton^{-1} (FAOSTATS, 2013). It was in 2003 that the highest price of eggplant (for the producers) was registered in Barbados: 2,215 USD·ton^{-1}; it is also the highest price registered among the Caribbean nations.

The unit price of eggplant will depend on its quality. This is why it is important to develop effective methods to measure objectively the quality of this agricultural produce.

3.4. Potential Pests for Eggplant During Pre-harvest

Pests that damage eggplant crops include the shoot and fruit borer (*Leucinodes orbanalis*), *Epilachna* beetle (*Epilachna vigintioctopunctata*), jassids, red spider mites, leaf rollers (*Eublemma divacea*), mealybugs (*Centrococcus insolitus*), cotton aphids, bud worm, lacewing bugs and termites (Lawande and Chavan, 1998).

The Colorado potato beetle (*Leptinotarsa decemlineata*) tends to colonize economically important crops different from potato, such as eggplant, tomato, and tobacco (Lorite et al., 2013). This insect develops resistance to insecticides, and it can overwhelm a crop and defoliate a plant.

Similar to *L. decemlineata*, flea beetles (*Epitrix* spp.) are known to be pests of tobacco, tomato, and eggplant (McLeod et al., 2002). The tiny flea beetle makes pinhole-sized feeding 'shot holes' in the leaves and plant of seedling eggplants, stunting their growth and often killing them altogether.

The red spider mite (*Tetranychus marinae* McGregor) is considered as another potentially highly destructive pest for vegetables, such as eggplant, tomato, cucumber, pepper, etc., and even a small number of *T. marinae* on plants can cause significant damage as they are a year-round pest (Reddy et al., 2011). The mite is usually found on the abaxial surface of leaves with the presence of web formation. Mata (1984) reported that feeding perforations on eggplant leaves by *T. marinae* become chlorotic and are seen as whitish to yellowish stipplings or dots at the upper surface of the leaf. Under substantial infestation, the chloritic areas may amalgamate so that leaves eventually turn yellow and can drop prematurely (Reddy et al., 2011).

The development of Good Agricultural Practices (GAP) is essential to avoid these pests. Since some of these insects can become resilient to insecticides and other chemicals, Hooks et al., (2013) recommend a different alternative as a control of pests like *L. decemlineata* and *Epirtrix* spp: Crimson clover (*Trifolium incarnatum* L.). *T. incarnatum* is a nitrogen fixer that converts atmospheric nitrogen into compounds that growing plants of eggplant need, attracts beneficial insects and increases the soil's organic matter, and also suppresses early season weeds while decreasing soil erosion and surface water pollution (Worthington, 2012).

3.5. Eggplant Quality During Postharvest Stages

Eggplant fruit has a specific spicy flavour and is eaten usually after roasting — as a single dish or as a component of vegetable dishes (Gajewski and Arasimowicz, 2004). But eggplant is so versatile that it can be eaten raw as well, or served as a baked, grilled, fried, or boiled vegetable, and can be used in stews or as a garnish (FAO, 2013). Eggplant is one of the most widespread vegetables in the world, commonly grown annually, or during warm seasons, in the tropics and sub-tropics (Mohammed and Brecht, 2003). There are a great number of cultivars that differ in size, shape, and colour. The dark purple or violet varieties are the most popular in the market (Sadilova et al., 2006). Eggplant requires warm to hot conditions and a relatively long period of time (5 to 6 months) to grow and represent an economical yield for the producer; the optimal growing temperature range is 21-30°C, with a maximum of 35°C and a minimum of 18°C; and the optimal soil temperature for seed germination is 24-32°C (Ullio, 2003). Eggplant is usually grown for a few months, although it can be cropped for over one year when conditions, such as water and fertilization, are optimal and plants are not stressed by diseases or insect pests (FAO, 2013).

Like sweet pepper, cucumber, sweet peas, sweet corn, etc., eggplant is an immature fleshy fruit, which means that it should be harvested at the physiologically non-mature stage. There is a need for experience in order to know when it is the most appropriate moment to harvest eggplant fruit. Eggplant possesses a dark purple skin when immature, but it turns opaque as it ripens. The right moment to harvest eggplant is between these two phases (Mohammed and Sealy, 1986). Esteban et al., (1992) reported that the content of sugars, ascorbic acid, and polyphenols increased during development of eggplants; the values of these concentrations reached a peak, approximately, when the fruit reached 80% of its total size. Maynard (1987) suggests that eggplant should be harvested at approximately this stage. Concellón et al., (2012) performed experiments to observe the quality changes of eggplant (an American dark purple variety called Lucia) during storage at two temperature conditions. The eggplants that were used in the experiments were harvested between 20 and 25 days post flowering. At this point, the fruit were physiologically immature: it had reached a mass that ranged from 150 to 200 g, a firm pulp, a glossy surface, and an incomplete seed development.

As eggplants ripen on the plant, they start to turn pale in the areas around the stem, and this decolouration spreads progressively to the calyx. Mohammed and Sealy (1986, 1988) advised that eggplants should be harvested when this decolouration is noticed for the first time, but they can be left on the plant up to one week after this decolouration is observed, without risks of losing their quality. If eggplants are left on the plant for longer than one week after the decolouration is noticed, they become opaque; their aspect ceases to be attractive; flesh loses its firmness; and its texture becomes fibrous (Lawande and Chavan, 1998). Furthermore, although the bitter flavours in eggplant are attributed to a production during seasons of high temperature, they are also associated to an over maturity of the fruit (Maynard, 1987). Those fruits on the plant that are beyond the optimal stage to be harvested should be cut and left in the field so that their organic matter stimulates the blossom of flowers (Mohammed and Brecht, 2003).

Other *S. melongena* that present symptoms of over maturity, rotting, sunken spots, sunburns, decay, damages due to insects, wounds, cracks, or any other signal of physical injury, should also be rejected in the field or before they are packed to be transported. The fruits are sometimes put in paper bags or wrapped in paper before being packed for shipping (Lawande and Chavan, 1998).

The requirements for eggplant to be discarded (based on scars or crusts caused by aphid, mites, etc.) depend on the variety. For instance, the variety 'Black Beauty' is not accepted for marketing exportation if scars and crusts are greater than 3 cm or if they have an accumulative length of 4 cm. Green spots in the stem are not acceptable for this variety either (Mohammed and Brecht, 2003).

The calyx should be attached to the eggplant fruit when it is harvested. The stem, on the other hand, should be removed because it is hard and can injure the fruit (Lawande and Chavan, 1998). Harvested eggplants should be placed carefully in appropriate containers right after being cut. Eggplant fruit, especially the dark purple varieties, are highly susceptible to sunburns. Morishita et al., (1994) conducted a study in which eggplants were exposed to sunlight, and wind (35°C, 2.5 $m \cdot s^{-1}$), for 10 minutes. The authors observed that the marketability of the fruits decreased. Exposure of eggplants to conditions of high solar radiation during one hour is quite enough to make the fruit not appealing for marketing. Therefore, it is recommended to put the harvested eggplants in containers with light-coloured walls in order to avoid as much solar radiation as possible.

Eggplants should be cooled down immediately and quickly, after being harvested. Mohammed and Sealy (1988) performed an experiment in which a batch of eggplants was cooled with water, and another group of eggplants was cooled with air. Eggplants were stored at 5, 15, and 28-30°C. After 8 days, the eggplants cooled with water and stored at 28-30°C showed a superior quality compared to the ones cooled with air and stored at that same temperature. It was concluded that cooling with water also delayed the symptoms of chilling injury in eggplants stored at 5°C. The water used to cool the eggplants should have 100 ppm of sodium hypochlorite, which is a good disinfectant.

As mentioned above, eggplants can be packed individually with paper, and placed in containers, carefully, so that their stems do not damage the adjacent fruits. Eggplants are usually packed in different kinds of containers, such as special crates, bushel baskets, and sometimes berry crates (Lawande and Chavan, 1998). Eggplants should not be packed too tight when transporting or storing. The weight per container should be monitored, and it should not exceed the recommended net weight, depending on the variety. For the ‘Long Purple’ variety it is appropriate for containers to have a net weight of about 9 kg, whereas for the ‘Black Beauty’ variety it is better to keep a lower net weight of about 4.9 kg (Mohammed and Brecht, 2003).

The respiration rate of eggplant is considered to be between low and moderate. Its rate of ethylene production is low, and the compound is not considered crucial for ripening control (it is a non-climacteric fruit) (Massolo et al., 2011). However, calyx abscission and increased deterioration (such as browning of pulp tissue) could be a problem if eggplant is exposed to > 1 ppm ethylene during distribution and short-term storage (Cantwell and Suslow, 1997). Massolo et al., (2011) evaluated the effect of 1-

Methylcyclopropene (1-MCP), a cyclic alkene that can block the ethylene action, on eggplant, during storage at 10°C. The authors determined that 1-MCP was effective to delay senescence, to maintain quality, and to reduce browning of the fruit pulp tissue. The low temperature played also an important role in delaying eggplant fruit deterioration, and reducing browning reactions in the calyx.

Refrigeration is not recommended for eggplant, because this crop is even more susceptible to chilling injury than tomatoes and green peppers. Eggplant should not be stored for long periods below 7-10°C (Concellón et al., 2007). Chilling injured eggplants present symptoms such as pitting, peel bronzing, and browning of seeds and pulp tissue. Concellón et al., (2012) found that pulp lightness (L) of eggplants held at 0°C did not change significantly during the first 3 days of storage, but afterwards, a continuous decrease was observed because of browning reactions. It is important to mention that susceptibility to chilling injury depends on factors such as cultivar, maturity, fruit size, and harvesting season (Abe et al., 1976, 1980; Uncini et al., 1976).

On the other hand, eggplants have a very limited short life when stored at warm conditions. Mohammed and Brecht (2003) stated that the shelf life of eggplants kept at room temperature is 2 or 4 days. The shelf life of eggplant can be extended up to 15 days when storage temperature is 7-14°C (Mohammed and Sealy, 1988).

Transpiration is the factor with the biggest effect on mass loss in the majority of horticultural produce. The mass losses are mostly translated into water losses. When moisture loss from eggplants is excessive, their pulp becomes soft, they shrivel, their peel loses its gloss and the calyx turns brown due to dehydration (Díaz-Pérez, 1998). Symptoms of deterioration in eggplants start to show when they have minimal water losses of 3% (Gull, 1981). If, during storage, relative humidity (RH) is set to 90-95%, water losses are minimized (Cantwell and Suslow, 1997). Wrapping eggplants with films is helpful to prevent humidity and firmness losses as well. This is mainly because of the high RH that is generated in the package (Gull, 1981). Water losses can also be prevented if eggplants are placed in perforated polyethylene bags. Besides, wrapping offers other advantages: it minimizes fruit deformation, reduces chilling injury, and reduces decay by preventing secondary infection of fruit packed in the same box (Risse and Miller, 1983). Thin layers of wax can also help increase the shelf life of eggplants. Wax gives the surface of the fruit lubrication, which reduces scratches during transportation (Mohammed and Brecht, 2003). With the application of these postharvest technologies, the shelf life of eggplant can be of 2-3 weeks. However, wrapped eggplants that are stored at higher temperatures (above 30°C) tend to decay much faster because the RH inside the package gets remarkably high. These conditions of high temperature and RH favour the growth of microorganisms that deteriorate the fruit (Mohammed and Sealy, 1986).

Some diseases on *S. melongena* may occur during pre harvest stages and postharvest storage. The most common diseases are rotting caused by *Alternaria* tenuis, bacterial wilt caused by *Pseudomonas solanacearum*, Phomopsis blight caused by *Phompsis vexans*, damping-off caused by *Phythium* spp., *Phytophthora* spp., and *Rhizoctonia* spp. (Lawande and Chavan, 1998).

Rotting due to *Alternaria tenuis* causes the development of dark, sunken, and circular areas. These areas, which may occur on any part of the surface, including the calyx, have determined margins when they are small or when they fuse together to create irregular shapes. Fungi grow on the surface, on old wounds, and their colouration is dark gray, although it may be velvet-like and olive green if fungi are covered with spores (Mohammed and Brecht, 2003). Fungi can penetrate the fruit pulp through surface lesions, where the affected tissue turns from bronzed to a gray-bronzed colour, and the fruit texture turns sponge-like. Rotting due to *Alternaria* is a reaction to chilling injury of eggplant fruit. Scars, rotting caused by *Alternaria*, and dead of the pulp tissue were evident at room temperature after eggplant fruits were exposed to 2-5°C for 6 days or at 4°C for 10 days (Ryall and Lipton, 1979).

3.5.1. Chemical Composition

In fresh weight, eggplants contain about 7% of dry matter (1.4% of proteins, and 4% of carbohydrates); the rest is mostly moisture (Gajewski et al., 2009). However, the composition of eggplant varies during storage. Fresh fruit and vegetables are living tissues that unceasingly lose water. Growing crops can replace lost water from the soil, but harvested crops cannot. Consequently, as mentioned above, eggplants will inevitably lose water over time due to transpiration. The rate at which mass losses occur will depend on factors such as harvest, storage, and transportation conditions (Díaz-Pérez, 1998).

Flick et al., (1978) reported the amino acid profiles of proteins in purple, green, and white eggplants. The purple varieties showed larger amounts of protein than the white and green varieties. Glutamic and aspartic acids were the most abundant amino acids in purple eggplants with, respectively, 3.582 and 3.274 mg·g^{-1} (in dry weight basis). Purple eggplant showed also significant amounts of essential amino acids, such as leucine, valine, lysine, and isoleucine.

Eggplant is an extraordinary source of micronutrients. But it is not only rich in vitamins B_1, B_2, B_6, C, K, thiamine, niacin, and pantothenic acid, and minerals like magnesium, potassium, manganese and copper (Alam et al., 2006; Gajewski et al., 2009); eggplant also offers a decent content of phenolic compounds (Hanson et al., 2006; Singh et al., 2009), which have beneficial effects on human health for having antioxidant, antibacterial and immunostimulant properties (Gajewski et al., 2009).

Whitaker and Stommel (2003) found 5-*O*-caffeoyl-quinic acid (chlorogenic acid) (Fig. 3.2) to be the most abundant phenolic acid in different eggplant samples. Concellón et al., (2012) detected by HPLC that chlorogenic acid was the most abundant, and that it accumulated in eggplant fruit held at 10°C, increasing by 60% after a storage period of 14 days. They also studied the effect of a low temperature (0°C) on the phenolic content of eggplant. There was a reduction from a maximum of 818 to 489 mg·kg^{-1} after 14 days of cold storage. They attributed this reduction of phenolic antioxidants to browning reactions, although they determined that in some cases, after long periods of storage, losses of 50% of soluble phenolic antioxidants in eggplant might occur in the absence of browning. Stommel and Whitaker (2003) showed that chlorogenic acid typically ranges from 70 to 95% of total phenolics in eggplant fruit flesh. Chlorogenic acid is the result from the esterification of caffeic acid and the aliphatic alcohol (-) quinic acid (1L-1(OH)-3,4/5-tetrahydroxycyclo-hexne carboxylic acid).

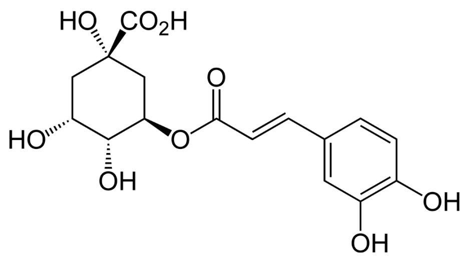

Fig. 3.2 Chemical structure of chlorogenic acid (5-*O*-caffeoyl-quinic acid).

The purple type of eggplant is the most cultivated one (Moncada et al., 2013). Anthocyanins are responsible for this particular colouration; they are pigments that belong to phenolic flavonoids, a powerful antioxidant group (Vinson et al., 1998).

Delphinidin-3-*p*-coumaroylrutinoside-5-glucoside (nasunin) (Fig. 3.3) is the most common anthocyanin in eggplant (Salidova et al., 2006). Matzusoe et al., (1999) identified nasunin as the most abundant anthocyanin of almost all the cultivars that they studied. This anthocyanin ranged from 69 to 88%.

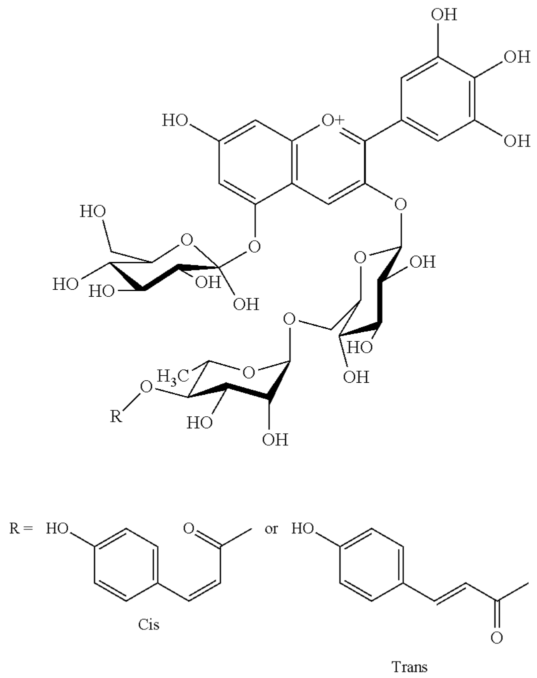

Fig. 3.3 Chemical structure of nasunin, delphinidin-2-*p*-coumarolyrutinoside-5-glucoside.

3.6. Subjective Scale for Quality Evaluation of Crops

Quality of horticultural crops has a maximum value at harvest. Irrevocably, there will be quality losses along the postharvest distribution chain, where crops are exposed to a series of stresses of different nature.

During the postharvest distribution chain, exposures either to abiotic stress during handling (e.g. physical), transport (e.g. temperature and vibration), and storage (e.g. temperature reduction, changes in the atmosphere composition), or a combination of biotic and abiotic stresses (e.g. commodities containing a load of fungal spores that will proliferate during storage), occur until crops reach the consumption stage (Pedreschi et al., 2013).

Quality losses through the postharvest distribution chain not only reduce profitability of producers and other participants, but they as well deprive people of the volume and range of produce available for purchase (Hewett, 2012). In general, one-third of the food production for human consumption is lost, that is 1.3 billion tons of wasted food every year. Due to strict quality standards in developed countries, more than 40% of the food losses occur at the retail and consumer stages (Pedreschi et al., 2013). Much of the food that is discarded in medium- and high-income countries is still suitable for human consumption. On the contrary, in less developed countries, most of the food losses occur in the early stages of the food distribution chain (Pedreschi et al., 2013).

Food losses are significant in staple crops but much higher in perishable foods (Pedreschi et al., 2013). *S. melongena* is a very perishable vegetable, and its freshness matters for both the producer and the consumer. The swift changes of eggplant freshness during postharvest storage cause substantial price variation.

Kader (2010) suggests a general rating scale (that goes from 1 to 9, 9 being the best) to determine the overall quality of horticultural crops (Table 3.2). The quality of horticultural crops is mostly based on size, shape, colour, gloss, flavour, firmness, texture, taste and freedom from external and internal defects (Jha and Matsuoka, 2000).

Table 3.2 Rating scale for overall visual quality of produce (Kader, 2010)

Quality index	Interpretation	Description
9	Excellent	Essentially no symptoms of deterioration
7	Good	Minor symptoms of deterioration, not objectionable
5*	Fair	Deterioration evident, but not serious, limit of saleability (marketability)
3	Poor	Serious deterioration, limit of usability
1	Extremely poor	Not useable

*5 is the minimum value for any crop to be accepted in a marketing system

In the United States of America, it is stipulated that the quality factors that should be taken into account for eggplant quality include colour, turgidity, shape, size, and lack of defects and symptoms of rotting or decay (Kader, 1996). There are many varieties of eggplant, which differ in terms of size, shape (oval-shaped or long-shaped) and colours (dark purple, violet, striped, white, etc.). Lawande and Chavan (1998) stated that eggplant fruits show superior quality if their maximum diameter does not exceed about 10 cm. Ryall and Lipton (1979) confirmed that eggplants that grow up to 15 cm in diameter remain tender and does not acquire bitter flavours. As mentioned above, there are white, yellow, green, and stripped eggplant varieties, and elongated or pear-shaped forms. The most popular in the markets of North America are the dark purple, large-fruited, and more or less round ones, such as 'Black Beauty' and 'Fort Mayers Market' varieties (Lawande and Chavan, 1998). Recently, characteristics such as surface stiffness and peel gloss are considered as eggplant quality parameters (Jha and Matsuoka, 2002b). So, an American eggplant that receives a 9 in the scale that Kader (2010) proposes should be uniformly egg to globular in shape; it should have a dark purple, glossy and smooth skin and a fresh green calyx; and it should have a firm and turgid flesh. Additional quality indices are size (e.g. maximum diameter not greater than 10 cm), freedom from growth or handling defects and decay (e.g. nonappearance of fungi and bruising). The physical characteristics of eggplant change rapidly during storage mostly owing to the fact that eggplant fruit loses water through transpiration. Although subjective visual quality rating scales have been developed for many fruits and vegetables (Kader, 2010), not one has been reported for eggplant.

The general visual rating scale can be very helpful to have an idea of how eggplant quality is at a particular link of the postharvest distribution chain. However, eggplant quality is assessed manually, by sensing the surface gloss and stiffness. This subjective appreciation might lead to under or overestimations of its freshness and, hence, its price. This may also lead to an increase of PHL at the retailer or at the consumption stage, since there is a chance for fruits to be discarded when they are still suitable for consumption.

3.7. Objective Methods for Quality Evaluation of Eggplant

3.7.1. Destructive Methods

Destructive methods refer to techniques for which samples must be destroyed in order to be analyzed. Fruit quality assessments usually involve measuring flesh firmness using a penetrometer. Generally, a probe, with either a flat or convex tip, is driven into the flesh, and the maximum force is recorded (Harker et al., 1996). This is an example of a destructive technique because the fruit or vegetable has to be punctured and cannot be reused for further experimentation (Macnish et al., 1997). Gajewski et al., (2009) measured the firmness with a Fruit Firmness Tester HPE II (Bareiss, Germany), equipped with a 5 mm diameter and round-ended probe. The authors also determined the force needed to puncture the fruit flesh without skin using a hand penetrometer (David Bishop Instruments), using a 10 mm diameter probe.

To analyze sugars, organic acids, amino acids, proteins, lipids, and fatty acids, or other chemical components in the fruits, chemical extraction is the most common method used (Wang, 1999). Chemical analysis is also used to measure the nutritional quality of horticultural crops. As discussed above, there are a significant number of publications of eggplant being subjected to destructive methods to assess its internal quality (e.g. pulp and seed browning due to chilling injury), and chemical analyses to determine its content of sugars, ascorbic acid, phenolic compounds, amino acids, and anthocyanins.

The major disadvantages of the destructive procedures are that most of them represent hard and laborious laboratory techniques, and that samples cannot be used repeatedly.

3.7.2. Non-Destructive Methods

Non-subjective and non-destructive approaches for quality evaluation of many fruits and vegetables have become popular. These non-destructive techniques are usually based on the detection of several physical properties that correlate satisfactorily with certain factors of a product (Jha and Matsuoka, 2000).

Non-destructive methods have an obvious advantage for estimating quality: they allow the samples to be measured repeatedly to get valuable and significant information without altering the physical and chemical properties of the fruits (Dull et al., 1980). Mizrach et al., (1992), Takao and Ohmori (1994) and Lesage and Destain (1995) describe devices that are used to test firmness by compressing the fruit surface, but without application of such excessive force that might rupture the tissue. Such non-destructive testing devices allow fruits to be used in packing sheds or in storage facilities for repeated measurements over time without causing substantial damage to the produce (Macnish et al., 1997).

Wang (1999) mentioned some technologies and their uses as non-destructive methods: light reflection or transmission, fluorescence, delayed light emission, and near infrared spectrometry for evaluating surface attributes and internal constituents; nuclear magnetic resonance imaging or spectroscopy for detecting internal disorders and composition; acoustic or ultrasonic sensing for measuring firmness, softening, maturity, and ripeness; air puff-laser reading for detecting firmness, etc. Recently, hyperspectral-imaging method has been explored as a non-destructive tool to predict the chemical composition of foods, such as fat content in pork (as a tool to categorize its quality), or sugar distribution in melons; or to evaluate physical quality attributes, such as detection of bruise apples or pickling cucumbers (Liu et al., 2010; Sugiyama and Tsuta, 2010; Wang and ElMasry, 2010; Ariana et al., 2006).

There is limited work on eggplant to develop objective and non-destructive methods to determine its quality changes at various storage conditions. In this work, non-destructive tests (to determine attributes like density, surface gloss and stiffness) were carried out to develop a freshness index for eggplant. Correlations between different ratios (peel gloss, surface stiffness, density, and weight) and the freshness index were established to find kinetic models to predict such index with simple parameters such as the initial weight of an eggplant and its weight in any point of time. The spectral data of the eggplant images were also used to predict the developed freshness index at different temperature-storage conditions.

3.7.2.1 Weight, Volume and Density of Eggplant during Postharvest Storage

Moisture loss during postharvest storage is one of the changes that cause quality decline in eggplant fruit. Transpiration is the main cause of mass losses in the majority of horticultural produce. Eggplants stored at 15.5°C (92% RH, 0.13 kPa vapour pressure difference) have a mass loss rate of about 0.12% day^{-1} (Risse and Miller, 1983). Díaz-Pérez (1998) determined the separate contributions of the skin and calyx to whole-fruit (skin plus calyx) transpirations. The experiment consisted of fresh packed eggplants of different sizes (fruit 100 g or less were referred to as ‘small’, while fruit > 100 g were referred to as ‘large’) being placed in a controlled-temperature room. Fruit mass was determined daily over a period of 4 days. The rate of water loss (WL) was measured as a daily percent mass loss of the fruit with respect to the mass of the fruit the day before each measurement. To estimate skin transpiration, petroleum jelly was applied to the calyx. It was found that the calyx is the main route for fruit water loss; it is responsible for at least 60% of fruit transpiration. This is why postharvest treatments intended to reduce water loss from the calyx could be beneficial in extending the shelf life of eggplant. Díaz-Pérez (1998) found that fruit transpiration rate declined as eggplant increased in size. Concellón et al., (2012) also evaluated water losses as one of the quality changes in dark purple American eggplant (cv. Lucía) at two different temperature conditions (0 and 10°C).

It was determined that WL increased during storage at both temperature conditions. After 14 days WL was 4.2% in fruit stored at 10°C as compared to 1.6% in fruit held at 0°C. It is worth mentioning that Concellón et al., (2012) covered the eggplant fruits with perforated PVC (50 µm thick). When eggplants are covered with films, weight loss is reduced dramatically, keeping a good quality for even 15 days. This prolonged good quality, as mentioned before, is due to the modified atmospheres and the saturated microambient created inside the cover. However, when temperature is 29-30°C, the outcome is the opposite: the rate of decay and rotting increases, especially at the end of the calyx. At this temperatures, RH inside the package increases. These conditions favour the growth and development of microorganisms that deteriorate the fruit (Mohammed and Brecht, 2003).

Jha et al., (2002) studied the volume changes of an Asian type of eggplant (a long and slender variety) during storage at different periods and temperatures. The volume of water displaced is equal to the volume of the body that is immersed. Individual mass, volume, and density of eggplants changed considerably with storage time ranging between 0 and 168 h at 15-30°C and 90% RH. The WL of eggplant over time was linear (the rate was higher as temperature was increased), while the volume first decreased at a higher rate and then slowed down before becoming almost constant at each storage temperature. The density for this particular variety of eggplant increased significantly over 72 h in the case of 20 and 30°C. The density of eggplant stored at 25°C increased until 120 h. After reaching the peak, density values decreased sharply and gently at higher and lower storage temperatures, respectively. This behaviour of density was attributed to the rates of weight and volume losses (the mass decreased at a lower rate than that of volume).

Water losses in eggplant are definitely related to other quality changes. When eggplant loses water, they shrink. This shrinkage leads to softening of the pulp and to volume being reduced. Since the gloss is related to the smoothness of a surface, it also decreases when eggplants shrivel for losing water. Of particular interest for this work is an American (dark purple) variety of eggplant whose density change during storage has not been studied yet.

3.7.2.2 Surface Stiffness of Eggplant

Stiffness is a term used to describe the force needed to achieve a certain deformation of a structure. This is described by the expression in Eq. 3.1 (Baumgart, 2000):

$$Stiffness = \frac{Load}{Deformation} \quad (3.1)$$

A load can be a force, a moment, a stress, or a combination of some of these physical variables acting on a structure (a geometrical body consisting of a solid material) (Baumgart, 2000). Deformation means that the actual geometrical configuration of the elastic structure is different from the original 'unloaded' reference configuration; it is always a comparison of two different configurations of a structure. The measure of a deformation can be a strain, a displacement, an angle or a modification of these variables (Baumgart, 2000).

The term 'stiffness' of a structure requires an exact description of the load configuration and the exact localization and kind of deformation measured. Otherwise, the measured or calculated values cannot be compared with results from other authors (Baumgart, 2000). In the International System of Units (IS), stiffness is typically measured in Newtons per meter ($N \cdot m^{-1}$).

Jha and Matsuoka (2002a) studied the changes of eggplant surface stiffness (Ryoma variety) at different storage periods and temperatures. In order to measure stiffness of eggplant, they carried out compression tests using a uniaxial compression-testing machine (Aikoh, model–1307, Osaka, Japan) attached with a deformation measuring dial gauge, strain magnifier and data recorder. Deformation in eggplant was kept fixed (about 2-2.5 mm), so that the fruit peel was not injured during the experiment. The slope from the force-deformation curve that they obtained was recorded as 'surface stiffness' (in $N \cdot mm^{-1}$). The compression tests were applied on fresh eggplants (the same day they were harvested). After experimentation, eggplants were stored in a humidity and temperature-controlled chamber. RH of the chamber was set at 90±5%, while temperatures were maintained at 15, 20, 25 and 30°C. The average surface stiffness of fresh eggplant was found to be 1.10 $N \cdot mm^{-1}$; and it decreased significantly with storage time. The higher the temperature, the higher the rate at which surface stiffness decreased, consistently, during the first 96 h of storage. Interestingly, the surface stiffness of the eggplants stored at 30°C increased at 120 h of storage, but decrease at later storage periods occurred. On the other hand, the eggplants stored at 20 and 25°C showed a minimum surface stiffness at 120 h of storage. The surface stiffness of these eggplants increased at 144 h of storage, and then it decreased again at 168 h. Eggplants stored at 15°C showed almost a continuously decreasing surface stiffness with storage time. However, no work has been found on measuring surface stiffness of American varieties of eggplant, nor the effect of light on surface stiffness has been studied.

3.7.2.3 Peel Gloss of Eggplant

For many fleshy fruits and vegetables, gloss is an important physical aspect of their appearance (Mizrach et al., 2009). Usually, the surface gloss of eggplant is sensed by subjective visual inspection. Nonetheless, automated visual inspection by computer-based systems has been developed in the food industry to replace the traditional inspection by human inspectors because of its cost-effectiveness, consistency, superior speed, and accuracy (ElMasry and Sun, 2010).

Gloss is an attribute that causes the surface of an object to have a shiny or lustrous appearance; it is generally associated with specular reflection by the surface of objects (Mizrach et al., 2009). There are some devices that can be used directly to quantify the gloss of an object. But conventional glossmeters can measure gloss of uniform, flat surfaces; therefore, they are not suitable for fruits, vegetables, and other crops, because of their uneven and often curved surfaces (Hutchings, 1999).

Surface appearance is associated with the distribution of light by the object. The four types of light distribution and their respective relationships to surface appearance are (Ji et al., 2006):

1. Specular reflection at the first surface of the object (glossy)
2. Absorption within the object (colour)
3. Scattering within the object (diffuse reflection and transmission: translucency and haze)
4. Transmission through the object (transparency, opacity, and clarity)

Nussinovitch et al., (1996) developed a gloss measurement system for fruits and vegetables (banana, tomato, eggplant, onion and bell green pepper). Their system consisted of a support plate as the base. The fruit or vegetable to be tested sits on a disc in the centre that rotates to allow surface scanning. Two arches, attached to the base, are lined with photodiodes; a half-arch holds an adjustable light source, preferably a laser that can be beamed directly at different surface angles of the revolving support plate. The laser is connected through a cable to a power source and the output of photosensors (reflected light from the surface of the fruit or vegetable) passes via cable to amplifying means connected to a computer.

Jha et al., (2002) and Jha and Matsuoka (2002b) developed a gloss measurement system, focusing on eggplant fruit (*Ryoma* variety). They determined the surface gloss index by using a spectroradiometric system. The spectroradiometer measures the spectral radiant energy emitted by the object and amplifies the same by the inbuilt mechanism of the system before processing and converting the emitted energy into DC signal. This signal is further amplified, digitized and transferred to a computer for additional processing and display. The relative reflectance as a function of wavelength, known as the gloss index, was computed. During experiments, the wavelength of incident light varied between 0.405 and 0.780 µm (the visible range). The gloss index for the entire range of wavelength falling on the object was obtained.

Since the gloss property is related to surface composition and morphology, most changes in the latter would presumably result in changes in the former (Jha et al., 2002). The glossy surface of fresh fruits and vegetables can be greatly reduced with WL and other postharvest handling conditions (Mitcham et al., 1996). Jha et al., (2002) and Jha and Matsuoka, (2002b) studied the effect of storage period on the peel gloss of eggplant and they found a strong correlation between changes of weight and gloss. However, no studies of the effect of different storage conditions on the peel gloss of eggplant are available, especially for the American varieties.

Hyperspectral imaging technique has been regarded as a smart and promising analytical tool for analyses conducted in research, control and industries (ElMasry and Sun, 2010). Hyperspectral imaging has some advantages over spectroscopy (the methodology followed by Jha and Matsuoka (2002b) and Jha et al., (2002)). Both technologies offer spectral and multi-constituent information of a sample, but hyperspectral imaging goes beyond that. ELMasry and Sun (2010) summarizes some of the advantages of hyperspectral imaging. Rather than collecting a single spectrum at one spot on a sample, as in spectroscopy, hyperspectral imaging records a spectral volume that contains a complete spectrum for every spot (pixels) in the sample. Besides, hyperspectral imaging has the flexibility in choosing any region of interest (ROI) in the image even after image acquisition. As well, its ability to build chemical images permits labeling of different entities in a sample simultaneously and quantitative analysis of each entity.

On the other hand, hyperspectral imaging has some disadvantages. One of them is that it takes a long time for image analysis; hence this method has — to a very limited extent — been directly implemented in on-line systems for automated quality evaluation purposes (ElMasry and Sun, 2010).

A near-infrared (NIR) imaging system was developed to capture hyperspectral images from eggplants in the spectral region of 900 to 1700 nm in order to interpret their peel gloss as a quality feature. The effect of different light and temperature conditions on peel gloss of an American variety of eggplant was studied as well.

3.8. Summary

Quality evaluation methods for eggplant, an economically important vegetable, still have opportunities for development. The eggplant quality is based on subjective and visual inspection of its external appearance: peel gloss, surface stiffness and health of its stem and calyx. Non-invasive, subjective and objective, methods for quality evaluation for many fruits and vegetables have been developed based on the detection of physical properties that correlate with certain factors, but very limited work has been done for this purpose for eggplant, especially for the American varieties.

Hyperspectral imaging, which combines spectroscopy and imaging, has many potential applications in agriculture-food industry. Measurement of peel gloss using this technique might be more accurate compared to spectroscopy. The major limitation of spectroscopy is that the information acquired from the measurements is from a specific area of the sample i.e. a point measurement that does not have information from spatial distribution of light reflectance.

Non-destructive compression tests may be helpful to describe, objectively, the rigidity or stiffness of a fruit. Quality parameters (surface stiffness and peel gloss) may be helpful to find correlations with the quantity parameters (mass, volume and density) of fresh and stored eggplants.

References

Alam, S.N., Hossain, M.I., Rouf, F.M.A., Jhala, R.C., Patel, M.G., Rath, L.K., Sengupta, A., Baral, K., Shylesha, A.N., Satpathy, T.M., Shivalingaswamy, T.M., Cork, A., and Talekar. N.S. 2006. Implementation and promotion of an IMP strategy for control of eggplant fruit and shoot borer in South Asia. Technical bulletin No. 36. AVRDC publication number 06-672. AVRDC —

The World Vegetable Center, Shanhua, Taiwan. 74 pp.

Abe, K., Chachin, K., and Ogata, K. 1976. Chilling injury in eggplants fruits. II. The effects of maturation and harvesting season on pitting injury and browning of sedes and pulp during storage. J. Jpn. Soc. Hort. Sci. 45:307-312

Abe, K., Chacin, K., and Ogata, K. 1980. Chilling injury in eggplant fruits. VI. Relationship between storageability and contents of phenolic content in some eggplant cultivars. J. Jpn. Soc. Hort. Sci. 49:269-276

Ariana, D.P., Lu, R., and Guyer, D.E. 2006. Near-infrared hyperspectral reflectance imaging for detection of bruises on pickling cucumbers. Computers and electronics in agriculture. 53: 60-70

Aubert, S., Daunay, M.C., and Pochard, E. 1989. Saponosides stéroïdiques de l'aubergine (Solanum melongena L.). I-intérêt alimentaire, méthodologie d'analyse, localization dans le fruit. Agronomie. 9: 641-651.

Bauer, S., Schulte, E., and Their H.P. 2005. Composition of the surface waxes from bell pepper and eggplant. Eur. Food Res. Technol. 220: 5-10.

Baumgart, F. 2000. Stiffness — an unknown world of mechanical science? Inury. Int. J. Care Injured. 31: S-B14-S-B23.

Cantwell, M., and Suslow, T.V. 1997. Eggplant: recommendations for maintaining postharvest quality. Available on: http://postharvest.ucdavis.edu/pfvegetable/Eggplant/. Accessed on November 16th, 2012.

Cao, G., Sofic, E., and Prior, R.L. 1996. Antioxidant capacity of tea and common vegetables. J. Agric. Food Chem. 44: 3426–3431.

Concellón, A., Añón, M.C., and Chaves, A.R. 2007. Effect of low temperature storage on physical and physiological characteristics of eggplant fruit (Solanum melongena L.). LWT 40: 389-396

Concellón, A., Zaro, M.J., Chaves, A.R., and Vicente, A.R. 2012. Changes in quality and phenolic antioxidants in dark purple American eggplant (Solanum melongena L. cv. Lucía) as affected by storage at 0°C and 10°C. Postharvest Biology and Technology. 66: 35-41.

Daunay, M.C., and Janick, J. 2007. History and iconography of eggplant. Chronica Horticulturae. 47(3): 16-22.

Daunay, M.C., Aubert, S., Frary, A., Doganlar, S., Lester, R.N., Barendse, G., van der Weerden, G., Hennart, J.W., Haanstra, J., Dauphin, F., and Jullian E. 2004.

Eggplant (Solanum melongena) fruit color: pigments, measurements and genetics. In: Proceedings of the 12th Eucarpia Meeting on Genetics and Breeding of Capsicum and Eggplant, Noordwijkerhout, The Netherlands, 2004, 108-116 pp.

Daunay, M.C., Lester, R.N., Gebhardt, C., Hennart, J.W., Jahn, M., Frary, A., and Doganlar, S. 2001. Genetic resources of eggplant (Solanum melongena L.) and allied species: a new challenge for molecular geneticists and eggplant breeders. In van der Berg, RG., Barendse, GWM, van der Weerden, G.M., Mariani, C (eds.) Solanaceae V. Advances in taxonomy and utilization. Nijmegen University Press, Nijmegen, The Netherlands, 251-274 pp.

Díaz-Pérez, J.C. 1998. Transpiration rates in eggplant fruit as affected by fruit and calyx size. Postharvest Biology and Technology. 13: 45-49.

Dull G.G., Birth, G.S., and Magee, J.B. 1980. Nondestructive evaluation of internal quality. HortScience 15: 60-63.

EGGNET (Eggplant Genetic Resources Network). 2005. Management, conservation, and utilization of genetic resources of eggplant. Accessed July, 2013. http://www.bgard.science.ru.nl/eggnet/eggnet01.html.

ElMasry, G., and Sun, D.W. 2010. Principles of hyperspectral imaging technology. In: Hyperspectral imaging for food quality analysis and control. First Edition. Editor: Sun, D.W. 3-43.

Esteban, R. M. M. M. Esperanza, L. M., Robredo, and F. J. López-Andreu. 1992. Changes in chemical composition of eggplant fruits during development and ripening. J. Agric. Food Chem. 40: 998-1000.

FAO (Food and Agriculture Organization of the United Nations). 2013. Accessed July, 2013. http://www.vegetableipmasia.org/Crops/Eggplant.html

FAOSTAT (Food and Agriculture Organization of the United Nations). Accessed June 2013. http://faostat.fao.org.

Frary, A., Doganlar, S., and Daunay, M.C. 2007. Eggplant. In: Genome mapping and molecular breeding in plants. Volume 5 Vegetables. C. Kole Edition. Editor: Shreck, S. Germany. Springer Berlin Heidelberg New York. 287-313. 408 pp.

Flick, G.J., Burnette, F.S., Aung, L.H., Ory, R.L., and St. Angelo, A.J. 1978. Chemical composition and biochemical properties of mirlitons (*Sechium edule*) and purple, green, and white eggplants (*Solanum melongena*). J. Agric. Food Chem. 26 (5): 1000-1005.

Gajewski, M., and Arasimowicz, D. 2004. Sensory quality of eggplant fruits (Solanum melongena L.) as affected by cultivar and maturity stage. Pol. J. Food Nutri. Sci. 13/54, No 3: 249-254

Gajewski, M., Katarzyna, K., and Bajer, M. 2009. The influence of postharvest storage on quality characteristics of fruit of eggplant cultivars. Not. Bot. Hort. Agrobot. Cluj 37: 200-205.

Gull, D.D. 1981. Handling Florida vegetables. Eggplant. Univ. Fla. Veg. Crops. Fact Sheet. SS-VEC-932.

Hanson, P.M., Yang, R.Y., Tsou, S.C.S., Ledesma, D., Engle, L., and Lee, T.C. 2006. Diversity in eggplant (Solanum melongena) for superoxide scavenging activity, total phenolics, and ascorbic acid. J. Food. Comp. Anal. 19: 594-600.

Hewett, E.W. 2012. Postharvest technology innovation and opportunities of extension for horticultural produce: perspective and trends. Acta Hort. 943: 25-32.

Jha, S.N., and Matsuoka, T. 2000. Review: Non-destructive techniques for quality evaluation of intact fruits and vegetables. Food Sci. Technol. Res., 6(4): 248-251.

Jha, S.N. and Matsuoka, T. 2002a. Surface stiffness and density of eggplant during storage. Journal of Food Engineering. 54: 23-26.

Jha, S.N., and Matsuoka, T. 2002b. Development of freshness index of eggplant. Applied Engineering in Agriculture. 18(5): 555-558.

Jha, S.N., Matsuoka, T., and Miyauchi, K. 2002. Surface gloss and weight of eggplant during storage. Biosystems Engineering. 81(4): 407-412.

Ji, W., Pointer, M.R., Luo, R.M., and Dakin, J. 2006. Gloss as an aspect of the measurement of appearance. J. Opt. Soc. Am. A. 23:22-33.

Kader, A. 2010. Rating scale for overall visual quality. of produce. In: Produce quality rating scales and color charts. Second edition. Compilors: Kader, A.A., and Cantwell, M. Postharvest technology research and information center, UC Davis.

Kader, A.A. 1996. Maturity, ripening, and quality relationships of fruit-vegetables. Strategies for Mark. Orient. Greenhouse Production. Eds. A.F. Abou-Hadid, R.A. Jones. Acta Hort. 434.

Lawande, K.E., and Chavan, J.K. 1998. Eggplant (Brinjal). In: Handbook of vegetable science and technology. Production, composition, storage, and processing. Salunkhe, D.K., and Kadam, S.S. Eds, New York: 225-244.

Lesage, P., and Destain, M.F. 1995. Measurement of tomato firmness by using a non-destructive mechanical sensor. Postharvest Biology and Technology. 8: 45-55.

Liu, L., Ngadi, M.O., Prasher, S.O., and Gariépy, C. 2010. Categorization of pork quality using Gabor filter-based hyperspectral imaging technology. Journal of Food Engineering. 99: 284-293.

Lorite, P., Torres, M.I., and Palomeque, T. 2013. Characterization of two unrelated satellite DNA families in the Colorado potato beetle *Leptinotarsa decemlineata* (Coleoptera, Chrysomelidae). Bulletin of Entomological Research. 103: 538-546.

Luthria, D., Singh, A.P., Wilson, T., Vorsa, N., Banuelos, G.S., and Vinyard, B.T. 2010. Influence of conventional and organic agricultural practices on the phenolic content in eggplant pulp: plant-to-plant variation. Food Chemisitry. 121: 406-411.

Luthria, D. 2012. A simplified UV spectral scan method for the estimation of phenolic acids and antioxidant capacity in eggplant pulp extracts. Journal of functional foods. 4: 238-242.

Macnish, A.J., Joyce, D.C., and Shorter, A.J. 1997. A simple non-destructive method for laboratory evaluation of fruit firmness. Australian Journal of Experimental Agriculture. 37: 709-713.

Massolo, J.F., Concellón, A., Chaves, A.R., and Vicente, A.R. 2011. 1-Methylcyclopropene (1-MCP) delays senescence, maintains quality and reduces browning of non-climacteric eggplant (Solanum melongena L.) fruit. Postharvest Biology and Technology. 59: 10-15.

Mata, I.C. 1984. Biology of sweetpotato spider mite, *Tetranychus mariannae* McGregor (Tetranychidae: Acarina). Unpublished BS Thesis, Visayas State College of Agriculture, Baybay, Leyte, Philippines.

Matzusoe, N., Yamaguchi, M., Kawanobu, S., and Watanabe, Y. 1999. Effect of dark treatment of the eggplant fruit on fruit skin color and its anthocyanin component. J. Japan Soc. Hort. Sci. 68(1): 138-145.

Maynard, D. N. 1987 Commercial vegetable cultivars for Florida. Univ. Of Florida Coop. Ext. Serv., IFAS, Circular 530.

McLeod, P., Díaz, F.J., Johnson, D.T. 2002. Toxicity, persistence, and efficacy of spinosad, chlorfenapyr, and thiamethoxam on eggplant when applied against the eggplant flea beetle (Coleoptera: Chrysomelidae). J. Econ. Entomol. 95: 331-

335.

Mitcham, B., Cantwell, M., and Kader, A. 1996. Methods for determining quality of fresh commodities. Perishables Handling Newsletter. 85(2): 1-5

Mizrach, A., Nahir, D., and Romen, B. 1992. Mechanical thumb sensor for fruit and vegetable sorting. American Society of Agricultural Engineers. 35: 247-250.

Mizrach, A., Lu, R. and Rubino M. 2009. Gloss evaluation of curved-surface Fruits and Vegetables. Food Bioprocess Technol. 2: 300-307.

Mohammed, M., and Sealy, 1988. Hydrocooling and post-harvest quality in melongene. Trop. Agr. 65:161-165.

Mohammed, M., and Brecht, J.K. 2003. Immature Fruit Vegetables. In: Postharvest Physiology and Pathology of Vegetables. Second Edition. Editors: Bartz, J.A. and Brecht J.K. New York Basel. Marcel Dekker, Inc. 671-690. 773 pp.

Mohammed, M., and Sealy. 1986. Extending the shelf life of melongene using polymeric films. Trop. Agr. 63:36-40.

Moncada, A., Miceli, A., Vetrano, F., Mineo, V., Planeta, D., and D'Anna, F. 2013. Effect of grafting on yield and quality of eggplant (Solanum melongena L.). Scientia Horticulturae. 149: 108-114.

Morishita, M., Suzuki, T., Takaura, Y., Inno, Y., Tanigawa, N., Negoro, M., and Sarasi, K. 1994. The effect of transpiration treatment on the skin injury of eggplant (*Solanum melongena*) fruits. Bulletin of the Osaka Agricultural Research Center. 30: 21-27.

Mueller, L.A., Solow, T.H., Taylor, N., Skwarecki, B., Buels, R., Binns, J., Lin, C.H., Wrigth, M., Ahrens, R., Wang, Y., Herbst, E.V., Keyder, E.R., Mend, A.N., Zamir D., and Tanksley, S.D. 2005. The SOL genomic network. A comparative resource for Solanaceae biology and beyond. Plant Physiol. 138: 1310-1317.

Naujeer, H.B. 2009. Morphological diversity in eggplant (Solanum melongena L.), their related species and wild types conserved at the National gene bank in Mauritius. MA thesis, Swedish Biodiversity Centre. (Publication No. 57).

Nussinovitch, A., Ward, G., and Mey-Tal, E. 1996. Gloss of fruits and vegetables. Lebensm. — Wiss. U. — Technol. 29:184-186.

Pedreschi, R., Lurie, S., Hertog, M., Nicolai, B., Mes, J., and Woltering, E. 2013. Review: Post-harvest proteomics and food security. Proteomics. 13: 1772-1783.

Rashid, S.N., Alam, S.N., Rouf, F.M.A., and Talekar, N.S. 2003. Socio-economic parameters of eggplant pest control in Jessore District of Bangladesh. Shanhua, Taiwan: AVRDC — the World Vegetable Center. AVRDC Publication No. 03-556. 29 pp.

Reddy G.V.P., Kikuchi, R., Remolona, J.E. 2011. New mite species associated with certain plant species from Guam. J. Entomol. Res. Ser. II (43): 41-46.

Risse, L.A., and Miller, W.R., 1983. Film wrapping and decay of eggplant. Proc. Fla. State Hort. Soc. 96: 350-352.

Ryall, M.S., and Lipton, W.J. 1979. Handling, transportation and storage of fruits and vegetables. Vol. 1, 2nd ed. Vegetables and Melons. AVI Publ. Co., Inc. 587 pp.

Sadilova, E., Stintzing, F.C., and Carle, R. 2006. Anthocyanins, colour and antioxidant properties of eggplant (Solanum melongena L.) and violet pepper (Capsicum annuum L.) peel extracts. Z. Naturforsch. 61c: 527-535

Sekara, A., Cebula, S., and Kunicki, E. 2007. Cultivated eggplants – origin, breeding objectives and genetic resources, a review. Fol. Hort. 19 (1): 97-114.

Singh, A.P., Luthria, D., Wilson, T., Vorsa, N., Singh, V., Banuelos, G.S., and Pasakdee, S. 2009. Polyphenols content and antioxidant capacity of eggplant pulp. Food Chemistry. 114: 955-961.

Sugiyama, J., and Tsuta, M. 2010. Visualization of sugar distribution of melons by hyperspectral technique. In: In: Hyperspectral imaging for food quality analysis and control. First Edition. Editor: Sun, D.W. 349-368.

Swarup, V. 1995. Genetic resources and breeding of aubergine (S. melongena L.). Acta Horticulture. 412: 71-79.

Takao, H., and Ohmori, S. 1994. Development of device for nondestructive evaluation of fruit firmness. Japan Agriculture and Animal Husbandry. 23: 325-330.

Ullio, L. 2003. Eggplant growing. Agfact H8. 1.29, third edition. NSW Agriculture. Available on: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/126292/Eggplant-Growing-Agfact-H8.1.29.pdf. Accessed on October 16, 2013.

Uncini, L. F.L. Gorini, and A. Sozzi. 1976. Cultural value and reaction to cold storage of the first Italian eggplant hybrids (Solanum melongena L.) in comparison with other foreign varieties. Ann. Dell I.V.T.P.A 17:191-221 (in Italian)

Vinson, J.A., Hao, Y., Su, X., Zubik, L. 1998. Phenol antioxidant quantity and quality in foods: vegetables. J. Agric. Food Chem. 46: 3630-3634.

Wang, N., and ElMasry, G. 2010. Bruise detection of apples using hyperspectral imaging. In: Hyperspectral imaging for food quality analysis and control. First

Edition. Editor: Sun, D.W. 295-320.

Wang, C.Y. 1999. Postharvest quality decline, quality maintenance and quality evaluation. Proc. Int. Symp. on Effect of Pre- and Post Harvest Factores on Storage of Fruit. Acta Hort. 485: 389-392.

Whitaker, B.D., and Stommel, J.R. 2003. Distribution of hydroxycinnamic acid conjugates in fruit of commercial eggplant (Solanum melongena L.) cultivars. J. Agric. Food Chem. 51: 3448-3454.

Worthington, L. 2012. Serving up a bitter end for eggplant pests. Northeastern IPM Centre. Available on: http://www.northeastipm.org/about-us/publications/ipm-insights/serving-up-a-bitter-end-for-eggplant-pests/. Accessed on October 12, 2013.

CONNECTING TEXT

The review of literature showed the great need and potential for non-destructive measurement of eggplant quality. In the following section (Chapter IV), Instron testing machine and hyperspectral-imaging technique were used to determine, respectively, surface stiffness and peel gloss of fresh and stored eggplants. The effects of source (farms where eggplant fruit come from), and temperature and light conditions on eggplant quality were studied. Quantitative parameters (mass, volume, and density) were also analyzed.

IV. Evaluation of Quality of an American Variety of Eggplant (*Solanum melongena* L. cv. Traviata) Stored at Various Light and Temperature Conditions

4.1. Abstract

Eggplant (*Solanum melongena* L.) is an economically important vegetable crop. There are many varieties that differ in shape, colour, size, etc. The dark purple eggplants are the most cultivated. The objective of this work was to determine quality parameters of an American variety of eggplant from two different farms. Instron machine was used to conduct non-destructive compression tests to evaluate the surface stiffness of fresh and stored eggplants. Hyperspectral images of fresh and stored eggplants, in the near infrared (NIR) range, were acquired in order to interpret their peel gloss. Mass and volume of eggplants decreased during storage; density, on the other hand, increased significantly. The peel gloss consistently decreased during storage, except for the dark and low-temperature condition, where the eggplants gained gloss during the first six days of storage. After this period, peel gloss of eggplants started to decrease. Surface stiffness decreased during storage. Source, temperature and light exposure showed significant effects on the quality features of the fruit at different storage periods.

4.2. Introduction

Eggplant is an economically important vegetable crop of South Asian origin that is cultivated worldwide, although it is more common in the tropics and subtropics (Mohammed and Brecht, 2003). Its world production in 2011 was 46.8 million tons, with China (27.7 million tons) and India (11.9 million tons) as the largest producers (FAOSTAT, 2013). Eggplant is a source of vitamins and minerals, but its reputation is mostly owing to the fact that it is a good source of antioxidants such as alkaloids, anthocyanins and phenolic acids, which have beneficial effects on human health (Aubert et al., 1989; Gajewski et al., 2009). Eggplant is among the top vegetables in terms of Oxygen Radical Absorbance Capacity (ORAC) (Cao et al., 1996).

Eggplant reaches its peak quality when it is still in a non-mature stage on the plant. There are many eggplant varieties that differ in colour, shape, size, and flavour. The dark purple ones are the most popular in the market (Sadilova et al., 2006). A good quality eggplant of this type should have a dark purple, glossy and smooth skin, a fresh green calyx, and freedom from any visual defect. Eggplant is extremely perishable. Its shelf life ranges from 2 to 4 days when held at room temperature, due to high water losses (Mohammed and Brecht, 2003). When eggplants lose water, they turn opaque, sponge-like and more prone to decay. Although its shelf life may be extended up to 2-3 weeks with low temperatures, refrigeration is not recommended because eggplant is highly susceptible to chilling injury when stored for long periods at temperatures below 7-10°C (Concellón et al., 2007). Chilling injured eggplants show symptoms such as pitting, surface bronzing, and browning of seeds and pulp tissue (Cantwell and Suslow, 1997). Decay caused by *Alternaria* spp. is a response to chilling injury. The best temperature and relative humidity (RH) for storing American varieties of eggplant fruit are 10-12°C and 90-95%, respectively (Cantwell and Suslow, 1997). Covering eggplant with films or thin layers of wax is helpful to prevent the fruit from losing moisture; hence, its quality is maintained for longer periods (Mohammed and Brecht, 2003).

Quality evaluation approaches for horticultural crops are based on subjective and visual inspection of the fruit's external appearance (Jha and Matsuoka, 2000). Although there are some work done on studying the effect of temperature and storage period on quantity and quality features of Asian eggplant varieties (long and slender ones) (Jha and Matsuoka, 2002a; 2002b; Jha et al., 2002), in order to establish non-invasive methods for their quality evaluation, there is no work done for this purpose on American eggplant varieties. The effect of light on quantitative and qualitative parameters of eggplant, during postharvest storage, has not been studied either. The first objective of this research was to evaluate the use of hyperspectral imaging and Instron Testing machine as potential non-destructive test method to predict quality attributes of eggplant namely peel gloss and surface stiffness. It was also envisioned to study the effect of source (farms where fruits come from), light, temperature, and storage period on quantity (volume, mass, and density) and quality (surface stiffness, and peel gloss) parameters of fresh and stored eggplants (American type — Traviata).

4.3. Methods and Materials

4.3.1. Sampling of Eggplant

Eggplant (*Solanum melongena* L. cv. Traviata) was grown in local organic farms in Montreal, Quebec during the summer of 2013. *S. melongena* fruits were harvested manually when they were still in a non-mature stage on the plant. Fresh good quality eggplants (dark purple, smooth, and glossy skin and a fresh green calyx, and free from any visual defect) were selected for this research. In total, 48 eggplants (24 from each farm) were used for this experiment.

4.3.2. Experimental Design

A factorial design was used for this experiment. The factors were: source (farm where eggplants came from), temperature, light exposure, and storage period. Two levels of source, temperature, and light exposure were tested at seven intervals of postharvest storage (Table 4.1).

Table 4.1 Experimental design for quantity and quality evaluations of eggplant fruit

Factor	Levels
Source (Farm)	Tourne-Sol Co-operative (1) and Les Jardins Carya (2)
Temperature (°C)	10 and 27
Light exposure ($h{\cdot}d^{-1}$)	0 and 12
Storage period (h)	0, 48, 96, 144, 192, 240 and 288

*RH was set to be constant: 85±5%; light exposure is expressed in hours per day (h·d)

4.3.3. Postharvest Storage

The storage of eggplants took place in Conviron chambers (Controlled Environments Ltd., Winnipeg, Manitoba, Canada), which had 15 ft^2 of area. These chambers were located at the McGill University Phytotron. They were equipped with fluorescent tubes and incandescent bulbs, as well as temperature and humidity control. These chambers were programmed in order to have the storage conditions (SCs) that are shown in Table 4.2.

Table 4.2 The four storage conditions at which the Traviata variety of eggplant was subjected for a period of 12 days (288 h)

SC_1	SC_2	SC_3	SC_4
T = 10°C and 0 h of illumination (85% of RH)	T = 10°C and 12 h of illumination (85% of RH	T = 27°C and 0 h of illumination (85% of RH)	T = 27°C and 12 h of illumination (85% of RH)

*T stands for temperature

For the illumination, the two quality lights, fluorescent and incandescent, were used simultaneously. The light intensity in the control chambers was set to reach its maximum value, a photon flux of 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (this is when all the lights are on). According to Runkle (2006), the best unit of light intensity for studies involving plant responses is the $\mu mol \cdot m^{-2} \cdot s^{-1}$, which describes the number of photons of light within the photosynthetic waveband that an area of one square meter receives per second. The illumination was stepped between day and night; the lamps were on from 8:00 a.m. to 8:00 p.m. every day. It is important to make it clear that the maximum value of light intensity in the control chambers is only a fraction of the light intensity that may be reached outdoors on a bright day (10,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$) (Janick, 1972).

4.3.4. Experimentation

The eggplants were washed with cold water, dried with paper towels, and used for the experiments the day they were harvested (d 0). After experimentation, eggplants were wrapped in polyethylene film and then placed in their corresponding chamber. As seen in Table 4.1, the quality and quantity evaluations were carried out every 48 h.

The quantity evaluation consisted of taking measurements of mass, volume, and density of individual fruits. The quality evaluation included the hyperspectral imaging technique and the non-invasive compression tests to compute, respectively, the peel gloss and the surface stiffness of eggplant.

In order to simplify the discussion of the results, the four storage conditions were labeled SC_1, SC_2, SC_3 and SC_4 as described in Table 4.2. The low temperature (10°C) was chosen so that the eggplants would not suffer chilling injury. The RH was set to be 85±5%, because Cantwell and Suslow (1997) recommend using RH around 90% to maintain the quality of eggplant for longer periods.

4.3.4.1. Mass, Volume, and Density

An electronic precision balance with a least count of 0.01 g decimal place was used to measure the individual mass of fresh and stored eggplants. A tank full of water at 20°C was placed in a plastic container. Eggplant fruits were immersed, individually, in the tank. The amount of spilled water, which was collected in the plastic container, was measured using a graduated cylinder with a minimum graduation of 5 mL, and that was taken as the volume of each eggplant. Mass of each eggplant was then divided by the volume to calculate its density. Density was expressed in kilograms per cubic meter ($kg \cdot m^{-3}$).

4.3.4.2. Surface Stiffness

A deformation occurs if a mechanical structure (any geometrical body consisting of a solid material) becomes loaded. Stiffness is a term used to describe the force needed to achieve a deformation of a structure (Baumgart, 2000):

$$Stiffness = \frac{Load}{Deformation} \tag{4.1}$$

A similar non-invasive method by Jha and Matsuoka (2002a) was performed to obtain values of surface stiffness of fresh and stored eggplants. Instron Universal testing machine, model 4502, Series IX Automated Materials Testing System (Instron Corporation, Norwood, MA, USA) was used for this purpose. The compression was fixed to be 2.5 mm, which is enough not to puncture the peel of the fruit. Preliminary tests were performed to verify that at that depth the peel would not be damaged. The data tabulated in the computer produced a force-displacement curve (Fig. 4.1). The Modulus of Deformability (MD) is defined as the initial slope of the force-deformation curve. The MD is an indication of the stiffness of the material (Pons and Fiszman, 1996). So, the initial slope of the curve was taken as the surface stiffness of eggplant; it has units of Newtons per millimetre ($N \cdot mm^{-1}$).

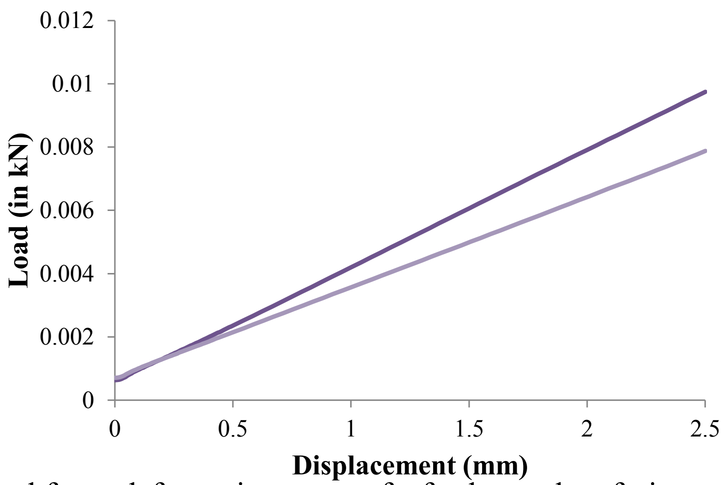

Fig. 4.1 A typical force-deformation curve of a fresh eggplant fruit

Capacity, least count (minimum amount of load noticeable), compression rate, and cross head (pressing tip, rounded edge, plunger) diameter of the load cell were 50 N, 0.0001 N, 5 millimetre per minute (mm·min^{-1}), and 5 mm, respectively. The eggplant fruits were kept horizontal during the experiment, and the non-destructive compression tests were conducted at two different points at latitudinal (with respect to the maximum diameter) angle of 90° to the centre of the eggplant.

4.3.4.3. Peel Gloss

The hyperspectral imaging system used for this study was similar to the one that Nour and Ngadi (2011) developed. The system consisted of a line-scan spectrograph (Hyperspec^{TM}; Headwall Photonics Inc., Fitchburg, MA, USA), an InGaAs camera, two light sources, a conveyer (Donner 2200 series; Donner Mfg. Corp., Hartland, WI, USA), an enclosure, a data-acquisition and pre-processing software, and a PC. The system was set to collect images in the spectral region of 900-1,700 nm, with a resolution of 2.8 nm. The conveyer was driven by a stepping motor with a user-defined speed (MDIP22314; Intelligent Motion System Inc., Marlborough, CT, USA).

In spectroscopy and Hyperspectral imaging, reflection angles larger than 50° are used for lower-gloss objects, whereas small reflection angles are used for high-gloss objects (Mizrach, et al., 2009). Since eggplant has a high-gloss surface (Jha et al., 2002; Jha and Matsuoka, 2002b) the two tungsten halogen lamps (50 Watts each) were positioned at an angle of 15°, with respect to the horizontal fruit, to provide efficient illumination for the crops as they were moved across the field of view of the camera.

4.3.4.3.1. Hyperspectral Image Acquisition, and Processing and Pre-Processing

MATLAB (The MathWorks, Inc., MA, USA) was used to process the images in order to obtain their spectral data that was used to interpret the peel gloss of eggplants. Image acquisition of eggplant fruit was done on day 0 (the day they were harvested), and every 48 h during 12 days. At each stage of stored eggplants, all the 48 eggplants (24 from each farm) were used for acquiring the images. All the images were recorded in raw files, which contained minimally processed data from the image sensor. At the stage of image pre-processing, all spectral images were corrected for the dark current of the camera before selecting the region of interest (ROI) of each sample.

To correct the spectral images, a dark image B, and a white image W were obtained by covering the lens with a cap and by taking an image from a standard white reference (Spectralon, Labsphere, North Sutton, NH, USA). Thus, the relative reflectance as a function of wavelength, $I_s(\lambda)$, was calculated as by Liu et al., (2010) expressed:

$$I_s(\lambda) = \frac{I_0 - B}{W - B} \tag{4.2}$$

where I_0 is the original spectral image.

The ROIs (Fig. 4.2), representing each eggplant with no calyx and stem, were selected manually from individual fruit raw images. The peel gloss (I_s) (dimensionless) for the ranges of wavelength 947-1,397 and 1,469-1694 nm (Fig. 4.3) falling on the object could be obtained by:

$$I_s = \int_{947}^{1397} I_s(\lambda)\mathrm{d}\lambda + \int_{1469}^{1694} I_s(\lambda)\mathrm{d}\lambda \tag{4.3}$$

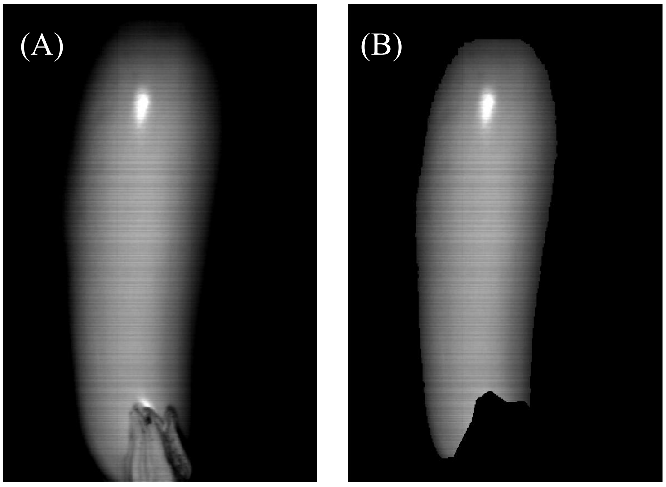

Fig. 4.2 Raw (A) and ROI (B) hyperspectral images of a fresh eggplant

Although the brightness of the surface of a material is usually the area under the curve of reflectance *vs.* wavelength within the visible range (390-700 nm), Silfsten et al., (2012) suggest that specular reflection data in the NIR range can be useful in the interpretation of gloss in the visible spectral range. As seen in Fig. 4.3, the surface spectral reflectance changes with the wavelength of incident light.

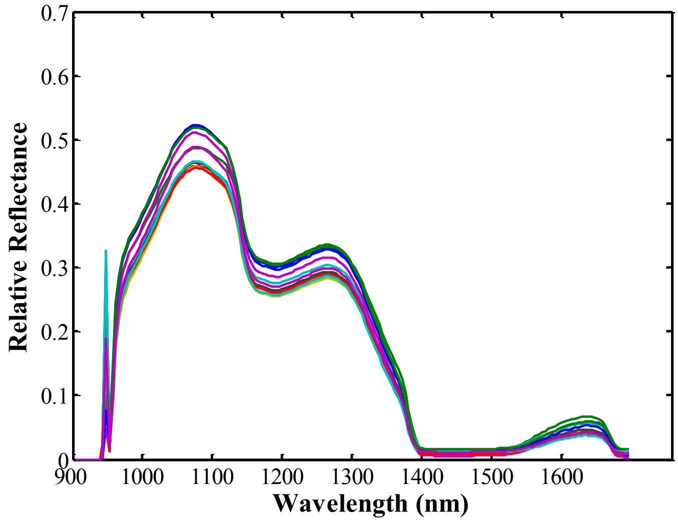

Fig. 4.3 Reflectance-wavelength curve of hyperspectral images of 12 fresh eggplant fruits in the spectral region 900-1,700 nm

Ward and Nussinovitch (1996) determined that the natural waxes are responsible for the peel gloss of eggplant due to their ability to reflect light. Both the visible and NIR radiation, penetrating the surface tissue, are reduced by the waxes. Consequently, the reflectance in the NIR range of wavelength can be useful to interpret the peel gloss.

4.4.6. Statistical Analysis

Generalized linear mixed models, with covariance structure based on time, were produced on SAS to analyze the experimental data. Local regression curves (LOESS) with confidence intervals ($\alpha = 0.05$) were produced. The smooth parameter is the proportion of the group that is fit by the polynomial function. A smooth parameter of 1 was used for the plots from the section of Results and Discussion. This means that 100% of the data was fit by each polynomial function. That is the reason why in some curves the different ratios at time = 0 are not exactly 1.

In the case of ratios (except for density ratios), the distribution was considered to be binomial. The p-values were obtained to determine the significance of the factors and/or their interactions.

4.4. Results and Discussion

4.4.1. Quantity Parameters

4.4.1.1 Mass, Volume, and Density

This experiment was divided in two stages. SC_2 and SC_3 comprised the first stage, and SC_1 and SC_4 the second one.

On the day that eggplants of the first stage of the experiment were harvested, the crops from source 1 had the following average values: maximum diameter (D_{max}) = 73.50 mm, length (L) = 140 mm, and mass (m) = 226.90. Similarly, the crops from source 2: D_{max} = 77.05 mm, L = 140 mm, and m = 277.08 g. For the second stage of the experiment, the eggplants from source 1 had the following average values: D_{max} = 77.05 mm, L = 150 mm, and m =259.18 g. The crops from source 2 that were used for the second stage had the following average values: D_{max} = 76.48 mm, L = 146 mm, and m = 305.20 g. The eggplants from the second stage were obtained from the farmers two weeks after obtaining the ones from the first stage. Fig. 4.4 (A) shows that fruits from source 2 had a higher mass than eggplants from source 1.

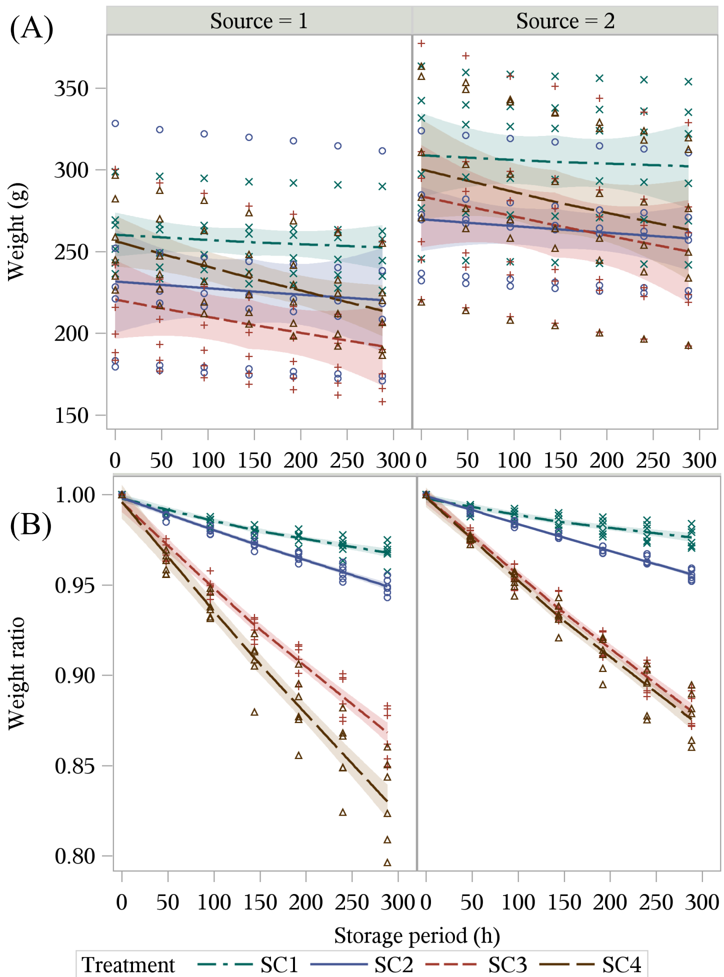

Fig. 4.4 Local regression curves of weight (A) and weight ratios (W/W_0) (B) of eggplant fruit during different conditions of postharvest storage. The colour bands represent the confidence limits

Mass decreased linearly during storage at all light and temperature conditions (Fig.

4.4). Source had a significant effect on weight ratios of eggplant at all storage periods ($p < 0.0001$). At 48 h of storage, temperature and light exposure had a significant effect on the weight ratios of eggplant ($p < 0.0001$, and $p = 0.0274$, respectively). At 96 and 144 h of storage, these factors were also significant. The two-way interaction temperature-light exposure was significant at 192 and 240 h of storage ($p = 0.0040$ and $p = 0.0017$, respectively). For the last storage period (288 h) the three-way interaction temperature-light exposure-source had a significant effect on the weight ratios of eggplant ($p = 0.0354$).

When the confidence limits (the coloured bands in Fig. 4.4-4.8) do not overlap, it means that there are significant differences between the treatments (SCs). Eggplants from both sources that were stored at low-temperature conditions had lower mass losses when kept in darkness (SC_1) than when they were exposed to 12 $h \cdot d^{-1}$ of light (SC_2) (Fig. 4.4 B). This was attributed to the fact that stomata from the calyx are triggered to open in the light so that carbon dioxide is available for the light-dependent process of photosynthesis, increasing the transpiration rate (Sterling, 2005). Transpiration is the main cause of mass losses of horticultural crops. Growing crops can replace lost water from the soil, but harvested fruits (which are still living tissues) cannot (Díaz-Pérez, 1998). Stomata, on the contrary, are closed in dark conditions (Sterling, 2005). The effect of light on weight ratios of the fruits from source 1 is consistent: the mass losses are higher for SC_4 than for SC_3. Interestingly, for the weight ratios of eggplants from source 2, the effect of light was not significant at any storage period when held at 27°C.

Temperature, definitely, was a significant factor for weight ratios of eggplant from both sources. Temperature greatly influences the magnitude of the driving force for water movement out of the fruit rather than having a direct effect on the calyx stomata (Sterling, 2005). This is because temperature changes the ability of air to hold water: warmer air holds more water than cool air. Therefore, warmer air increases the driving force for transpiration and cooler air decreases the driving force for transpiration. This is why mass losses were higher in fruits stored at 27°C than in those stored at 10°C.

Eggplant volume decreased linearly over time at the cooler SCs. And, for the warmer SCs, the volume decreased exponentially (Fig. 4.5). The reduction of volume of individual *S. melongena* was due to the fact that eggplants shrank as a consequence of moisture loss.

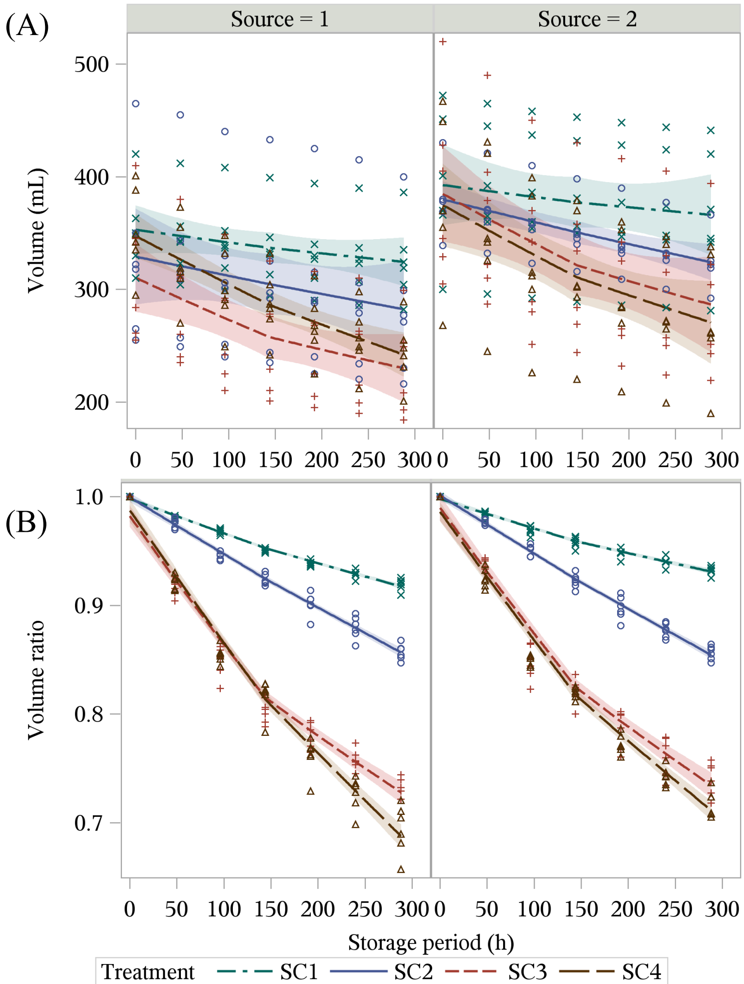

Fig. 4.5 Local regression curves of volume (A) and volume ratios (V/V_0) (B) of eggplant fruit during different conditions of postharvest storage. The coloured bands represent the confidence limits

Fig. 4.5 (A) shows that the eggplants from source 2 had a significantly higher volume than eggplants from source 1 ($p = 0.0067$). Source was a significant factor for volume of eggplants at all storage periods. This was consistent with their mass values. For the volume ratios, the two-way interaction temperature-light exposure was a significant factor at the storage periods 96 and 192 h ($p < 0.0001$). Source did not have a significant effect on the volume ratios at these storage periods.

At the storage period of 48 h, the two-way interactions temperature-light exposure and light exposure-source had significant effects on the volume ratios ($p = 0.0166$ and $p = 0.0069$, respectively). The same two interactions were significant at 144 h ($p < 0.0001$ and $p = 0.0055$, respectively). The three-way interaction temperature-light exposure-source was significant for volume ratios at the last two storage periods, 240 and 288 h (p = 0.0064 and p = 0.0067, respectively). Volume ratios of eggplants at cool-temperature conditions (SC_1 and SC_2), from both sources, were clearly different from each other (Fig. 4.5 B). For eggplants from source 2, light did not significantly affect the volume ratios of eggplants for any storage period at the temperature of 27°C. However, for fruits from source 1, stored at 27°C, light had a significant effect on their volume ratios at 144 h and later storage periods (Fig. 4.5 B).

Contrary to mass and volume losses, eggplant density increased over time at all SCs (Fig. 4.6). For SC_3 and SC_4, the density increased sharply during the first 108 h of storage. After this point, the rate decreased. Density increased because the rates at which volume declined were significantly higher than the rates at which fruit mass losses occurred. Similar results of density changes during different SCs of an Asian cultivar of eggplant have been reported (Jha and Matsuoka, 2002a; 2002b).

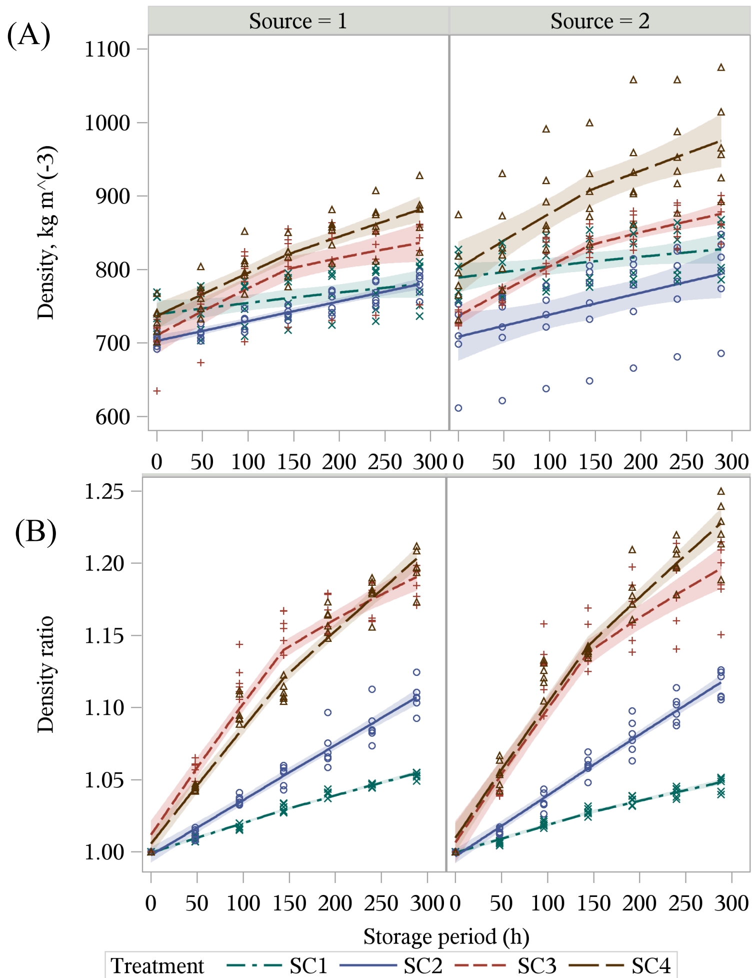

Fig. 4.6 Local regression curves of density (A) and density ratios (ρ/ρ_0) (B) of eggplant fruit during different conditions of postharvest storage. The coloured bands represent the confidence limits

Fresh eggplants from source 2 had, significantly, higher density values than those from Source 1 ($p = 0.0005$) (Fig. 4.6 A). Source was a significant factor on eggplant density at all SCs.

For the density ratios, temperature and the two-way interaction light exposure-source were significant at storage period 48 h ($p < 0.0001$); the two way-interactions temperature-light exposure and temperature-source were significant at storage periods 96 h ($p = 0.0001$ and $p = 0.0232$, respectively) and 288 h ($p < 0.0001$ and $p = 0.0306$, respectively); the three way interaction temperature-light exposure-source, at storage period 144 h, was significant ($p = 0.0057$); and the two-way interaction temperature-light exposure was significant at storage periods 192 and 240 h ($p = 0.0002$).

SC_1 and SC_2, as observed in Fig. 4.6 (B), are clearly different from each other in terms of density ratio of eggplant fruit from the two sources. At SC_1, the density ratio increased at a lower rate than at SC_2. SC_3 and SC_4, on the other hand, did not differ significantly, except for the storage periods 144 and 192 h for *S. melongena* from source 1, and the storage periods 240 and 288 h for fruits from source 2 (Fig. 4.6 B).

4.4.2. Quality Parameters

4.4.2.1 Surface Stiffness

The initial average values of surface stiffness of eggplant from source 1 and 2 were, respectively, 3.861 and 5.644 $N \cdot mm^{-1}$ (Fig. 4.7 A). These averages are higher than the ones that Jha and Matsuoka (2002a) reported for an Asian variety of eggplant.

Source was an extremely significant factor on surface stiffness of eggplant fruit at all storage periods ($p < 0.0001$). The eggplants from source 2 were stiffer than those from source 1. Gajewski and Arasimowicz (2004) determined that the stiffness of eggplant surface depends on maturity stage: the firmness of eggplant increases with fruit development. From this, we can suggest that eggplants from source 2 were more developed than eggplants from source 1. This is consistent with the fact that eggplants from source 2 had higher initial values of both weight and volume (Fig. 4.5 and Fig. 4.6). The surface stiffness of the eggplants from source 2 declined, initially, at a much higher rate than the fruits from source 1 (Fig. 4.7 A). The fruits from source 1 showed a more uniform initial surface stiffness, which suggests that the farm Tourne-Sol has a more standardized method of harvesting. The surface stiffness of eggplant, from the two sources, decreased linearly over time at both low-temperature conditions (SC_1 and SC_2), and exponentially at both high-temperature conditions (SC_3 and SC_4).

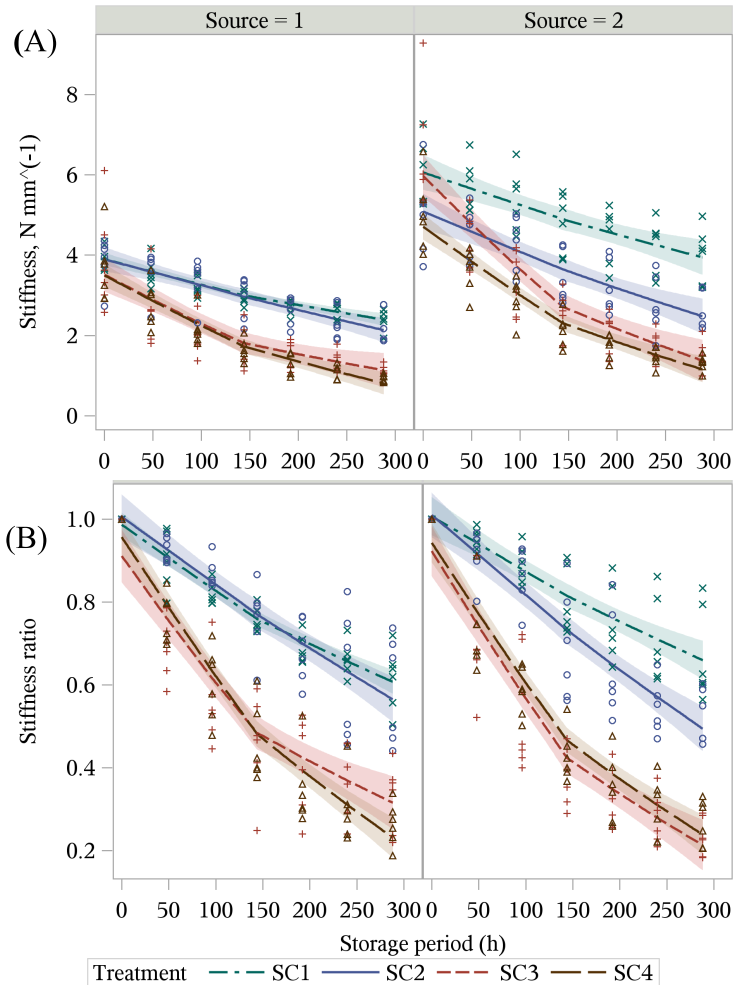

Fig. 4.7 Local regression curves of surface stiffness (A) and surface stiffness ratios (S/S_0) (B) of eggplant fruit during different conditions of postharvest storage. The coloured bands represent the confidence limits

For the surface stiffness ratios, temperature was the only significant factor at the storage periods of 48, 96, 144, and 192 h ($p < 0.0001$). However, at 240 h of storage, both temperature and light exposure had a significant effect on stiffness ratios ($p < 0.0001$ and $p = 0.0240$, respectively). The three-way interaction temperature-light exposure-source was significant at the last storage period ($p = 0.0265$). As shown in Fig. 4.7 (B), for the eggplants from source 2, the confidence limits of the two cooler SCs do not overlap at the storage periods of 192, 240, and 288 h. Stiffness ratios were higher at SC_1 (the cooler and dark storage condition). Jha and Matsuoka (2002a) attributed the decline of surface stiffness, during storage, to the shrinkage of eggplant fruit caused by the mass and volume losses. The upper layer of the fruit (epidermis) becomes loose; thus, it has minimal resistance to pressing during compression.

4.4.2.2 Peel Gloss

The peel gloss of eggplant fruit is an important parameter when it comes to its quality evaluation. The surface spectral reflectance changes with the wavelength of incident light. The area under the curve reflectance vs. wavelength, except for the interval 1,402-1,464 nm, where reflectance was negligible (Fig. 4.3), was used to interpret the peel gloss of eggplant fruit. Fig. 4.8 illustrates that the peel gloss of *S. melongena* (cv. Traviata), from both sources, declined over time at all SCs, except for SC_2, where peel gloss, first, increased slightly from 0 to 144 h of storage, and then declined for the rest storage periods.

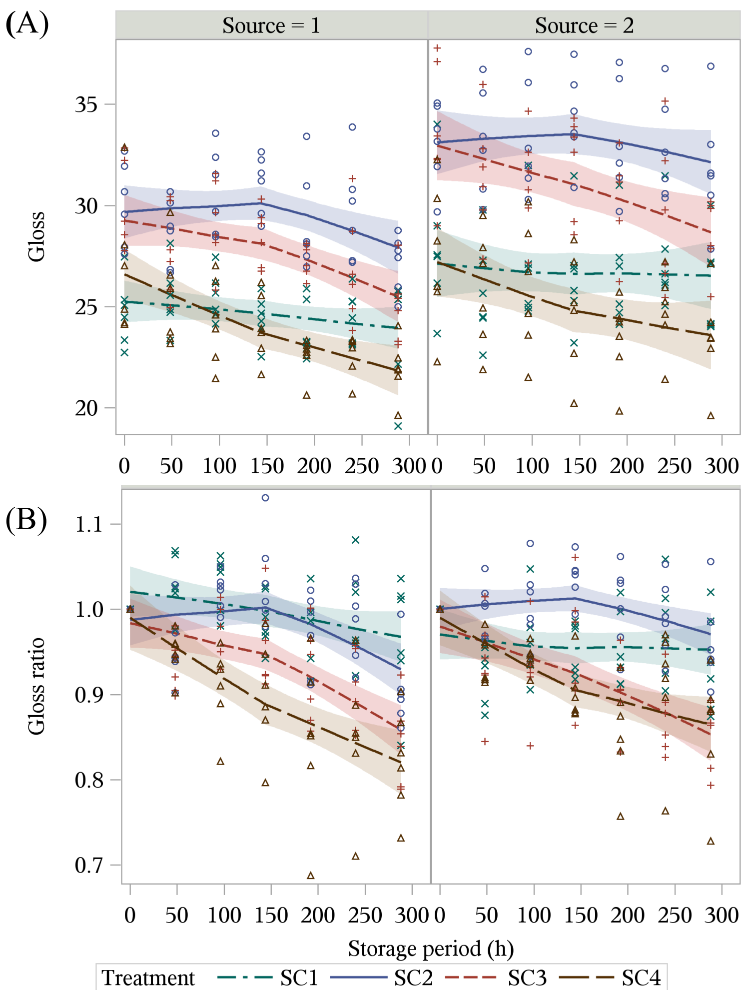

Fig. 4.8 Local regression curves of peel gloss (A) and peel gloss ratios (G/G_0) (B) of eggplant fruit during different conditions of postharvest storage. The coloured bands represent the confidence limits

Jha et al., (2002) suggested that the decrease in gloss with storage period was a consequence of the increasing roughness of the surface of the fruit. The increasing roughness during storage may be an indirect effect of moisture loss and shrinkage of the fruit. Shrinkage of eggplant stored at warmer conditions was very obvious. At cooler temperature, this shrinkage was much subtler. The shrinkage might have damaged the epidermal cells of eggplant and might have made the surface rough.

However, we have to consider that an important component of the fruit cuticle is wax, which is, in part, responsible for reducing both the visible and NIR radiation penetrating the surface tissue due to its ability to reflect light (Ward and Nussinovitch, 1996). Bauer et al., (2005) carried out an experiment in which they identified the waxes present in the peel of three eggplant cultivars. Since gloss is a function of the inherent reflectivity of surface and its specular and diffuse reflectances (Hunter, 1952; Skilling, 1948), epicuticular wax would be partially accountable for gloss properties of plant tissues. Ward and Nussinovitch (1996) found that by removing epicuticular wax of eggplant, tomatoes, and apples, there was a decrease in peel gloss of the fruits, which indicates its influence on the shininess. In their study, it was concluded that the smooth appearance of the lamellae-type wax pattern covering eggplant reflects light more efficiently than the amorphous wax layer covering tomato and the large overlapping platelets of the apple; therefore, eggplant was the crop with the highest values of peel gloss. So, changes in quantity and structure of the surface waxes of eggplant were other factors that triggered the decrease in its gloss during storage.

The peel gloss values of fresh eggplant from source 1 and 2 were significantly different from each other ($p = 0.0019$). The eggplants from source 1 were brighter than the fruits from source 2. This is consistent with the values of surface stiffness, weight, and volume of fresh fruits from both sources. It is important to mention that the peel gloss values of fresh eggplants from both sources that were subjected to SC_2 and SC_3 (first stage of the experiment) were significantly higher than the fresh fruits that were subjected to SC_1 and SC_4 (second stage of the experiment) (Fig. 4.8 A), possibly, because of a subtle reduction in the angle of one of the illumination sources. The fact that the fruits from both sources that were subjected to SC_1 and SC_4 were obtained 2 weeks after getting the *S. melongena* that were subjected to SC_2 and SC_3 (they belonged to different batches) could have been another reason why there were such significant differences between their initial peel gloss values.

For the peel gloss ratios of eggplant from the two sources, there were no significant differences during the first 48 h of storage. Temperature had a significant effect on the peel gloss ratios at storage periods of 96, 192, 240, and 288 h ($p = 0.0058$, $p = 0.0005$, $p = 0.0004$, and $p < 0.0001$, respectively). At 144 h of storage, the two-way interaction temperature-light exposure was significant ($p = 0.0467$). The two-way interaction light exposure-source was significant at 96 h of storage ($p = 0.0044$). As it can be noticed in Fig. 4.8 (B), eggplants experienced more peel gloss losses when held at warmer conditions. The confidence limits of SC_3 and SC_4 (warmer SCs) do not overlap at storage periods of 144 and 192 h for eggplants from source 1. Peel gloss ratios of *S. melongena* from source 1 that were subjected to SC_3 (dark and warmer condition) were significantly higher than the ones subjected to SC_4. Interestingly, for the fruits from source 2 that were subjected to SC_1 and SC_2, the effect of light was the opposite: during the storage period 96-192 h, the peel gloss ratios were significantly lower in darkness. In Fig. 4.8A, one can see that eggplants from both sources that were subjected to SC_1 increased slightly in peel gloss from 0 to 144 h of storage, and then the gloss started to decrease for the rest of the storage periods. Since eggplants were harvested in a non-mature stage, their light exposure at cooler temperature might have favoured a postharvest fruit development, increasing or rearranging the natural surface waxes.

4.5. Conclusion

This research showed the potential application of hyperspectral imaging technique and Instron Testing machine as tools for, respectively, measuring the peel gloss and surface stiffness of an American cultivar of eggplant fruit. The effects of source, storage period, and different light and temperature conditions on these quality parameters (peel gloss and surface stiffness), and also on quantity parameters (weight, volume and density), were studied. Source was a significant effect on both quality and quantity parameters. It was suggested that eggplants from source 2 were more developed than fruits from source 1. Eggplants from source 1 showed a more uniform stiffness from batch to batch, which shows that they have a more standardized method of harvesting. It was seen that both temperature and light exposure had a significant effect on the eggplant transpiration. At 27°C mass losses were higher than at 10°C. The effect of light was similar: mass losses were lower when eggplants were held in darkness conditions. Density increased during storage. This was attributed to the fact that the volume losses rate was higher than the rate at which fruit mass losses occurred. The peel gloss decreased during storage, except for the cooler and light condition. Eggplants from both sources increased in peel gloss during the first 144 h of storage, and then their gloss decreased during the rest of storage periods. It was concluded that, since eggplants were harvested in a non-mature stage, the light favoured the postharvest fruit development at the low temperature.

Acknowledgement

The Canadian International Food Security Research Fund (CIFSRF), which is a program of Canada's International Development Research Centre (IDRC) undertaken with the financial support of the Government of Canada provided through Foreign Affairs, Trade and Development Canada (DFATD), is acknowledged for financing this project.

References

Aubert, S., Daunay, M.C., and Pochard, E. 1989. Saponosides stéroïdiques de l'aubergine (Solanum melongena L.). I-intérêt alimentaire, méthodologie d'analyse, localization dans le fruit. Agronomie. 9: 641-651.

Bauer, S., Schulte, E., and Thier H.P. 2005. Composition of the surface waxes from bell pepper and eggplant. Eur. Food Res. Technol. 220: 5-10

Cantwell, M., and Suslow, T.V. 1997. Eggplant: recommendations for maintaining postharvest quality. Available online at: http://postharvest.ucdavis.edu/pfvegetable/Eggplant/. Accessed on November 16th, 2012.

Cao, G., Sofic, E., and Prior, R.L. 1996. Antioxidant capacity of tea and common vegetables. J. Agric. Food Chem. 44: 3426–3431.

Concellón, A., Añón, M.C., and Chaves, A.R. 2007. Effect of low temperature storage on physical and physiological characteristics of eggplant fruit (Solanum melongena L.). LWT 40: 389-396

Díaz-Pérez, J.C. 1998. Transpiration rates in eggplant fruit as affected by fruit and calyx size. Postharvest Biology and Technology. 13: 45-49.

FAOSTAT (Food and Agriculture Organization of the United Nations). Accessed June 2013. http://faostat.fao.org.

Gajewski, M., and Arasimowicz, D. 2004. Sensory quality of eggplant fruits

(Solanum melongena L.) as affected by cultivar and maturity stage. Pol. J. Food Nutri. Sci. 13/54, No 3: 249-254

Gajewski, M., Katarzyna, K., and Bajer, M. 2009. The influence of postharvest storage on quality characteristics of fruit of eggplant cultivars. Not. Bot. Hort. Agrobot. Cluj 37: 200-205.

Hunter, R.S. 1952 . Gloss Evaluation of Materials. ASTM Bull. No. 186: 48–55.

Janick, J. 1972. Horticultural Science. 2nd ed. San Francisco: Freeman, W.H. and Co. 586 pp.

Jha, S.N., and Matsuoka, T. 2000. Review: Non-destructive techniques for quality evaluation of intact fruits and vegetables. Food Sci. Technol. Res., 6(4): 248-251.

Jha, S.N., and Matsuoka, T. 2002a. Surface stiffness and density of eggplant during storage. Journal of Food Engineering. 54: 23-26.

Jha, S.N., and Matsuoka, T. 2002b. Development of freshness index of eggplant. Applied Engineering in Agriculture. 18(5): 555-558.

Jha, S.N., Matsuoka, T., and Miyauchi, K. 2002. Surface gloss and weight of eggplant during storage. Biosystems Engineering. 81(4): 407-412.

Liu, L., Ngadi, M.O., Prasher, S.O., and Gariépy, C. 2010. Categorization of pork quality using Gabor filter-based hyperspectral imaging technology. Journal of Food Engineering. 99: 284-293.

Mizrach, A., Nahir, D., and Romen, B. 1992. Mechanical thumb sensor for fruit and vegetable sorting. American Society of Agricultural Engineers. 35: 247-250.

Mohammed, M., and Brecht, J.K. 2003. Immature Fruit Vegetables. In: Postharvest Physiology and Pathology of Vegetables. Second Edition. Editors: Bartz, J.A. and Brecht J.K. New York Basel. Marcel Dekker, Inc. 671-690. 773 pp.

Nour, N.A., and Ngadi, M. 2011. Detection of omega-3 fatty acid in designer eggs using hyperspectral imaging. International Journal of Food Sciences and Nutrition. 62 (4): 418-422.

Pons, M., and Fiszman, S.M. 1996. Instrumental texture profile analysis with particular reference to gelled systems. Journal of Texture Studies. 27: 597-624.

Runkle, E. 2006. Light it up! Available on: http://www.hrt.msu.edu/energy/Notebook/pdf/Sec1/Light_it_up_by_Runkle.pdf. Accessed on October 24, 2013.

Sadilova, E., Stintzing, F.C., and Carle, R. 2006. Anthocyanins, colour and antioxidant properties of eggplant (Solanum melongena L.) and violet pepper

(Capsicum annuum L.) peel extracts. Z. Naturforsch. 61c: 527-535

Silfsten, P., Dutta, R., Pääkkönen, P., Tag, C.M., Gane, P.A.C., and Peiponen, K.E. 2012. Surface roughness and gloss study of prints: application of specular reflection at near infrared. Meas. Sci. Technol. 23: DOI 10.1088/0957-0233/23/12/125202 (8pp).

Skilling, H.H. 1948. Fundamentals of Electric Waves, p. 138. Wiley, New York.

Sterling, T.M. 2005. Transpiration — water movements through plants.

Ward, G., and Nussinovitch, A. 1996. Gloss properties and surface morphology relationships of fruits. Journal of Food Science. 61(5): 973-977.

CONNECTING TEXT

In Chapter IV, eggplant fruit from different farms were subjected to different storage conditions to study quality changes. It was observed that surface stiffness and peel gloss of eggplant declined and, conversely, their density increased over time at all storage conditions. For Chapter V, the same methodology was applied to develop a freshness index and kinetic models with which it was possible to predict such index with, for instance, initial values of weight of the fruits and their weight at any point in time. Stepwise regressions were performed to build predictive models for freshness index with the significant wavelengths.

V. Development of an Objective Freshness Index for an American Variety of Eggplant (*Solanum melongena* L. cv. Traviata)

5.1. Abstract

The objective of this work was to develop a non-subjective freshness index (I_f) for an American variety of eggplant (Solanum melongena L. cv. Traviata). I_f is defined as the dimensionless ratio of the product of the surface stiffness and peel gloss ratios to the density ratio. Storage temperature had a significant effect ($P < 0.0001$) on I_f. However, the produce source and light exposure did not have significant impact on the freshness index. I_f was plotted versus weight loss (WL), peel gloss loss (GL), surface stiffness loss (SL), density ratio minus one (DRMO), and storage period (in h). Models were obtained by following kinetic approaches. The model that best predicted the freshness index of eggplant was the one of I_f as a function of SL, which had a correlation coefficient (CC) of 0.99 and mean square error (MSE) of 0.0014. The least accurate kinetic model was If as a function of GL. A stepwise regression was performed in order to obtain the significant wavelengths to predict I_f as well, and CC values were 0.73 and 0.90 for 10 and 27°C storage temperature, respectively. I_f could be used as a tool to effectively estimate eggplant quality, and hence, help in fixing fair prices. Future study will focus on developing freshness indexes for other eggplant varieties, and models to predict them at different temperatures. Arrhenius's equation could be applied if more temperatures were studied.

5.2. Introduction

It is crucial that fruits and vegetables are harvested at their optimal stage, because quality of horticultural crops, as determined by appropriate physical, biochemical, and edible conditions, cannot be improved after harvesting operations (Prusky, 2011). In actual fact, their quality decreases, irrevocably, along the distribution stage. However, the maintenance of such quality may be attempted.

Eggplant is a fleshy non-mature crop, which means that its optimal phase to be harvested occurs when the fruit is not physiologically developed yet. The fruit should be harvested when it reaches approximately 80% of its total size, because that is when it reaches the peak concentrations of phenolic compounds, total sugars, and ascorbic acid (Maynard, 1987; Esteban et al., 1992). Besides, the optimal firmness and gloss of the fruit is reached at this stage of development. Mohammed and Sealy (1986; 1988) recommended for eggplant to be harvested when a decolouration near the stem is noticed for the first time. The fruit may be left on the plant up to one week after the decolouration is observed without risks of quality loss. After this point, its peel starts to become opaque, its firmness decreases (the texture of the pulp tissue gets fibrous), and it develops bitter flavours (Lawande and Chavan, 1998).

If the harvesting conditions are good (e.g. the fruits are sorted in containers in such a way that their stems will not scratch other fruits or will not receive much solar radiation), the fruit will be a high quality product. Cantwell and Suslow (1997) state that a high quality American eggplant should be medium sized and uniformly egg to globular in shape; with a fresh green calyx, a glossy and dark purple skin, a firm pulp tissue, and soft seeds. This high quality starts to decrease as soon as the fruit is harvested. Eggplant is a very perishable fruit. Its shelf life ranges from 2 to 4 days when held at temperatures of about 25°C, and, when kept in refrigeration condition, it suffers chilling injury (Mohammed and Brecht, 2003). Therefore, the best way to maintain the quality of eggplant is by applying temperatures between 7 and 14°C (Mohammed and Sealy, 1988; Cantwell and Suslow, 1997). Even so, the quality of eggplant changes rapidly, mostly because of water losses. Medlicott (1990) reports that when eggplant has an opaque and shabby peel, and a darkened calyx, it means that the fruit has suffered from excessive water loss and aging. These swift changes to eggplants' quality may cause a high variation in its price (Jha and Matsuoka, 2002b). However, determining quality can be a difficult task.

Kader (2010) suggests a subjective and general scale for quality evaluation of horticultural crops. This quality evaluation is mostly based on visual and subjective inspection of the external appearance (e.g. size, shape, colour, gloss, and freedom from defects and decay), and textural quality factors (e.g. firmness, rigidity, stiffness). This rating scale ranges from 1 to 9, being 9 the best. The minimum value for any crop to be marketable is 5. For instance, Kadar (2010) shows a quality rating scale for cucumber. A cucumber gets a 9 if it is bright green, firm, crisp, and turgid; a 5 if it is no longer crisp and turgid, if it gives easily in middle when compressed, and if water loss is apparent on stem and blossom ends; a 1 if the crop is soft and flabby, if it has a noticeable shrivelling at ends, if it shows irregular yellowing, and decay on sunken spots, if chilling injury occurred. However, for being a subjective rating scale, there are chances for over- or underestimations of the crop quality, and hence, its price.

So, the aim of this study was to develop a non-subjective freshness index for an American variety (Traviata) of eggplant fruit. A kinetic approach was used to find models to predict the freshness index with the initial values of the quality or quantity features of the fruit (e.g. weight, density, surface stiffness, and peel gloss) and the values of such parameters at any point in time. Using the same kinetic approach, a model to predict the freshness index with storage period was established. A stepwise regression was conducted to find the significant wavelengths to predict the freshness index with the spectral data that were obtained.

5.3. Materials and Methods

5.3.1. Experimentation

Quantitative (mass, volume, and density) and qualitative (surfaces stiffness and peel gloss) parameters of fresh and stored eggplants were determined. In total, 48 fruits (24 from each farm) were used for the experiments. The eggplants were wrapped in polyethylene film and stored in Conviron chambers (Controlled Environments Ltd., Winnipeg, Manitoba, Canada), which had light, humidity, and temperature control, and were located at the McGill University, Plant Science Department.

The methodology applied was exactly the same as the one from Chapter IV of this thesis. Individual eggplant mass was determined with an electronic balance. Volume was measured by the displaced water method. Non-invasive compression tests were conducted using Instron machine (the compression was fixed, 2.5 mm to not damage the peel), and the slope of the force-deformation curve was taken as the surface stiffness. Hyperspectral imaging technique, in the NIR range (900-1,700 nm), was used to interpret the peel gloss of the fruits. The area under the curve reflectance-wavelength was used for this purpose. Source, temperature, light exposure, and storage period were the factors taken into account for this experiment (Table 5.1).

Table 5.1 Factorial design for storage of eggplant fruit

Factor	**Levels**
Source	Tourne-Sol Co-operative and Les Jardins Carya
Temperature (°C)	10 and 27
Light exposure ($h \cdot d^{-1}$)	0 and 12
Storage period (h)	0, 48, 96, 144, 192, 240 and 288

*RH was set to be constant (85±5%); h·d — hours per day

In order to simplify the discussion of the results, the storage conditions (SCs) were labeled as SC_1, SC_2, SC_3, and SC_4 (Table 5.2).

Table 5.2 The different storage conditions at which eggplant fruits were subjected

SC_1	SC_2	SC_3	SC_4
T = 10°C and 0 h of illumination (85% of RH)	T = 10°C and 12 h of illumination (85% of RH	T = 27°C and 0 h of illumination (85% of RH)	T = 27°C and 12 h of illumination (85% of RH)

*T stands for temperature

During the experiment, the eggplants were checked for external symptoms of chilling injury (bronzed skin) or biological disease (fungi on skin or on calyx and stem).

5.3.2. Objective Freshness Index (I_f)

It was demonstrated in previous work (Chapter IV) that both surface stiffness and peel gloss of eggplant declined during postharvest storage, and, on the contrary, eggplant density increased significantly over time at all SCs. The freshness index was therefore defined based on these factors as presented by Jha and Matsuoka (2002b):

$$I_f = \frac{G_r S_r}{D_r} \tag{5.1}$$

where I_f is the freshness index, G_r the peel gloss ratio (G/G_0), S_r, the surface stiffness ratio (S/S_0), and D_r, the density ratio (D/D_0). G, S, and D are respectively, the peel gloss, surface stiffness, and density at any point in storage period, and the subscript 0 refers to the value of the parameter at day 0 (the day eggplants were harvested).

5.3.3. Statistical Analysis

A GLIMMIX procedure on SAS was used to determine the significant factors on the freshness index of eggplant.

Significant wavelengths can be sorted from the whole spectral cube through a variety of strategies, such as general visual inspection of the spectral curves and correlation coefficients (Keskin et al., 2004), correlelogram analysis (Xing et al., 2006), principal component analysis (Xing and De Baerdemaeker, 2005), analysis of spectral differences from the average spectrum (Liu et al., 2003), principal component transform and minimum noise fraction transform (Lu, 2003), partial least squares (PLS) and stepwise discrimination analyses (ElMasry et al., 2007), and stepwise regression (Chong and Jun, 2005).

Stepwise regressions were performed to determine the predictive wavelengths of I_f at both temperatures. A level of significance (α) of 0.05 was used for the data set of the eggplants that were stored at 27°C. However, since at that level of significance only one wavelength was found to be significant for I_f of the fruits that were stored at 10°C, there was need of using a higher α (0.1).

5.3.3. Mathematical Modelling

The freshness index was plotted vs. weight loss (WL; 1-Weight ratio), density ratio minus one (DRMO; $D_r - 1$), surface stiffness loss (SL; $1-S_r$) and peel gloss loss (GL; $1-G_r$), as well as storage period (h). The kinetic approach (integral method) suggested by Marangoni (2003) was used to determine the models to predict I_f. Since the order of the reaction was unknown, it was assumed to be n = 0, and then n = 1. The data were transformed accordingly (e.g. $\ln([I_f]/[I_{f0}]$, I_{f0} being I_f at day 0) when a linear first-order model was used. The model was then fitted to the data using standard least-squares error minimization protocols (i.e. linear or non-linear regression). From this exercise, a best-fit slope, *y*-intercept (which in most of the models was fixed to be 1 because I_f is known to always be 1 at the beginning), their corresponding correlation coefficient (CC), and mean square error (MSE) values were determined.

The MSE is a way to quantify the difference between values implied by an estimator and the actual values of the quantity being estimated. The lower the MSE, the better the estimator is, and the closer the value of CC to 1, the better the fit of the model to the data is. The order of the reaction was determined by comparing the CC and MSE values for the different fits of the kinetic models to the transformed data.

The significant wavelengths were used to conduct multiple linear regressions in The Scrambler ® to build the models to predict I_f.

5.3.3.1. Zero-Order Reaction

The rate equation for a zero-order reaction was expressed as suggested by Marangoni (2003):

$$\frac{d[I_f]}{dx} = -k_r[I_f]^0 \tag{5.2}$$

where x is weight loss (WL), density ratio minus one (DRMO), surface stiffness loss (SL), and peel gloss loss (GL), or storage period (in h), and k_r is the rate.

Since $[I_f]^0 = 1$, integration of Eq. (5.2) for the boundary conditions $I_f = I_{f0}$ at $x = 0$ and $If = I_{fx}$ at x,

$$\int_{I_{f_0}}^{I_f} d[I_f] = -k_r \int_0^x dx \tag{5.3}$$

yields the integrated rate equation for a zero-order reaction:

$$[I_f] = [I_{f_0}] - k_r x \tag{5.4}$$

where $[I_f]$ is the freshness index at x and $[I_{f0}]$ is the freshness index at $x = 0$.

5.3.3.1. First-Order Reaction

The rate equation of a first-order reaction for the freshness index as a function of x was expressed as:

$$\frac{d[I_f]}{dx} = -k_r[I_f] \tag{5.5}$$

Integration of Eq. 5.5 for the boundary conditions $I_f = I_{f0}$ at $x = 0$ and $I_f = I_{fx}$ at x,

$$\int_{I_{f_0}}^{I_{f_x}} \frac{d[I_f]}{[I_f]} = -k_r \int_0^x dx \tag{5.6}$$

yields the integrated rate equation for a first-order reaction:

$$ln\frac{[I_{f_x}]}{[I_{f_0}]} = -k_r x \tag{5.7}$$

or

$$[I_f] = [I_{f_0}]e^{-k_r x} \tag{5.8}$$

5.4. Results and Discussion

Temperature had a highly significant effect on the freshness index (p = 0.0072). Light exposure and produce source were not significant. Hence, the models, except for I_f as a function of SL, were developed for 10 and 27°C.

5.4.1. Freshness Index and Weight Loss

The weight loss (WL) was computed by subtracting the weight ratio from the unit ($1 - W/W_0$). As WL increased, I_f declined linearly at 10°C (Fig. 5.1 A) and it decreased exponentially at 27°C (Fig. 5.1 B). Based on the CC and MSE values, I_f as a function of WL at 10°C was best described with a zero-order reaction model, whereas at 27°C it was best modelled with a first-order reaction curve.

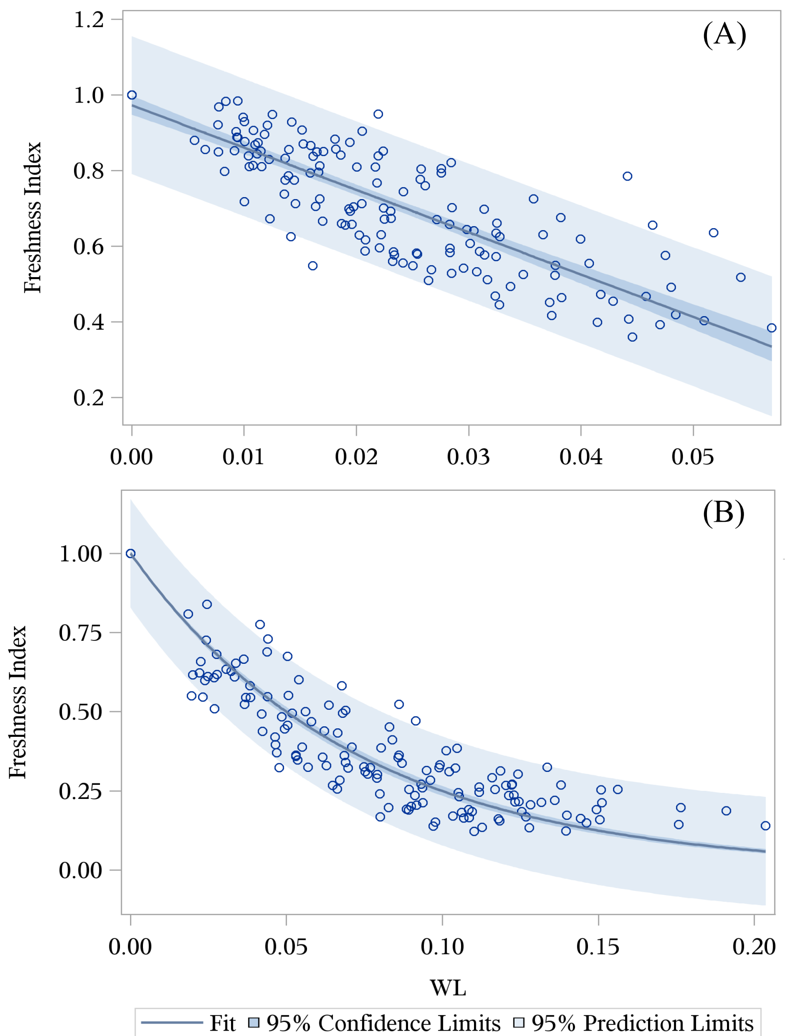

Fig. 5.1 Freshness index of eggplant (I_f) vs. WL at 10°C (A) and 27°C (B) with 95%

confidence and prediction limits

For a zero-order reaction, a plot of I_f versus WL yielded a straight line with negative slope $-k_r$ (Fig. 5.1 A).

Since it is known that the initial freshness index (I_{f0}) equals one, the freshness index in terms of WL at 10°C is expressed by:

$$I_f = 1 - 12.116(1 - {}^{W}/_{W_0}) \tag{5.9}$$

For a first-order reaction, a plot of ln([I_f]/[I_{f0}]) versus WL yielded a straight line with a slope $-k_r$ of –12.851 (Fig. 5.2). The CC value for this straight line was 0.88.

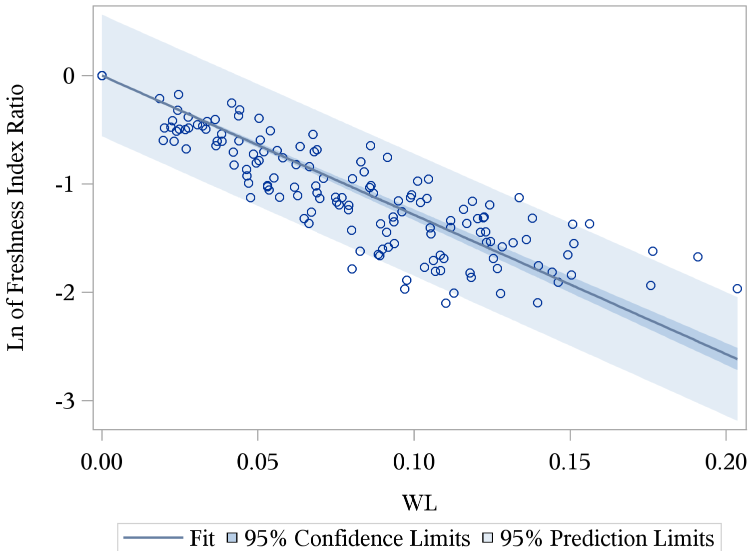

Fig. 5.2 Ln of freshness index ratio (I_f/I_{f0}) vs. WL of eggplant at 27°C with 95% of confidence and prediction limits. The slope is the rate k_r for the kinetic model

Since the initial value of freshness index (I_f) equals one, I_f as a function of WL at 27°C was expressed as:

$$I_f = e^{-12.851(1-{}^{W}/_{W_0})} \tag{5.10}$$

For the plot of the observed I_f versus the values predicted with the models of WL (Fig. 5.3), the CC values for 10 and 27°C are 0.86 and 0.95, respectively. The MSE values for 10 and 27°C are, respectively, 0.0073 and 0.0075. From this we can say that both

Eq. 5.9 and Eq. 5.10 are good predictors of freshness index.

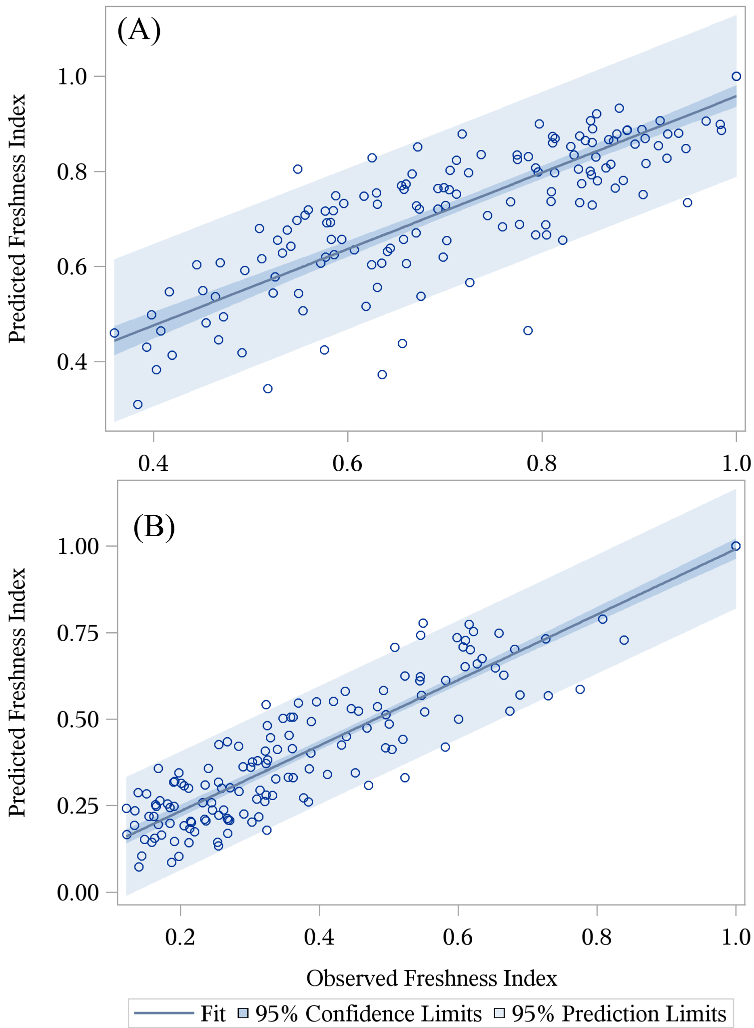

Fig. 5.3 Results for prediction of I_f for eggplants, and measured values at 10 (A) and 27°C (B), with 95% of confidence and prediction limits

The freshness index reached its minimum average value (0.19) at 27°C (Fig 5.1 B) when the fruit experienced an average WL of about 13.5%. The half-life reaction is another useful measure of the rate of a reaction. A reaction half-life in this case is the WL required for the initial freshness index to decrease by ½. The expressions for the half-life of reaction of first- and second-order reactions are, respectively:

$$n = 0 \ldots x_{1/2} = \frac{0.5[I_{f_0}]}{k_r} \tag{5.11}$$

and

$$n = 1 \dots x_{1/2} = \frac{\ln 2}{k_r} \quad (5.12)$$

The freshness index was halved when the moisture losses for the 10 and 27°C SCs were, respectively, 4 and 5%. Although the respiration rate of eggplant is considered to be between low and moderate, Gull (1981) states that the symptoms of deterioration in the fruit start to show when its water loss is of about 3%. In this study, like in the one carried out by Jha and Matsuoka (2002b), it is proven that I_f of this crop not only depends on the moisture loss of the fruit itself, but it is also dependent upon its early water losses (Fig. 5.1). When moisture loss from eggplant is excessive, its pulp becomes soft, it shrivels, its peel loses its gloss and the calyx turns brown due to dehydration (Díaz-Pérez, 1998a). These symptoms were observed in the fruits stored at 27°C after I_f of eggplant had lost more than 50% of its original value. For this reason, it is crucial to reduce the water losses as much as possible by applying postharvest technologies. The low temperature (10°C) was an effective way to reduce the rate of water loss of the fruit (Fig. 5.1). Wrapping the eggplants may have also played an important role in preventing WL. This was owing to the fact that a high RH was created inside the package (Gull, 1981). Mohammed and Brecht (2003) stated that eggplant fruits that are wrapped and stored at 30°C tend to decay faster than when they are not wrapped, mostly because the RH inside the package gets so high that the growth of microorganisms that deteriorate the fruit is favoured. However, out of the 24 eggplants that were wrapped and stored at 27°C only 2 fruits showed symptoms of biological disease in their calyx and stem, and, out of the 24 wrapped eggplants stored at 10°C, only 1 fruit showed symptoms of a biological disease on its skin. Risse and Miller (1983) wrapped eggplants and stored them at 7 and 15°C. The authors mention that one of the advantages of wrapping is that the film reduces decay by preventing secondary infection of fruit packed and stored together.

5.4.2. Freshness Index and Density Ratio

Density ratio minus one (DRMO) was plotted vs. freshness index (Fig. 5.4). The freshness index decreased exponentially as DRMO increased at both 10 and 27°C.

The density ratio increased during the experiment because, as opposed to weight and volume, the fruit density increased over time. Kinetic models of first-order reactions were the ones that had higher CC values when describing freshness index as a function of DRMO. However, the rates for the models were significantly different for each temperature condition.

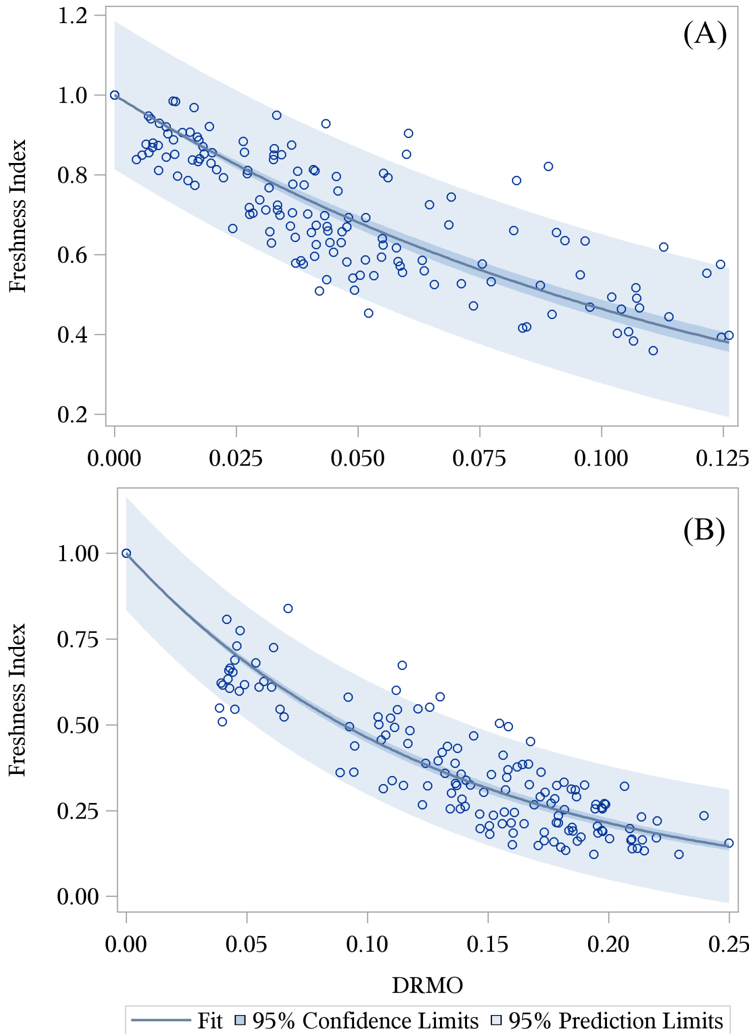

Fig. 5.4 Freshness index vs. DRMO at 10 (A) and 27°C (B), with 95% of confidence and prediction limits

The models so obtained for I_f with DRMO at 10 and 27°C are, respectively:

$$I_f = e^{-7.4392\left({}^{D}/_{D_0}-1\right)} \tag{5.13}$$

and

$$I_f = e^{-7.9114\left({}^{D}/_{D_0}-1\right)} \tag{5.14}$$

The MSE values for Eq. 5.13 and Eq. 5.14 are, respectively, 0.0088 and 0.007. The CC values for those same equations are, respectively, 0.83 and 0.91.

Jha and Matsuoka (2002a) observed that the density (D) of an Asian eggplant fruit increased, during storage at 4 temperatures (15, 20, 25, and 30 °C), at different rates. In this study, eggplant D increased during storage, too, at the both temperatures. The increase of the fruit D of this study was attributed to the fact that the rate at which volume decreased was higher than the rate at which WL occurred.

By applying the Eq. 5.12, the expression to calculate the half-life of a first-order reaction, we determined that I_f was halved when the D_r at 10 and 27°C were, respectively, 1.093, and 1.088. The volume ratio is equal to the weight ratio divided by the density ratio. From this, it was calculated that when the freshness index was 0.50, the volume losses of eggplant oscillated between 87 and 88%.

When we plot the observed I_f *vs.* the values that were predicted with DRMO, the CC values were 0.86 and 0.95, respectively, for eggplants stored at 10 and 27°C.

5.4.3. Freshness Index and Stiffness Losses (SL)

Surface stiffness of eggplant was the parameter that decreased the most during storage at 10 and 27°C. So, it can be said that the surface stiffness loss is the factor that has the biggest effect on the freshness index of eggplant.

As shown in Fig. 5.5, the freshness index decreased linearly as SL of eggplant increased over time at the two temperatures.

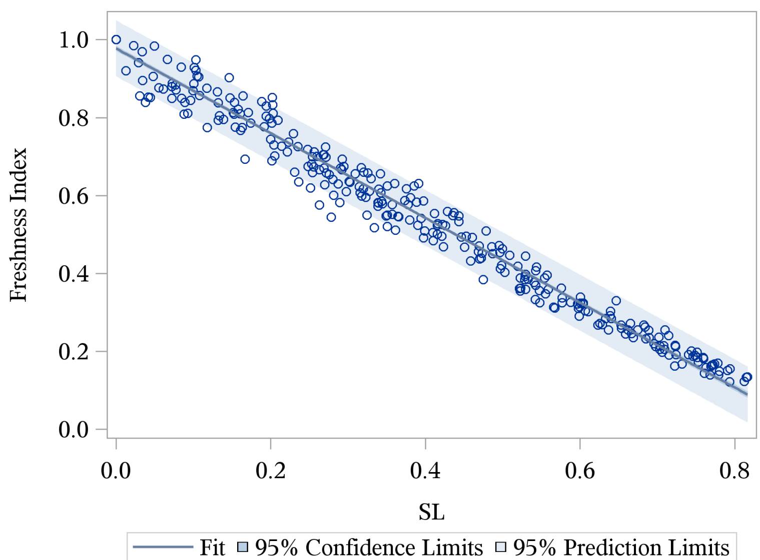

Fig. 5.5 Freshness index (I_f) vs. SL of eggplant stored at 10 and 27°C, with 95% of confidence and prediction limits

Since the freshness index overlapped at the two temperatures when it was plotted vs. SL, I_f as a function of SL was found to follow the same model of a zero-order reaction for the two temperature conditions:

$$I_f = 1 - 1.1303(1 - {}^{S}/_{S_0}) \tag{5.15}$$

The model of I_f as a function of SL was an excellent predictor. The CC was 0.99 and the MSE 0.0013. Fig 5.6 shows that there is high correlation (CC = 0.99 and MSE = 0.0014) between the observed I_f and the values predicted with Eq. 5.15.

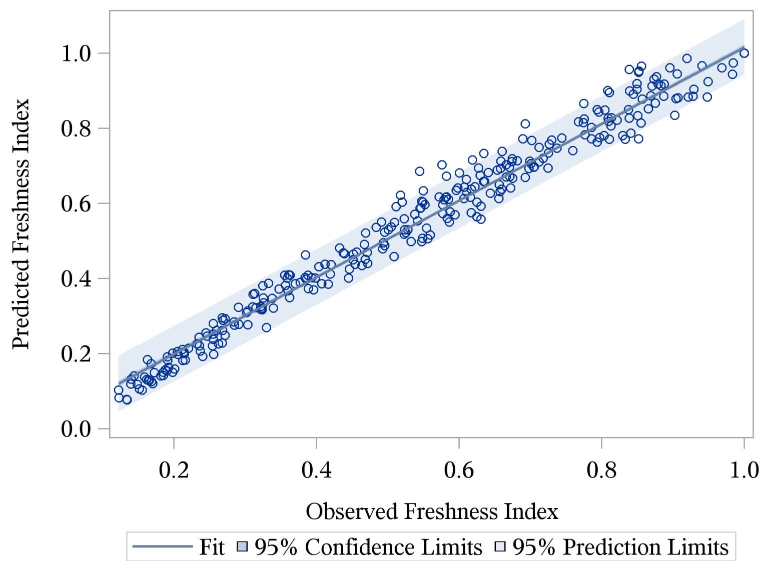

Fig. 5.6 Results for prediction of I_f of eggplant using Eq. 5.15, and observed values at 10 and 27°C, with 95% of confidence and prediction limits

I_f was halved when the surface stiffness of the fruit had lost a 44% of its original value. At 10°C, SL reached a maximum value of 56%. On the other hand, at 27°C, the highest SL was around 82%, where the observed I_f was 0.13. The low temperature of 10°C was effective to reduce the SL. The fact that the fruits were wrapped in polyethylene film played an important role in maintaining their surface stiffness by preventing the fruit from losing water. Díaz-Pérez (1998b) carried out an experiment in which it was observed that the firmness of eggplant was maintained when wrapping the fruits in high-density polyethylene (HDPE). In their study, the low firmness losses of eggplant were owing to the fact that the transpiration rate of the fruit was reduced six times (in the case of the American variety) compared to the uncovered fruit that were stored at 20°C.

5.4.4. Freshness Index and Peel Gloss

Based on the CC and MSE values, I_f as a function of GL was determined to follow first-order reaction models (Fig. 5.7).

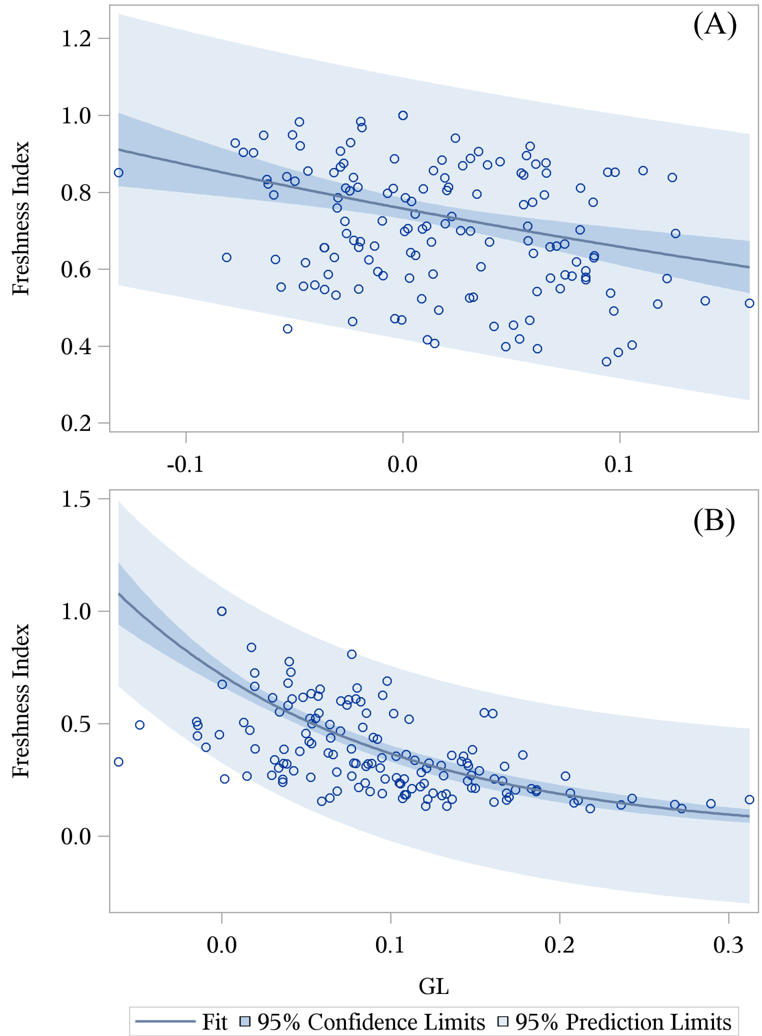

Fig. 5.7 Freshness index vs. GL at 10 (A) and 27°C (B), with 95% of confidence and prediction limits

The models to predict the freshness index as a function of GL for storages at 10 and 27°C are, respectively:

$$I_f = 0.738e^{-1.5904(1-{}^{G}/_{G_0})} \quad (5.16)$$

and

$$I_f = 0.635e^{-6.2034(1-{}^{G}/_{G_0})} \tag{5.17}$$

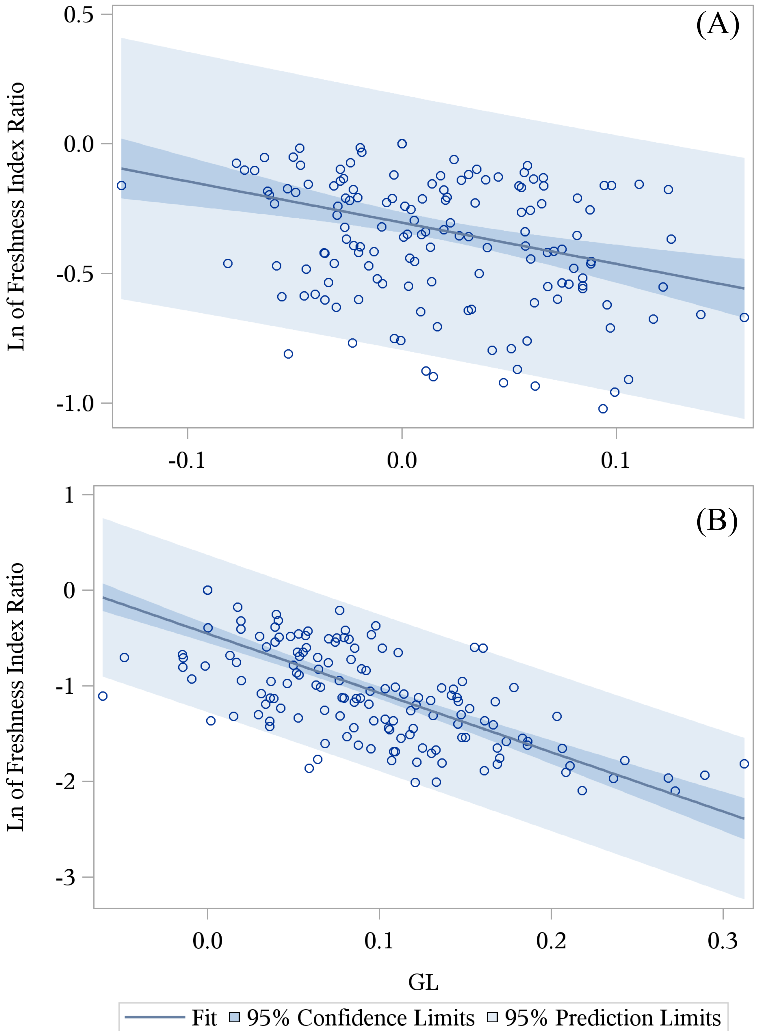

Fig. 5.8 Ln of freshness index ratio (I_f/I_{f0}) vs. GL at 10 (A) and 27°C (B) with 95% of confidence and prediction limits

Eq. 5.16 and Eq. 5.17 are the least accurate predictors of freshness index. The CC and the MSE values for Eq. 5.16 are, respectively, 0.31 and 0.0296. When the observed values were plotted against the predicted scores using Eq. 5.16, the correlation was found to be very low (CC = 0.31). The CC for Eq. 5.17 is higher (0.73), but the MSE is higher as well (0.0385). The correlation between the observed values of freshness index and the ones predicted with Eq. 5.17 is not as low (CC = 0.70). The very low correlation between freshness index and GL at 10°C is owing to the fact that the peel gloss actually increased slightly at this temperature during the first 6 days of storage (Chapter IV), whereas I_f consistently decreased.

5.4.5. Freshness Index and Reflectance (Stepwise Regression)

The stepwise regression determined that the best wavelengths to predict I_f, for the fruit stored at 10°C, were 947, 1,033, 1,047, 1,076, 1,680, and the ranges 961-975 and 995-1,014 nm. Fig. 5.9 shows the observed freshness index *vs.* the values that were predicted with the model built with the significant wavelengths for the fruits stored at 10°C.

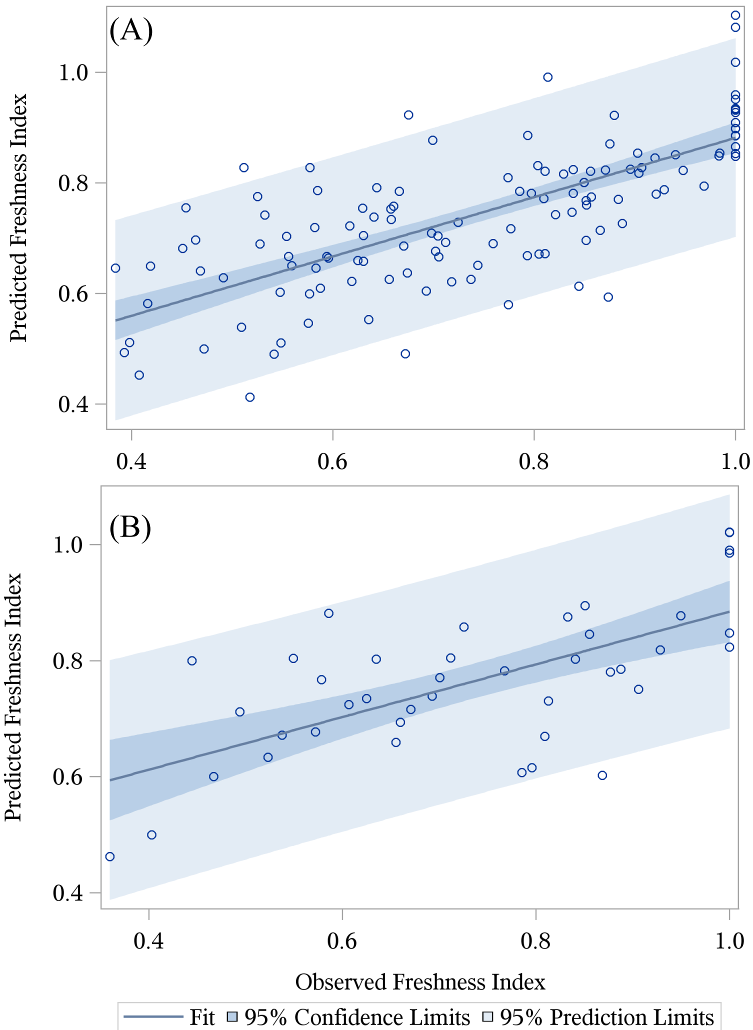

Fig. 5.9 Calibration (A) and test (B) results for prediction of I_f using multiple linear regressions with the significant wavelengths from the stepwise regression, and observed values at 10°C, with 95% of confidence and prediction limits

The CC and the MSE for the calibration were, respectively, 0.73 and 0.0081. This model was much better than I_f as a function of GL at 10°C (Eq. 5.16). For the test, the CC and the MSE were consistent: 0.66 and 0.0093, respectively.

For the fruits stored at 27°C, the stepwise regression determined that the best wavelengths to predict I_f were 947, 1,033, 1,047, 1,090, 1095, 1,129, 1,134, 1,232, 1,349, and the ranges 1,244-1,253 and 1,273-1,287 nm.

In Fig. 5.10 it can be appreciated that the observed I_f vs. the values predicted by the model built with the significant wavelengths for the eggplants stored at 27°C.

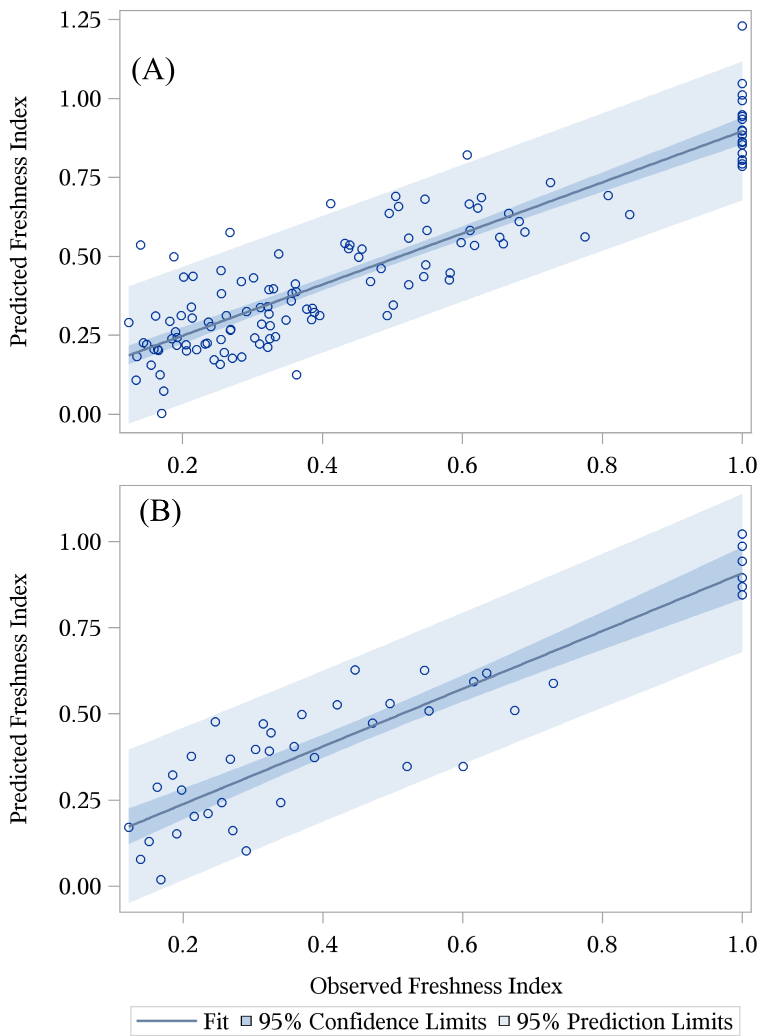

Fig. 5.10 Calibration (A) and test (B) results for prediction of I_f using multiple linear regressions with the significant wavelengths from the stepwise regression, and observed values at 27°C, with 95% of confidence and prediction limits

The CC and the MSE for the calibration were, respectively, 0.90 and 0.0119. When the model was tested, the CC and MSE values were determined to be, respectively, 0.91 and 0.0115. This model was also a better than the one obtained as a function of GL at 27°C (Eq. 5.17).

The main advantage of predicting I_f with the significant wavelengths of the NIR range is that the temperature at which the eggplant have been stored is the only parameter required, unlike the previous models, for which initial values of quality parameters (e.g. weight, surface stiffness, density or peel gloss) are needed in order to make a prediction. In most cases, we will not have access to the initial values of such parameters.

5.4.6. Freshness Index and Storage Period

Freshness index was also plotted against storage period (Fig. 5.11).

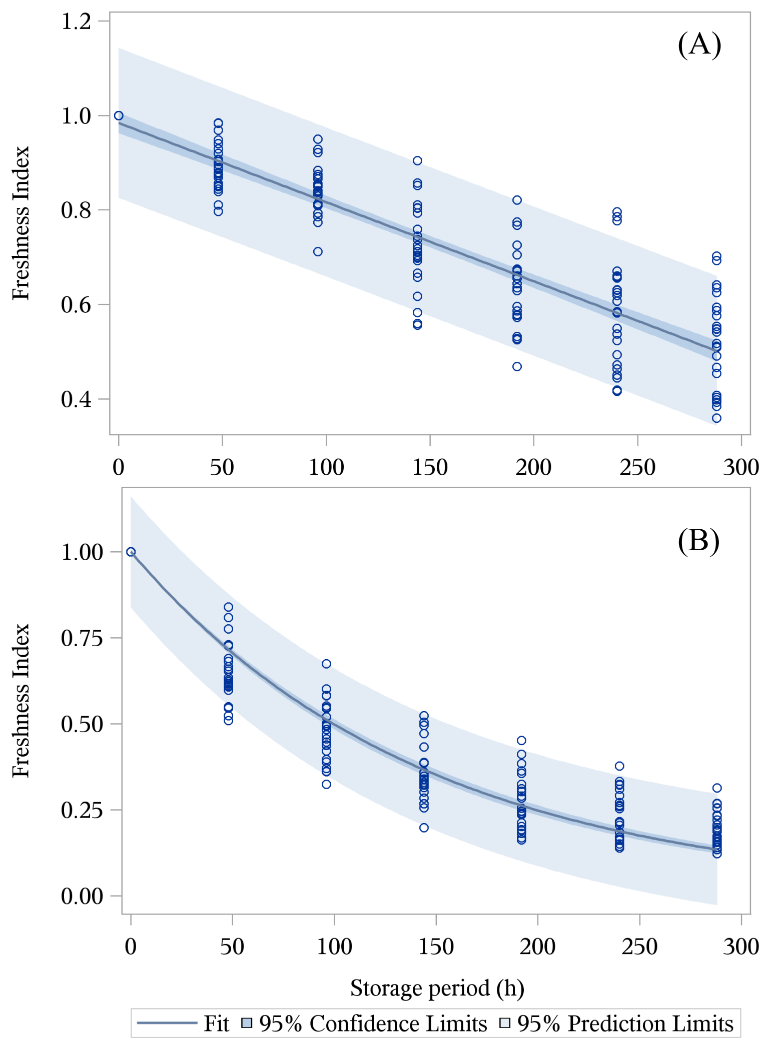

Fig. 5.11 Freshness index vs. storage period (t in h) at 10 (A) and 27°C (B) with 95% of confidence and prediction limits

Based on the CC and MSE values, it was found that a zero-order kinetic model better described I_f as a function of storage period at 10°C, whereas a first-order reaction curve fitted better the data from I_f at 27°C. The predictive model for freshness index of eggplant with storage period at 10 and 27°C are expressed in Eq. 5.18 and Eq. 5.19, respectively, as:

$$I_f = 1 - 0.0018(t) \tag{5.18}$$

and

$$I_f = e^{-0.0064t} \tag{5.19}$$

where t is the storage period in h.

The CC and MSE values for I_f as a function of storage period at 10°C are 0.90 and 0.0063, respectively. The CC and MSE values for I_f as a function of storage period at 27°C are, respectively, 0.91 and 0.0067.

When plotting the observed values versus the predicted ones based on Eq. 5.18 and Eq. 5.19, a significantly high correlation was found in both cases (CC = 0.89 and CC = 0.91, respectively). Mohammed and Brecht (2003) reported that the shelf life of eggplant fruit ranges from 2 to 4 days when held at temperatures above 25°C. As one can see in Fig. 5.9, the freshness index of eggplant (cv. Traviata) was halved after 108 h (approximately, 4.5 days) of storage at 27°C, and after 277 h (almost 12 days) of storage at 27°C. This is consistent with what Mohammed and Brecht (2003) and Cantwell and Suslow (1997) expressed about extending the shelf life of eggplants up to 15 days with controlled low temperatures of 10-14°C. In the experiment conducted by Jha and Matsuoka (2002b), the freshness index of eggplant was halved after 36 h of storage at 20°C, which confirms what Cantwell and Suslow (1997) emphasize about the Asian — elongated, slender, light to dark purple — varieties: they are extremely perishable. This may be attributed to the fact that they differ greatly in terms of respiration rate. Díaz-Perez (1998b) reported that, in uncovered eggplants, the transpiration rate of American fruits was found to be 11 times lower than the one of Japanese fruits, when stored at 20°C.

5.4.7. Eggplant Quality at the Final Period of Postharvest Storage

The eggplants exposed to 10°C had lost about 52% of their freshness after 288 h of storage. As shown in Fig. 5.12 the fruits subjected to cooler storage were somewhat shrivelled after 288 h; the skin was slightly wrinkled.

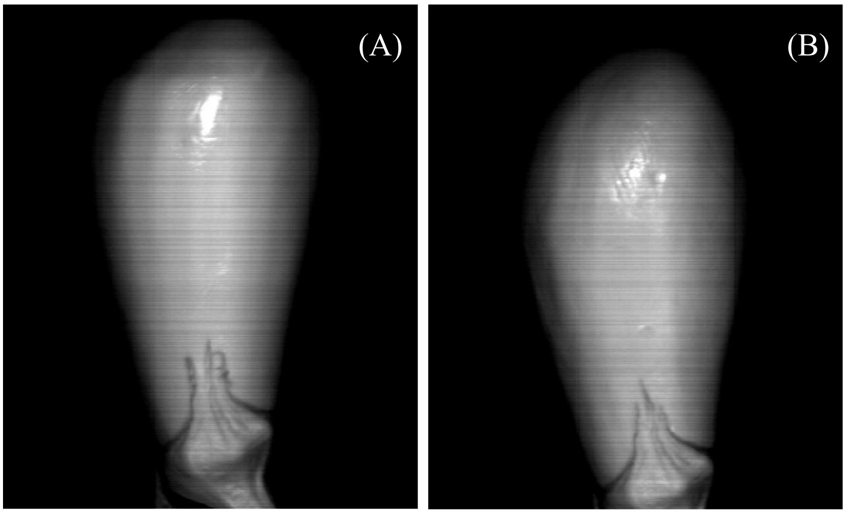

Fig. 5.12 Raw hyperspectral images of an eggplant fruit at 0 (A) and 288 h (B) of storage at 10°C

With respect to texture, the eggplants stored at 27°C were slightly soft at the end of the experiment. However, they did not show symptoms of decay or any biological disease, except for one fruit. Hence, they were still suitable for human consumption.

The only eggplant that developed a biological disease, during cooler postharvest storage, presented a dark gray, soft, sunken, and circular area on the bottom of the fruit. This description fits very well with the one that Mohammed and Brecht (2003) makes about the decay caused by *Alternaria tenius*. Ryall and Lipton (1979) stated that rotting caused by *Alternaria* is a response to chilling injury. The hyperspectral images of that particular eggplant showed a dark and circular patch on the damaged area.

The eggplants exposed to 27°C presented severe shrivelling due to water loss that occurred after a storage period of 288 h; the skin of the fruit was significantly wrinkled. As shown in Fig 5.13, the fruits stored at 27°C experienced a dramatic loss of volume after 288 h of storage. With respect to texture, the fruit was really flaccid, as mentioned above. Nevertheless, they were still suitable for human consumption.

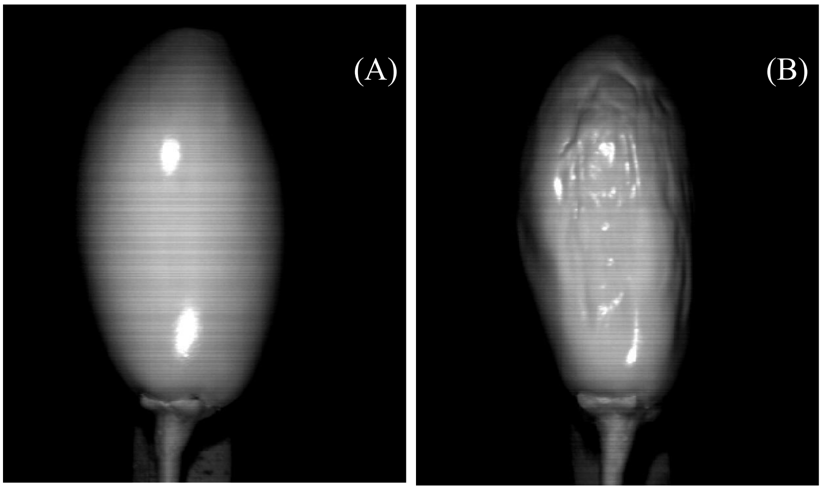

Fig. 5.13 Raw hyperspectral images of an eggplant fruit at 0 (A) and 288 h (B) of storage at 27°C

Two fruits exposed to 27°C of storage developed slightly symptoms of a biological disease that were apparent in their calyx and stem. Díaz-Pérez (1998b) reported that, although the eggplants covered with polyethylene film and stored at 20°C were less dehydrated, the fruits showed a considerably higher incidence of fungal rots caused by *Cladosporium* spp. and *Alternaria* spp. On the other hand, as mentioned above, Risse and Miller (1983) state that one of the advantages of wrapping fruits with films is that decay is reduced because secondary infection of fruits packed and stored in the same place is prevented. In this study, we determined that wrapping the eggplants that were stored at 27°C did not favour significantly the development of microorganisms that usually cause their decay.

5.5. Conclusion

A non-subjective freshness index was developed for an American variety of eggplant fruit. It was determined that temperature had a very significant effect on the freshness index ($p = 0.001$). Kinetic approaches were applied to find models with which it was possible to predict the freshness index at the different temperatures. The best model was the freshness index as a function of surface stiffness loss (CC = 0.99). The least accurate model was the freshness index as a function of peel gloss loss (CC for 10 and 27°C were, respectively, 0.31 and 0.73). A stepwise regression was conducted to determine the significant wavelengths to predict the freshness index at the two studied temperatures. The main advantage of using reflectance at the chosen wavelengths, and the storage period to predict the freshness index at the studied temperatures is that there is no need of knowing the initial values of any quantity or quality parameter.

The freshness index that was developed is an objective tool that can be useful to avoid over or underestimations of eggplant quality and, therefore, to fix fair prices for it. Although, like Jha and Matsuoka (2002b) suggest, in order to validate this concept, it would be required to apply it for several years and to develop it for more varieties and storage conditions of this vegetable crop.

In the future, it would be interesting to study how the freshness index of more varieties of eggplant behaves at more temperatures, and to develop the models to predict it at such temperatures. By doing so, not only the kinetic approaches can be developed, the Arrhenius' equation could be applied, too.

Acknowledgement

The Canadian International Food Security Research Fund (CIFSRF), which is a program of Canada's International Development Research Centre (IDRC) undertaken with the financial support of the Government of Canada provided through Foreign Affairs, Trade and Development Canada (DFATD), is acknowledged for financing this project.

References

Cantwell, M., and Suslow, T.V. 1997. Eggplant: recommendations for maintaining postharvest quality. Available on: http://postharvest.ucdavis.edu/pfvegetable/Eggplant/. Accessed on November 16th, 2012.

Chong, L.G., and Jun, C.H. 2005. Performance of some variable selection methods when multicollinearity is present. Chemometrics and Intelligent Laboratory Systems. 78 (1): 103-112.

Díaz-Pérez, J.C. 1998a. Transpiration rates in eggplant fruit as affected by fruit and calyx size. Postharv. Biol. Technol. 12: 76-82.

Díaz-Pérez, J.C. 1998b. Empaque de berenjena (*Solanum melongena* L.) 'Clásica' y 'Japonesa' con películas de polietileno. Agrociencia. 32: 71-74.

ElMasry, G., Wang, N., Vigneault, C., Qiao, J., and ElSayed, A. 2007. Early detection of apple bruises on different background colors using hyperspectral imaging. LWT — Food Science and Technology. 41 (2): 337-345.

Esteban, R. M. M. M. Esperanza, L. M., Robredo, and F. J. López-Andreu. 1992. Changes in chemical composition of eggplant fruits during development and ripening. J. Agric. Food Chem. 40: 998-1000.

Gull, D.D. 1981. Handling Florida vegetables. Eggplant. Univ. Fla. Veg. Crops. Fact Sheet. SS-VEC-932.

Jha, S.N., and Matsuoka, T. 2002a. Surface stiffness and density of eggplant during storage. Journal of Food Engineering. 54: 23-26.

Jha, S.N., and Matsuoka, T. 2002b. Development of freshness index of eggplant. Applied Engineering in Agriculture. 18(5): 555-558.

Kader, A. 2010. Rating scale for overall visual quality. of produce. In: Produce quality rating scales and color charts. Second edition. Compilors: Kader, A.A., and Cantwell, M. Postharvest technology research and information center, UC Davis.

Keskin, M., Dodd, R.B., Han, Y.J., and Khalilian, A. 2004. Assessing nitrogen content of golf course turfgrass clipping using spectral reflectance. Applied Engineering in Agriculture. 20 (6): 851-860.

Lawande, K.E., and Chavan, J.K. 1998. Eggplant (Brinjal). In: Handbook of vegetable science and technology. Production, composition, storage, and processing. Salunkhe, D.K., and Kadam, S.S. Eds, New York: 225-244.

Liu, Y., Windham, W.R., Lawrence, K.C., and Park, B. 2003. Simple algorithms for the classification of visible/near-infrared and hyperspectral imaging spectra of chicken skins, feces, and fecal contaminated skins. Applied Spectroscopy. 57 (12): 1609-1612.

Lu, R. 2003. Detection of bruises on apples using near infrared hyperspectral imaging. Transactions of the ASABE. 46 (2): 523-530.

Marangoni, A.G. 2003. Tools and techniques of kinetic analysis. In: Enzyme Kinetics: a modern approach. John Wiley & Sons, Inc. ISBN: 0-471-15985-9.

Maynard, D. N. 1987 Commercial vegetable cultivars for Florida. Univ. Of Florida Coop. Ext. Serv., IFAS, Circular 530.

Medlicott, A. P. 1990. Product specifications and post harvest handling for fruits, vegetables, and root crops exported from the Caribbean. Caricom Export Development Project Rpt. 53-56.

Mohammed, M., and Brecht, J.K. 2003. Immature Fruit Vegetables. In: Postharvest Physiology and Pathology of Vegetables. Second Edition. Editors: Bartz, J.A.

and Brecht J.K. New York Basel. Marcel Dekker, Inc. 671-690. 773 pp.

Mohammed, M., and Sealy. 1986. Extending the shelf life of melongene using polymeric films. Trop. Agr. 63:36-40.

Mohammed, M., and Sealy, 1988. Hydrocooling and post-harvest quality in melongene. Trop. Agr. 65:161-165.

Prusky, D. 2011. Reduction of the incidence of postharvest quality losses, and future prospects. Food Sec. 3: 463-474.

Risse, L.A., and Miller, W.R., 1983. Film wrapping and decay of eggplant. Proc. Fla. State Hort. Soc. 96: 350-352.

Ryall, M.S., and Lipton, W.J. 1979. Handling, transportation and storage of fruits and vegetables. Vol. 1, 2nd ed. Vegetables and Melons. AVI Publ. Co., Inc. pp 587.

Xing, J., and De Baerdemaeker, J. 2005. Bruise detection on “Jonagold” apples using hyperspectral imaging. Postharvest Biology and Technology. 37 (1): 281-290.

Xing, J., Bravo, C., Moshou, D., Ramon, H., and De Baerdemaeker, J. 2006. Bruise detection on “Golden Delicious” apples by VIS/NIR spectroscopy 2006. Computers and Electronics in Agriculture. 52: 11-20.

VI. Summarized Conclusions

The quality evaluation of fruits and vegetables is usually subjective, based on specific features of the crops, such as their size, shape, colour, gloss, firmness, and freedom from external and internal defects. Although eggplant (*Solanum melongena*) is known for being a very perishable fruit, both consumer and producer still face the problem of its quality determination at different stages of the food supply chain.

This work consisted of the study of the effect of different produce sources (farms), and temperature and light storage conditions (SCs) on both quantity (e.g. mass, volume, and density) and quality (e.g. surface stiffness, and peel gloss) losses of an American variety of *Solanum melongena* (cv. Traviata).

Non-invasive compression tests were performed using the Instron Testing machine to measure surface stiffness of eggplant. The compression was fixed to be 2.50 mm, which was enough to not rupture the peel of the fruit. The slope of the force-deformation curve (Modulus of Deformability, in $N \cdot mm^{-1}$) was considered as the surface stiffness of the fruit. Hyperspectral-imaging technique was assessed as a tool to interpret the peel gloss of eggplant. Spectral data of fresh and stored eggplants were collected in the near infrared (NIR) range (900-1,700 nm). Two intervals (960-1,380 and 1540-1,690 nm) were taken into account to calculate the area under the curve of reflectance *vs*. wavelength, which was the index of peel gloss of eggplant. The density was computed by dividing the fruit's mass by its volume. The latter was measured by the water displacement method.

Since the surface stiffness and peel gloss decreased during postharvest storage, and, on the contrary, the fruit density increased over time, a freshness index for this American variety of eggplant was defined as the product of the peel gloss and surface stiffness ratios divided by the density ratio. It was found that temperature had a highly significant effect on the freshness index ($p < 0.0001$). On the other hand, the produce source and the fruit light exposure did not have an impact on it. I_f was plotted versus weight, stiffness, and gloss losses (WL, SL, and GL, respectively), and density ratio minus one (DRMO) as well. Kinetic approaches were applied in order to fit curves, at 10 and 27°C, with which it was possible to predict such index with the values of quantity or quality parameters at any point in storage period (e.g. weight (W), surface stiffness (S), peel gloss (G), or density (D)) and the initial values of such parameters. The model that best predicted the freshness index was found to be the one of I_f as a function of surface stiffness loss (SL; 1 – S/S_0). Temperature was not significant for this model, which had a correlation coefficient (CC) of 0.99, and a mean square error (MSE) value of 0.0013. The least accurate models were the ones of I_f as a function of GL. However, the models from the multiple linear regressions, which took into account the significant wavelengths for I_f obtained from the stepwise regressions, were good models. When the predicted I_f values were plotted versus the observed ones, the linear curve showed a CC of 0.73, and an MSE of 0.0081 for 10°C; and a CC of 0.90 and an MSE of 0.012 for 27°C. The advantage of the models derived from the significant wavelengths is that there is no need of knowing initial values of quality parameters (e.g. weight, surface stiffness, etc.) of the crop. The temperature at which the eggplant fruit has been stored would be the only parameter required to predict its freshness index.

In the future, it would be very interesting to explore if similar methodologies could be applied to other crops from the Solanaceae family, such as tomato (*Solanum lycopersicum*) and other varieties of eggplant. More temperature conditions should be studied in the future to find a temperature dependency in order to apply the Arrhenius' equation.