POSTHARVEST QUALITY MANAGEMENT OF CUCUMBER AND EGGPLANT

by

Patrick Cortbaoui

A thesis submitted to McGill University in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

Department of Bioresource Engineering
McGill University
Montreal

April 2015

ABSTRACT

One-third of global food produced for human consumption, which amounts to about 1.3 billion tons is lost or wasted annually. Measuring postharvest losses is an essential operational strategy to enhance postharvest management and to curtail quality loss of fresh horticultural commodity. The goal of this study was to develop and test different methods that characterize and quantify postharvest losses of cucumber and eggplant in St. Kitts-Nevis and Guyana. The study also allowed investigating the influence of temperature and light on quality changes during handling practices of freshly harvested crops.

Three approaches were deployed in the study. The first approach consisted of field-based activities in St. Kitts-Nevis and Guyana using producer household surveys (PHS) and modified count and weight (MCW) method. Results from PHS baseline surveys revealed that farmers sell most of their harvested crops to local markets, keeping the remaining crops for household consumption. In Guyana, the majority of farmers (97%) reported selling their crops at harvest, while in St. Kitts-Nevis, 61% of farmers stored them before selling. While farmers in St. Kitts-Nevis reported 30% postharvest losses of crops due to spoilage, those in Guyana reported considerably less. Results from modified count and weight method revealed that small producers experienced greater postharvest loss compared to large ones due to spoilage and lack of market access. As the produce travelled throughout the supply chain, it started to lose significantly ($P < 0.05$) its freshness and its marketable value as well. This loss was due to inappropriate handling and exposure to undesirable environmental conditions.

The second approach entailed laboratory-based work to simulate the environmental conditions during postharvest handling process in the studied countries. This approach was associated with activities investigating the effect of constant and fluctuating environmental factors including temperature and light on quality changes of eggplant and cucumber such as color, texture, weight loss, quality index and phytochemical content. Under isothermal conditions, four storage combinations of temperatures and light were studied for 10 day-period as follows: SC1=10^{o}C/with light, SC2=30^{o}C/with light, SC3=10^{o}C/without light, and SC4=30^{o}C/without light. Under non-isothermal conditions, another four combinations of temperatures and light

were conducted (S1=25°C/2 hours without light, S2=25°C/3 hours with light, S3=30°C/12 hours with light and 20°C/12 hours without light for a total of 72 hours, and S4=10°C/144 hours without light). This scenario represented all steps of the supply chain of fresh produce starting at the producer level, followed by the distributor, the retailer and end up at the consumer level. Major postharvest losses occurred after 10 days of storage at 30^{o}C in the presence of light. Under these conditions, the firmness of eggplant samples decreased from 5.31 N to 0.77 N (85.5% loss), the weight loss increased up to 21%, significant ($P < 0.05$) color difference was observed, and the crops became unmarketable after 8 days of storage. However, when the crops were wrapped using food grade polyethylene film, quality losses were reduced significantly ($P < 0.05$) with the exception of color attribute. Under non-isothermal conditions, the majority of losses happened after 77-hour period of storage (S3) due to the effect of fluctuating temperature and light every 12-hour period. Crude extracts of freeze-dried produce were used to determine the total phenolic contents (TPC) using the Folin-Ciocalteu method. Exposing vegetables to high temperature (30^{o}C) and direct light was found to significantly degrade their phenolic content. However, a rise in TPC was observed ($P < 0.05$) when the crops were maintained at 10^{o}C in complete darkness. In addition, storage at fluctuating environmental conditions was found to be the main driver to worsen the phenolic degradation in fresh eggplant (49.7% loss) and cucumber (83.8% loss). Kinetic models were used to provide a structural framework for quantitatively describing and predicting those losses.

In the third approach, the Taguchi method was used to quantify postharvest quality loss of both cucumber and eggplant and to optimize environmental conditions during the handling process. The Taguchi method has been widely and successfully used in various subject areas, but no application of this method to postharvest quality management has been reported until the present time. The experimental design included the 4 three-level factors and an L-9 orthogonal array. Traditionally, the Taguchi approach was used to express loss in monetary terms. For the purpose of the study, the word "*loss*" means the loss of quality and is expressed in unit scale. The results revealed that fresh cucumber lost some of its quality attributes immediately after harvest. At firmness of 15.68 N, the loss was equivalent to 13.68 units. However, at 7.68 N firmness, the loss value was increased by almost 4 times (56.98 units). In terms of quality index (QI), it was noticed that even when the score was high (QI = 9 points), the produce had lost 8.74 units of its quality. In theory, the only time when the loss is equal to zero is when the cucumber fruit is still attached to its mother plant. When the quality index dropped to 1.67 points, the loss was increased by almost 30 times more (loss = 254.91 units). The results showed how large the extent of loss could be when fresh cucumber is stored under undesirable conditions. The Taguchi approach was successfully used to quantify and to predict postharvest quality losses in response to different combinations of environmental factors and their levels. In addition, this approach enabled the identification of optimum conditions of temperature, light and relative humidity, for the storage of fresh produce.

RÉSUMÉ

Le tiers de la production alimentaire mondiale qui s'élève à plus de 1,3 milliards de tonnes, est perdue ou gaspillée chaque année. La quantification des pertes encourues après la récolte est une stratégie opérationnelle essentielle pour améliorer la gestion post-récolte et pour réduire les pertes de produits horticoles frais. Le but de cette étude était de développer et de mettre à l'essai, différentes méthodes pour caractériser et quantifier les pertes post-récoltes de concombre et d'aubergine à Saint-Kitts-et-Nevis et en Guyane. Cette étude a aussi permis d'étudier l'influence de la température et de la lumière sur les changements de qualité durant les différentes étapes de mise en marché des produits fraîchement récoltés.

Trois approches ont été déployées dans cette étude. La première approche a consisté à faire des sondages auprès des producteurs et de quantifier les pertes post-récoltes auprès des différents segments de la chaîne de distribution de Saint-Kitts-et-Nevis et en Guyane. Les résultats ont révélé que les agriculteurs vendent la plupart de leurs récoltes aux marchés locaux et en gardent une partie pour leur consommation personnelle. En Guyane, plus de 97% des agriculteurs interrogés ont indiqué qu'ils avaient vendu leurs produits dès la récolte, tandis qu'à Saint-Kitts-et-Nevis, près de 61% des agriculteurs les avaient stockés avant de les vendre aux marchés. Alors que les agriculteurs de Saint-Kitts-et-Nevis ont rapporté des pertes post-récoltes de l'ordre de 30% des cultures en raison de la détérioration, ceux en Guyane en ont rapporté beaucoup moins. De plus, les petits producteurs ont encouru de plus grandes pertes post-récolte en raison de la détérioration des produits et leur manque d'accès au marché. De plus, il a été démontré que la qualité des produits diminuait avec le temps passé dans la chaîne de distribution. Ces pertes ont été généralement causées par une mauvaise manipulation et l'exposition à des conditions environnementales indésirables.

La deuxième approche était basée sur des travaux en laboratoire pour simuler les conditions environnementales présentes durant la chaîne de distribution dans les pays étudiés. Cette approche a permis de quantifier les effets de la température et de la lumière sur les changements de qualité de l'aubergine et le concombre. Les paramètres étudiés étaient la couleur, la texture, la perte de poids, l'indice de la qualité et les teneurs en composés phénoliques. Dans un premier temps, les quatre combinaisons de températures d'entreposage et de lumière étudiées étaient:

SC1 = 10°C / avec la lumière, SC2 = 30°C / avec la lumière, SC3 = 10°C / sans lumière, et SC4 = 30°C / sans lumière. La durée de conservation était de 10 jours. Dans un deuxième temps, des conditions changeantes ont été étudiées. Elles étaient de : S1 = 25°C / 2 heures sans lumière, S2 = 25°C / 3 heures avec la lumière, S3 = 30°C / 12 heures de lumière et 20°C / 12 heures sans lumière pour un total de 72 heures, et S4 = 10°C / 144 heures sans lumière). Ces scénarios ont permis de reproduire toutes les étapes de la chaîne de distribution de produits frais, des producteurs jusqu'aux consommateurs.

Des pertes importantes sont survenues après 10 jours d'entreposage à 30°C en présence de lumière. Sous ces conditions, la fermeté des échantillons d'aubergine a diminué de 5,31 N à 0,77 N (85,5% de perte), la perte de poids était de près de 21%, les changements de couleur étaient significatifs, et les produits étaient invendables après le huitième jour d'entreposage. Cependant, la perte de qualité des produits enveloppés d'un film de polyéthylène de qualité alimentaire était inférieure ($P < 0.05$) sauf pour l'attribut de couleur. Sous les conditions changeantes d'entreposage, les pertes les plus élevées ont été observées sous le traitement S3 de 77 heures en raison de l'effet de la température élevée et de la présence de la lumière à raison de 12 heures par jours. Des produits lyophilisés ont été utilisés pour déterminer la teneur en composés phénoliques totaux (PTC) en utilisant la méthode de Folin-Ciocalteu. Les légumes entreposés à 30 ° C et en présence de lumière directe ont obtenu des teneurs en composés phénoliques les plus bas. Les teneurs en PTC les plus hautes ont été mesurées dans les légumes maintenus à 10 ° C dans l'obscurité. L'entreposage sous des conditions environnementales fluctuantes s'est révélé être le plus dommageable pour les teneurs en composés phénoliques pour l'aubergine (perte de 49,7%) et le concombre (perte de 83,8%). Des modèles cinétiques ont été proposés pour décrire quantitativement la progression de la qualité et prédire les pertes.

Dans la troisième approche, la méthode Taguchi a été utilisée pour quantifier les pertes de qualité post-récolte du concombre et de l'aubergine. Cette approche a permis d'optimiser les conditions de l'environnement au cours du processus de manutention. A ce jour, la méthode Taguchi est largement utilisée avec succès dans plusieurs domaines, mais c'est la première fois qu'elle est appliquée à la gestion de la qualité post-récolte. Le dispositif expérimental utilisé comprenait quatre facteurs à trois niveaux et un réseau orthogonal L-9. Traditionnellement, la méthode Taguchi est utilisée pour exprimer les pertes en termes monétaires. Pour les fins de cette étude, le mot «perte» signifie la perte de qualité exprimée à l'échelle de l'unité. Les résultats ont indiqué que le concombre frais perdait de la qualité immédiatement après la récolte. Avec une fermeté de 15,68 N, la perte correspondait à 13,68 unités. Cependant, lorsque la fermeté diminuait à 7,68 N, la valeur des pertes était de quatre fois supérieure (56,98 unités). En termes d'indice de qualité (IQ), il a été remarqué que même lorsque le score était élevé (QI = 9 points), le produit avait déjà perdu 8,74 unités de qualité. En théorie, le seul moment où la perte est de zéro, c’est au moment où le concombre est encore attaché à la plante mère. Une diminution de l'indice de qualité de 1,67 point correspondait à une perte 254,91 unités. Les résultats ont permis de démontrer l’ampleur de la perte lorsque le concombre frais est entreposé sous des conditions indésirables. Dans cette étude, l’approche Taguchi a été utilisée avec succès pour quantifier les pertes post-récoltes résultant de différentes combinaisons de facteurs environnementaux. De plus, cette approche a permis d'identifier les conditions optimales de température, d’humidité relative et d’éclairage, pour l’entreposage des légumes frais.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Prof. Michael Ngadi for his guidance, wisdom, and inspiration during the writing of this thesis and for giving me the opportunity to pursue my graduate studies with him. I am looking forward to any opportunities to work further with him in the future. To Prof. Leroy Phillip, I thank him for his insight and leadership during the time that I was working with him. It was a great pleasure to work together as a team. I would like also to give a sincere thanks to Prof. Valérie Orsat and Prof. Cristina Ratti for their valuable comments and inputs during the writing of my research proposal. A special thanks goes to the Graduate Program Director Prof. Vijaya Raghavan for his help. I am also grateful to Prof. Danielle Donnelly and her team, to Prof. Salwa Karboune; and to Dr. Kebba Sabally for their recommendations and collaborations during the phytochemical analysis.

A special thanks goes to a friend who was always present when needed, Mrs. Denyse Johnston for her editing and proofreading of my papers. My sincere appreciation goes to Mrs. Helen Rimmer for her help and guidance to graphically design my posters and factsheets. My full gratitude goes to Mr. Yvan Gariépy for all his help and guidance for the use of some laboratory equipment. I would like to thank Dr. Theresa Thompson, Prof. Sonia Laszlo and Mrs. Louise Johnson-Down for their help, collaboration and time during the data analysis of the baseline survey. I also acknowledge the assistance and support of all managers, staff, farmers, distributors, and retailers in Guyana and St. Kitts-Nevis. I would like to thank Mrs. Susan Gregus, Mrs. Abida Subhan, Mrs. Patricia Singleton, Mrs. Leslie LaDuke and Mrs. Sharon Campbell for their help with administrative matters at Macdonald Campus.

Funding for this project was provided by 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 the Department of Foreign Affairs, Trade and Development Canada (DFATD). I am also grateful for the additional financial support from McGill University through the Graduate Excellence Award for the years 2012 to 2015 and from Prof. Michael Ngadi as well.

Special thanks are given to all those past and present members of our research group for their advices and valuable inputs, Dr. Akinbode Adedeji, Mr. Peter Adewale, Mr. Farzad Saadatian, Ms. Tina Beigi, Ms. Audrey Yank, Dr. Laura Li Liu, Mr. Ogan Mba, Mr. Chijoke Ejebe, Mr. Chijioke Nwankpa, Mr. Hernán Rey Sánchez Solano, Mr. Luis Nieto Salvador, Mr. Adeyemi Adegbenjo and Mr. Arturo Mayorga Martínez. A special thanks goes to Mr. Ebenezer Kwofie, Dr. Jamshid Rahimi and Mrs. Raffaella Carvalho for their help and friendship along my studies.

My warmest appreciation goes to my mom for her unconditional support and encouragement to follow my own path in life. To my brother and sister, they should follow their dreams; I will always support them. My deepest gratitude goes to my girlfriend for her exceptional support, her unlimited patience and her continuous understanding throughout the years of my studies. Finally, this thesis is dedicated in memory of my father; I'll make you proud, I promise.

CONTRIBUTION OF AUTHORS

The work stated here was completed by Patrick Cortbaoui and supervised by Prof. Michael Ngadi of the Department of Bioresource Engineering, Macdonald Campus of McGill University, Montreal, Canada. The Ph.D. candidate was responsible for the experimental setup, design of experiment, technical work in the field, analytical work in the laboratory, data analysis, and preparing the manuscripts and thesis. Prof. Michael Ngadi is the research supervisor, who provided supervisory guidance, funding and constructive comments in relation to the field and laboratory experiments and reviewing of the manuscripts (Ch. 3, 4, 5, 6 and 7).

The manuscripts listed below have been submitted for publication:

1. **Cortbaoui, P. E.** and M. Ngadi. **2015.** Characterization of postharvest practices and losses of fresh produce along the Caribbean supply chain: Guyana and St. Kitts-Nevis. ***Journal of postharvest technology.***
2. **Cortbaoui, P. E.** and M. Ngadi. **2015.** Quantifying quality changes in dark purple eggplant as affected by fluctuating storage conditions and wrapping materials. ***Postharvest biology and technology.***
3. **Cortbaoui, P. E.** and M. Ngadi. **2015.** Influence of fluctuating environmental factors on phytochemical changes in eggplant and cucumber during postharvest storage. ***Journal of the science of food and agriculture.***
4. **Cortbaoui, P. E.** and M. Ngadi. **2015.** A new method to quantify postharvest quality loss of cucumber using the Taguchi approach. ***Food science and quality management*** (accepted).
5. **Cortbaoui, P. E.** and M. Ngadi. **2015.** Optimization of postharvest handling process of eggplant using the Taguchi technique. ***Journal of food engineering.***

Part of the thesis was presented at scientific and technical conferences as listed below:

1. **Cortbaoui, P. E.** and M. Ngadi. *An innovative method to quantify postharvest quality loss of cucumber using Taguchi approach.* American Society of Agricultural and Biological

Engineers & Canadian Society of Bioengineering. Annual International Meeting, New Orleans, LA, USA, July 26-29, **2015**. (Oral Presentation).

2. **Cortbaoui, P. E.** and M. Ngadi. *Optimization of postharvest handling process to reduce quality loss of fresh eggplant using Taguchi technique.* ICEF12 - 12th International Congress on Engineering and Food, Engineering challenges: bridging science and food innovations. Quebec City, Quebec, Canada, June 14-18, **2015**. (Poster Presentation).
3. **Cortbaoui, P. E.** and M. Ngadi. *Caribbean postharvest handling: availability in local food production to alleviate food insecurity*. McGill University. 7th McGill Food Security Conference, Montreal, Quebec, Canada, October 28-29, **2014**. (Moderated Poster Presentation).
4. **Cortbaoui, P. E.** and M. Ngadi. *Impact of fluctuated temperature and light on phytochemical quality changes of eggplant and cucumber during post-harvest storage*. International Union of Food Science and Technology. 17th World Congress of Food Science and Technology & Expo, Montreal, Quebec, Canada, August 17-21, **2014**. (Moderated Poster Presentation).
5. **Cortbaoui, P. E.** and M. Ngadi. *Quantifying postharvest quality changes of fresh crops as affected by temperature fluctuations during handling process.* American Society of Agricultural and Biological Engineers. Northeast Agricultural and Biological Conference, Kemptville, Ontario, Canada, July 27-30, **2014**. (Moderated Poster Presentation).
6. **Cortbaoui, P. E.** and M. Ngadi. *Taguchi approach for quantifying postharvest quality loss of fresh produce.* American Society of Agricultural and Biological Engineers & Canadian Society of Bioengineering. Annual International Meeting, Montreal, Quebec, Canada, July 13-16, **2014**. (Oral Presentation).
7. **Cortbaoui, P. E.** and M. Ngadi. *Improving post-harvest handling efficiency along Caribbean supply chain and livelihood implications.* Caribbean Week of Agriculture, Coming Soon: A Healthier, Food Secure Caribbean, Guyana International Conference Centre, Georgetown, Guyana, October 10-11, **2013** (Factsheet).
8. **Cortbaoui, P. E.** and M. Ngadi. *Novel approaches to mapping post-harvest losses for improved food security in CARICOM countries.* Caribbean Week of Agriculture, Coming Soon: A Healthier, Food Secure Caribbean, Guyana International Conference Centre, Georgetown, Guyana, October 10-11, **2013** (Factsheet).

9. **Cortbaoui, P. E.**, M. Ngadi and L. Phillip. *Mapping post-harvest losses of fresh produce in CARICOM along the supply chain.* Caribbean Week of Agriculture, Coming Soon: A Healthier, Food Secure Caribbean, Guyana International Conference Centre, Georgetown, Guyana, October 10-11, **2013** (Un-moderated Poster Presentation).
10. **Cortbaoui, P. E.**, M. Ngadi and L. Phillip. *Novel approaches to mapping postharvest quality loss of fresh produce for improved food security in CARICOM countries*. Caribbean Week of Agriculture, Coming Soon: A Healthier, Food Secure Caribbean, Guyana International Conference Centre, Georgetown, Guyana, October 10-11, **2013** (Oral Presentation).
11. **Cortbaoui, P. E.**, M. Ngadi and L. Phillip. *Assessment of postharvest losses for horticultural crops in the Caribbean.* CIFRSF CARICOM Project Interactive Information Dissemination Workshop, Trinidad and Tobago Bureau of Standards, Macoya, Trinidad and Tobago, West Indies, March 5, **2013** (Oral Presentation).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

a*	Red/green color coordinate
ADP	Adenosine diphosphate
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
b*	Yellow/blue color coordinate
C_0	Initial quality before any storage
CARICOM	Caribbean community
$C_6H_{12}O_6$	Glucose molecule
C_{eq}	Quality at equilibrium
CIFSRF	Canadian International Food Security Research Fund
CO_2	Carbon dioxide molecule
C_t	Measured quality parameter at time t
DFATD	Department of Foreign Affairs, Trade and Development Canada
DOE	Design of experiment
E_a	Activation energy of the reaction (J/mol)
F	Applied force (N)
FAO	Food and agriculture organization
FBM	Food Balance Model
FC	Folin-Ciocalteu
f_F	Degree of freedom of a particular factor
FFE	Fractional factorial experiments
GAE	Gallic acid equivalent
GMP	Good manufacturing practices
ha	Hectare
HACCP	Hazard analysis and critical control points
H_2O	Water molecule
IDRC	Canada's International Development Research Centre
IICA	Inter-American Institute for Cooperation on Agriculture

ISO	International Standards Organization
k	Rate constant (day^{-1})
$k_{cucumber}$	Rate constant for cucumber (day^{-1})
k_{eff}	Value of the rate constant at the effective temperature (day^{-1})
$k_{eggplant}$	Rate constant for eggplant (day^{-1})
k_L	Proportionality or loss constant
k_{ref}	Rate constant at reference temperature
k_t	Transpiration coefficient ($g{\cdot}m^{-2}{\cdot}Pa^{-1}{\cdot}s^{-1}$)
k_{TCD}	Rate constant when measuring total color difference
$k_{unwrapped}$	Rate constant for unwrapped produce
k_{WL}	Rate constant when measuring weight loss
$k_{wrapped}$	Rate constant for wrapped produce
L	Loss
L*	Lightness color coordinate
LAC	Latin America and the Caribbean
LAFA	Loss Adjusted Food Availability
LB	Larger the better
m	Target value
MAMR	Ministry of Agriculture and Marine Resources
MCW	Modified count and weight
MT	Million tons
m_t	Transpiration rate ($g{\cdot}m^{-2}{\cdot}s^{-1}$)
N	Maximum load
n	Number of observations or replicates
Na_2CO_3	Sodium carbonate anhydrous
NAREI	National Agricultural Research and Extension Institute
NCDs	Non-communicable diseases
O_2	Oxygen molecule
p_a	Water vapour pressure in the air (Pa)
PAPI	Paper-and-pencil interviews
PDCA	Plan-Do-Check-Act

PDSA	Plan-Do-Study-Act
PHL	Postharvest loss (es)
PHS	Producer household surveys
P_i	Percent influence
P_{in}	Inorganic phosphate
p_s	Water vapour pressure at surface (Pa)
QI	Quality index
R	Universal gas constant (8.314 J/mol.K)
R^2	Coefficient of determination
RH	Relative humidity (%)
SB	Smaller the better
SC	Storage condition
S_F	Sum of squares of a particular factor
SPC	Statistical process control
S/N	Signal-to-noise ratio
S_T	Total sum of squares of all factors
t	Storage time (days)
t_{total}	Cumulative storage time (days)
T	Absolute temperature (^oC)
T_{eff}	Effective temperature (^oK)
T_i	Absolute temperature (^oK)
TPC	Total phenolic content
T_{ref}	Reference temperature (^oK)
UV	Ultraviolet
V_e	Variance for the error term
W_f	Final weight of the produce
WHO	World health organization
W_i	Initial weight of the produce
WL	Weight loss
y	Value of quality characteristic
ΔE	Total color difference

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Notwithstanding the apparent abundance of food, nearly 870 million people around the world suffer from hunger and malnutrition (FAOSTAT, 2013). A clear pathway to ensure the availability of food and alleviating poverty is to minimize the postharvest losses (PHL). One-third of global food produced for human consumption is lost or wasted which amounts to about 1.3 billion tons per year (Gustavsson et al., 2011). Losses of fresh fruits and vegetables are of considerable interest due to their extremely high values reaching 50% in developed countries and 55% in developing countries (FAO, 2011). Several reasons are attributable for this situation such as the distance occurring between the producer and the consumer and improper postharvest practices including harvesting, handling, storage and processing of the produce. Fruits and vegetables are known to provide the necessary food to assure a balanced diet for a healthy population (FAO, 2002). They can play a crucial role in reducing the occurrence of chronic diseases caused by unhealthy diet. More significantly, whether in developed or developing countries, fruits and vegetables (Tiwari et al., 2013) are the main source of essential vitamins, minerals, and dietary fibre feeding the world populations.

Agriculture is a key economic and development sector in all countries across the globe. While the world looks forward to feeding 9 billion people in 2050, postharvest management of the produce quality and quantity is required to play an important role in reducing these losses and increasing world food supplies in a largely effective manner. The setback to postharvest effort is the lack of clear knowledge and effective measurement of the magnitude of the losses. Current postharvest data varies widely in magnitude being quoted as 10 to 70% (Samuoliene et al., 2012; Xiao et al., 2014). These measurements are sometimes either not traceable or estimated from data sets collected 30 years ago. This is mainly due to measurement problems such as the complexity of postharvest loss concept, major gaps in the knowledge of measuring these losses and the multiple definitions of quality.

Effective, consistent and new methods for postharvest quality management of fresh horticultural commodities are therefore a necessary first step toward reaching the goal of reducing postharvest losses. In light of this need, this dissertation investigated methodologies for quantifying postharvest quality loss of cucumber and eggplant as affected by inappropriate handling and undesirable environmental conditions.

1.2 HYPOTHESES

1. Postharvest quality management is essential to minimize postharvest losses and maximize food availability of fresh produce.
2. Effective measurement of the magnitude of postharvest loss is a fundamental step in postharvest quality management.
3. Kinetic models will provide a structural framework for quantitatively describing quality change rates of cucumber and eggplant during handling as affected by environmental factors.
4. Taguchi approach can quantify quality loss and predict the quality outcomes of fresh commodity during postharvest storage.
5. Taguchi approach can be applied as a robust quality management technique to optimize postharvest handling of fresh produce.

1.3 OBJECTIVES

The general objective of this doctoral dissertation is the enhancement of postharvest management of fresh cucumber and eggplant through the application of reliable methodologies to effectively quantify postharvest quality losses. This research project included three major sections: (A) Quantifying postharvest losses of Caribbean grown crops, (B) Investigating the effect of environmental factors on quality changes during handling activities, and (C) Enabling the identification of optimal conditions to reduce postharvest quality loss along the food handling process.

The research project has the following specific objectives:

1. To characterize postharvest practices and losses during production and marketing of Caribbean grown vegetables using producer household surveys and modified count and weight method.
2. To study the effect of fluctuating storage conditions and wrapping materials during

postharvest storage on quality attributes in dark purple eggplant.

3. To investigate the influence of fluctuating environmental factors such as temperature and light on the phytochemical content of freshly harvested cucumber and eggplant.
4. To quantify postharvest quality loss of freshly harvested cucumber using the Taguchi approach and to predict intrinsic quality attributes as affected by environmental factors as the produce moved from farm to fork.
5. To identify the optimum handling conditions of eggplant using the Taguchi technique.

1.4 RESEARCH DESIGN AND STUDY ROUTE

Field research activities took place in Caribbean countries, more specifically in Guyana and St. Kitts-Nevis. For the purpose of this project, two different study sites in both countries were selected. Local communities from geographical regions of Parika/Black Bush Polder and Mansion/Stapleton were involved from Guyana and St. Kitts-Nevis, respectively.

Laboratory research activities took place in Montreal - Canada, more specifically at Macdonald campus of McGill University. For this project, controlled storage chambers and the food bioprocess engineering laboratory of the Plant Science and Bioresource Engineering departments were used, respectively.

Figure 1.1 describes graphically the different steps of the research project including both the problem and the objective maps followed in the study.

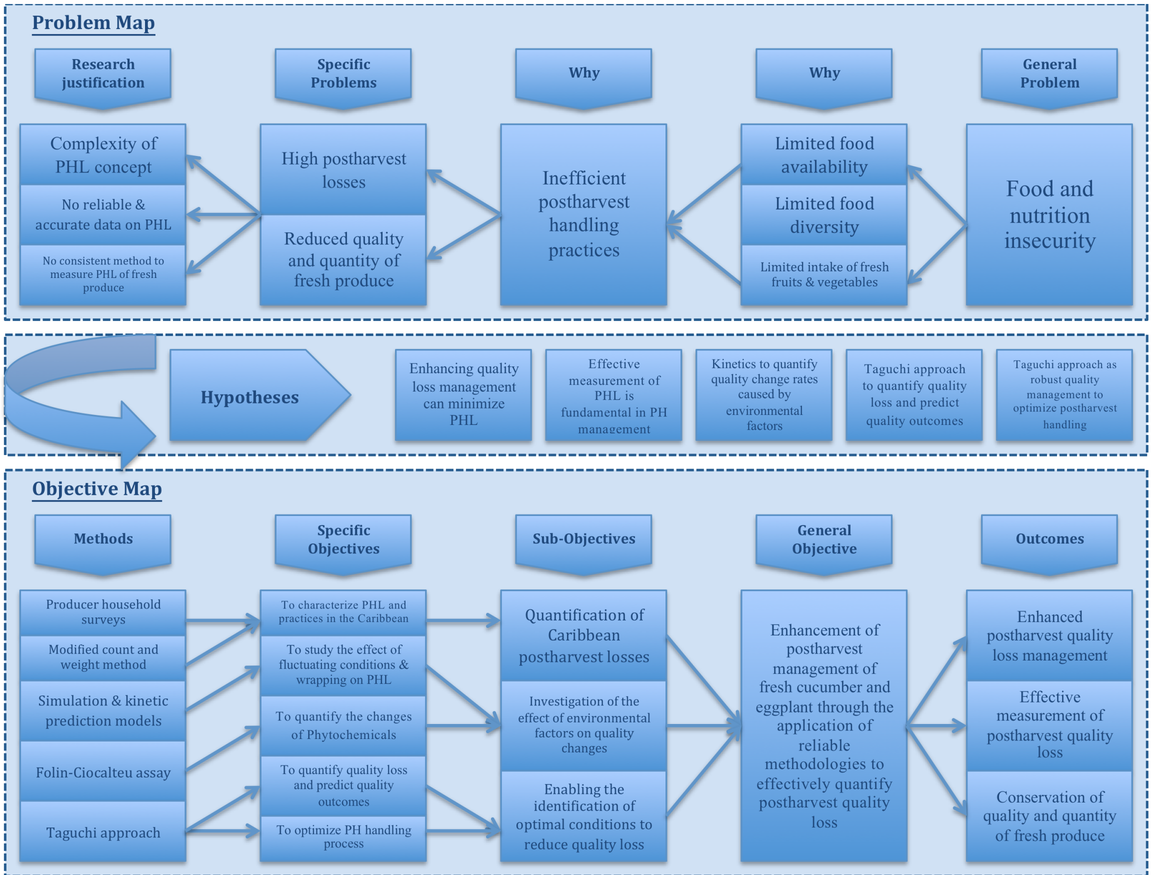

Figure 1.1 Study route of the research project

CHAPTER 2. LITERATURE REVIEW

2.1 THE HORTICULTURAL INDUSTRY

2.1.1 Fresh fruits and vegetables economy

Fruits and vegetables are known to provide the necessary food to assure a balanced diet for a healthy population. They can play a crucial role in reducing the occurrence of chronic diseases caused by unhealthy diet (FAO, 2002). Fruits and vegetables are the main source of essential vitamins, minerals, and dietary fibre feeding the world populations (Tiwari et al., 2013). According to FAO statistics, in 2011, almost 640 million tons of fruit and more than 1 billion tons of vegetables were harvested throughout the world (Table 2.1).

Table 2.1 Fruits and vegetables production per regions (FAOSTAT, 2013)

	Fruit excluding melons (MT)			Vegetables & melons (MT)		
	1990	**2000**	**2011**	**1990**	**2000**	**2011**
Africa	48	62	88	33	49	70
Americas	100	132	144	56	76	80
Caribbean	5	6	7	1	3	3
World	353	474	637	466	781	1090

In Canada, the production of vegetables has increased over the last 60 years (Table 2.2). Similarly, global fruit and vegetable production has demonstrated a significant increase over the years, especially in developing countries. Known as high-value crops, fruits and vegetables can generate more income, ensure nutritive and diversified food and enhance livelihood of local communities. Daily consumption of fruits and vegetables has also the potential to improve health. World Health Organization estimates that low fruit and vegetable intake contributes to 1.7 million deaths worldwide annually (WHO, 2012).

Table 2.2 Production of vegetables in Canada (Statistic Canada, 2015)

Vegetable	1941	2011
	Hectares	
Beets	859	1,556
Cabbage	2,423	4,156
Carrots	2,477	9,480

Cauliflowers	847	1,829
Celery	546	840
Cucumbers	1,183	2,339
Green Beans	1,850	8,497
Green Peas	7,524	11,965
Lettuce	934	3,382
Onions	2,438	5,927
Sweet Corn	8,543	23,173
Tomatoes	13,643	7,424

2.1.2 Postharvest physiology of perishable crops

Postharvest engages all actions that take place after production of agricultural commodities, including handling, storage, packaging, transportation, processing and marketing from the producer all the way to the distributor (Golob et al., 2002). Most fruits and vegetables are highly perishable plant produce (Table 2.3), they are alive and persist to be active metabolically even after harvesting. However, their metabolism is different with that of the mother plant growing in its original environment since the harvested produce undergoes varying degrees of stress and senescence mechanisms.

Table 2.3 Differences between durable and perishable commodities (Golob et al., 2002)

Durables	Perishables
Suitable for preservation	Not suitable for preservation
Low moisture content, usually 10-15%	High moisture content, usually 50-90%
Small unit size, less than 1 g	Large unit size, typically 5 g to 6 kg
Often symmetrical in shape	Often asymmetrical in shape
Hard texture	Soft texture
Stable-inherent storage life of years	Perishable-natural storage life of a few days to months depending on type.
Losses mainly caused by external factors, e.g. mould, insects and rodents	Losses caused by external factors, mainly moulds and bacteria, and internal factors, e.g. respiration, sprouting, ripening, etc.

2.1.2.1 Respiration

Respiration is a metabolic process that occurs continuously in all living cells. In freshly harvested fruits and vegetables, physiological modifications due to the respiration process occur and sometimes at accelerated rates (Thompson, 2003). Respiration is the conversion or the oxidation of organic matter such as starch, sugar, and organic acids to produce simpler molecules like CO_2 and H_2O with the release of energy (heat) to maintain cell's metabolism, tissue and quality of the commodity (Bhande et al., 2008). The availability of oxygen (O_2) is very essential during respiration resulting in an "aerobic respiration process". The overall process of aerobic respiration involves the synthesis of adenosine triphosphate (ATP), which is commonly known as energy trapping device (Uchino et al., 2004), from adenosine di-phosphate (ADP) and inorganic phosphate (P_i). In addition, glucose coalesces with oxygen to generate carbon dioxide, water and heat (Eq. 1):

$$C_6H_{12}O_6 + 6\,O_2 + 38\,ADP + 38\,P_i \Rightarrow 6\,CO_2 + 44\,H_2O + 38\,ATP \qquad (1)$$

The release of heat can be detrimental for the plant tissue, causing the temperature of the produce to increase and resulting in qualitative and quantitative degradation of the commodity (Becker et al., 1996). The rate of deterioration is proportional to the respiration rate of the produce (Fonseca et al., 2002). Horticultural crops are classified based on their respiration rates (Kader, 2002) ranging between very low (<5 mg $CO_2 \cdot kg^{-1} \cdot hr^{-1}$) such as dates, dried fruits and vegetables; and extremely high (>60 mg $CO_2 \cdot kg^{-1} \cdot hr^{-1}$) including asparagus and mushrooms. Several factors influence the produce respiration rate such as temperature, commodity and genotype, maturity, climacteric behaviour, and chemical composition of the atmosphere (Cortbaoui, 2005). During respiration, the commodity accelerates the use of its internal energy and water reserves causing losses in nutritive values and general appearance (Kader et al., 2004). Respiration process is highly affected by relative humidity (Golob et al., 2002). As the temperature falls, the relative humidity of air rises, slowing down respiration rate of the produce (Yahia, 2005). Thus, controlling the respiration process by maintaining proper storage conditions such as low temperature and high relative humidity has become very essential to enhance the quality of fruits and vegetables at the commercial level.

2.1.2.2 Transpiration

Transpiration is a process by which fresh crops lose their water by evaporation (Becker et al., 1996). Moisture inside the produce is moved through the outer skin, and then evaporated resulting in a cooling of the commodity (Cortbaoui, 2005). Kader (2002) showed that direct losses in mass and appearance occur during transpiration that cause wilting and death of the produce in addition to firmness and nutritional losses. Transpiration rate is affected by environmental factors such as temperature, relative humidity and atmospheric pressure (Watkins, 2003). Storage at low humidity facilitates the transmission of water vapour from the commodity surface into the surrounding air. The transpiration rate is also dependent on internal factors such as the morphology and the anatomy of the horticultural commodity, surface-to-volume ratio and maturity stage (Cortbaoui, 2005).

The transpiration is a process of mass transfer throughout the surface of the produce and it can be determined by the following equation (Becker et al., 1996):

$$m_t = k_t\left(p_s - p_a\right) \tag{2}$$

Where "m_t" is the transpiration rate ($g \cdot m^{-2} \cdot s^{-1}$), "$k_t$" is the transpiration coefficient ($g \cdot m^{-2} \cdot Pa^{-1} \cdot s^{-1}$), "$p_s$" is the water vapour pressure at surface (Pa), and "p_a" is the water vapour pressure in the air (Pa). The transpiration process represents an economic loss through the loss of water from the produce, which results in a loss of its marketable quality due to wilting and shrivelling (Cortbaoui, 2005).

2.1.3 Eggplant

Eggplant (*Solanum melongena* L.) belongs to the Solanaceae plant family and commonly known as aubergine, is considered among the 30 most commonly produced and consumed horticultural crops worldwide (Concellón et al., 2007; Florkowski et al., 2014). It is best grown in tropical and sub-tropical areas (Loose et al., 2014) and has high economic and nutritional values worldwide (FAO, 2013; Okmen et al., 2009). According to recent statistics from the Food and Agriculture Organization (FAO), the global production of eggplant was 48MT in 2012 occupying an area of 1,853,023 ha (FAO, 2013). It contains a large amount of polyphenols, vitamins and minerals, which provide a wide variety of health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer benefits (Boulekbache-Makhlouf et al., 2013; Mukherjee et al., 2013). In many countries in Asia and Latin America, the majority of eggplant fruits are cultivated and harvested by farmers of small land holdings and are considered as a vital source of income for them (Hanson et al., 2006). Eggplant, like many other fresh plant products, is highly perishable and persists to be active metabolically even after harvesting (Kader et al., 2004).

Usually eggplants are egg-shaped or globular and have a bright green calix and firm texture (Gross et al., 2014; Jha et al., 2002). At the international level, the dark purple eggplant is the most commercially consumed fruit among other eggplant varieties (Zaro et al., 2014a).

2.1.4 Cucumber

Cucumber fruit (*Cucumis sativus* L.) belongs to the Cucurbitaceae plant family that can be cultivated in subtropical and tropical environments; therefore, they are native to many countries of the world (Ismail et al., 2010). Cucumber is known for its fresh crisp taste, high nutritional value and great health promotion capacity. This crop provides a variety of health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer benefits (Mukherjee et al., 2013). According to FAO statistics, the global production of cucumber was 65MT in 2012 grown in an area of 2,109,650 ha (FAOSTAT, 2013). Cucumber is a highly perishable crop and the environmental conditions under which cucumber is produced, transported and displayed have a significant effect on the keeping quality of this food and the amount that is lost. Depending on the cultivar, the most common quality cucumber fruit should be dark green and firm with no wrinkled ends (Gross et al., 2014). Desirable size and green peel of cucumber fruits are the main selection criteria by the consumer.

2.2 POSTHARVEST LOSSES OF FRUITS AND VEGETABLES

2.2.1 Postharvest losses and food security: An overview

Despite its simple definition, food security is an enormously complex issue and cannot be simply reduced to a single, atomistic poverty issue. It has several assumptions including social, economic and environmental aspects, which increase the number of factors influencing it and make it a real challenging task to achieve. According to the United Nations (2013), projected world population growth is from 6.1 billion in 2000 to 9.1 billion in 2050, increasing therefore by 49%. Despite enormous achievements in science and technology to meet the global increase in food demand due to human population growth in developing countries and the increase in income in developed countries, nearly 870 million people around the word suffer from hunger and malnutrition, another billion is overweight and obese (FAOSTAT, 2013). Defining food security was largely discussed and elaborated by local, national and international organizations. One of the most acceptable definition (WFS, 1996) is that "*Food security exists when all people,* *at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*".

Recent studies commissioned by FAO revealed that roughly one-third of global food produced for human consumption is lost or wasted (Gustavsson et al., 2011). Losses of fresh fruits and vegetables are of considerable interest due to their extremely high values reaching 50% in developed countries and 55% in developing countries (FAO, 2011). A clear pathway to ensure the availability of food is to minimize the postharvest losses rather than producing more food. In addition to enhancing livelihood, this step will impact positively the environment and the climate change (Gustavsson et al., 2011; Hodges et al., 2011). Postharvest losses (PHL) therefore have a huge implication on food security and human livelihood. It threatens not only food but also nutrition and income security (Affognon et al., 2015). The removal of food from the chain as a result of PHL increases food prices. Postharvest losses are basically the reduction in foodstuff, which may affect their quantity and quality (World Bank, 2011). These losses occur along the supply chain, from the field to the final consumer plate. In developing countries losses occur at production and processing levels while in industrialized countries losses happen at retail and consumer levels. In most developing countries the losses are generally attributed to rough handling and inadequate cooling and temperature maintenance.

While the world looks forward to feed 9 billion people in the near future, postharvest management is required to play an important role in reducing the losses and maximizing the value of fruits and vegetables. In doing so, basic postharvest technologies which will slow down deterioration and maintain quality and safety, thus, maintaining quality in appearance, texture, flavor and nutritive value, protecting the safety of food as well as reducing the overall losses between harvest and consumption are an urgent call (Grolleaud, 2002).

2.2.2 Types of postharvest losses

Postharvest losses generally refer both to the reduction in amounts (quantitative) and the value (qualitative) of the food. Along the supply chain, part of the food is lost due to pest and diseases while other part is lost due to poor handling. This not only reduces the availability of food but also its quality. In this section quantitative and qualitative losses of fruits and vegetables and their impact are discussed.

2.2.2.1 Quantitative losses

Quantitative losses are losses in terms of physical substance indicating a reduction in weight and volume, which can be assessed and measured (Kitinoja & Kader, 2002). They occur when there is reduction in the amount of food available for consumption. In the field, heat from the sun together with the respiration heat up the produce and this accumulation of heat is known to reduce its shelf life. When fruits and vegetables are handled carelessly, the internal bruises result in physiological damages as well as breaking the skin or splitting (Kader, 2005). This increases the loss of water and the rate of physiological breakdown in addition to providing avenues for infections leading to decay (Grolleaud, 2002). Quantitative food losses along the chain occur in different forms as a result of spoilage or wastage. Spoilage is used to describe the losses that occur during harvest, transport, storage, processing and packaging (Burden & Wills, 1989). These losses are higher in developing countries than in the developed world. In most developed countries foods fit for consumption are sometimes dumped in the field. Lundqvist et al. (2008) referred to this as wastage and defined it as deliberately discarding and throwing away of food that is "fit for purpose and perfectly good to eat". This usually occurs toward the end of the supply chain mainly at the consumer level.

2.2.2.2 Qualitative losses

Fruits and vegetables provide essential minerals and vitamins in everyday diet. Their quality deteriorates with time as a result of physiological factors, mechanical damage or disease and pest. Qualitative postharvest losses occur when produce suffers loss in edibility, nutritional quality, caloric value and consumer acceptability (Knight et al., 2007). The physiological deterioration is caused by high temperature and low humidity conditions, which increases the deterioration rate. This results in unpalatable flavors and failure in ripening of produce (Kader, 2004). The impact of qualitative losses outweighs the occurrence of the actual physical loss. This is because with quality loss, the farmer tends to suffer direct financial loss, transcended through postharvest operators and marketers. This quality loss then increases cost of quality compliance systems, which monitors standards in the chain. Qualitative postharvest losses along the value chain have the potential of undermining product trade confidence, which eventually results in downward price pressure.

2.2.3 Environmental factors contributing to postharvest losses

2.2.3.1 Temperature

Inadequate temperature can be detrimental for quality of fresh produce (Concellón et al., 2007). Kader (2002) stated that temperature is the major environmental factor that affects the deterioration rate of non-chilling sensitive commodities. For each increase of 10^0C above optimum conditions, the rate of deterioration increases by 2 to 3 times. Exposing harvested commodity to elevated temperature can initiate a favorable environment for pathogens to grow and cause serious safety issues for consumers. Moreover, storing crops at high temperatures was demonstrated to be the driver behind accelerated respiration and transpiration rates, which can further deteriorate the postharvest quality of the produce. Precooling the commodity immediately after harvest can alleviate the effect of high temperature on crop losses and extend their shelf life (Cortbaoui et al., 2005; Vigneault et al., 2007). Temperature affects not only the appearance and shelf life but also the texture, nutritional value and organoleptic characteristics such as flavor and aroma (Burden & Wills, 1989). Vitamins degradation is often associated with storage temperature. At higher temperature, nutritional value loss, such as vitamin C degradation is rapid. For example, there is negligible vitamins C loss in lemon at 13^oC but a significant loss at 24^oC (Lange et al., 1994).

2.2.3.2 Relative humidity

Relative humidity is another environmental factor that can cause serious quality loss to fresh commodities. The rate of water loss from the fruits and vegetables is greatly dependent on the percent of moisture present in the surrounding air; the lower the relative humidity the higher the water loss (Kader, 2002; Watkins, 2003). Low humidity results not only in direct quantitative losses (weight reduction) but also in qualitative losses such as wilting, shrivelling and softening (FAO, 2007; Hung et al., 2011). Relative humidity influences the quality of fruits and vegetable during storage. High relative humidity favours some products but is detrimental to others. For instance, storing peaches at high humidity (95-99%) does not increase their shelf life, however, for cherries and lemons, it extended shelf life (Somner et al., 1960). The recommended commercial storage for eggplant is set generally for less than 14 days at $10\text{-}12^0C$ and 90 to 95%RH (Gross et al., 2014). High humidity reduces peel desiccation and fruit deformation such as peel greening, chilling injury and decay (Paull, 1999). Higher relative humidity (98-100%) is usually recommended for fruits and vegetables.

2.2.3.3 Light

The presence or absence of light during product storage has a direct impact on the overall postharvest quality of fruits and vegetables affecting their phytochemical content (Sharkey et al., 1984). In some fruits and vegetables rich in antioxidants, like eggplant and cucumber, the presence of light aids deterioration and reduces quality (Xiao et al., 2014a). Sanz et al. (2009) have shown that accelerated degradation in quality and reduced shelf life was observed with stored asparagus under continuous lighting conditions. Other studies carried out by Martinez et al. (2011) revealed that light could also promote browning of fresh-cut lettuce. In other vegetables such as the basil leaf, detachment and exposure of leafy vegetables to darkness or low lights induces senescence due to water and nutrient deficiency and absence of photosynthesis (Massa et al., 2008). Postharvest senescence is known to increase overall losses due to rapid decline in quality (Ella et al., 2003). To improve the shelf life of some vegetables like lettuce, radish and spinach, several lighting systems have been employed to supplement storage lighting and proven to be successful (Hassan et al., 2010).

2.2.4 Existing methods of measuring postharvest losses

Postharvest loss is a complex problem. One key setback to postharvest effort is the lack of clear knowledge and appreciation of the magnitude of the losses. Current postharvest data varies widely in magnitude being quoted as 10 - 70 % (FAO-World Bank, 2010; Lundqvist et al., 2008). The amount of loss differs between crops, geographies, growing conditions, and along the different segments in the supply chain. Measuring these losses is very challenging and generally, qualitative losses are more difficult to measure than quantitative. The extent of these losses is considerable for fruits and vegetables, which are relatively less hardy and easily deteriorate during the entire value chain. In addition, it is difficult to generate a comprehensive view of the extent of postharvest loss because available information is limited. Unfortunately, most of the available postharvest losses are based on estimated numbers and few actual measured data. These measurements are sometimes either not traceable or estimated from data sets collected 30 years ago (Affognon et al., 2015). The current literature does not offer integrated and reliable approaches for evaluating postharvest losses of fresh produce (Aulakh et al., 2013). In many countries, most postharvest loss data are obtained through surveys, whereas other estimation method such as the "Loss-Adjusted" data is also used. In the United States for example, the Loss Adjusted Food Availability (LAFA) data, which is a standard proxy for food consumption, adjust for spoilage and other loss and provide information on the availability of food for human consumption.

Quantitative postharvest losses are estimated by measuring food weight loss. Conventionally, this is done by finding weight ratios of produce and their non-edible component. This method underestimates losses, hence modified version such as the modified count and weight approach also known as "gravimetric methods" have been developed and are widely used (Compton et al., 1998; Compton et al., 1999). These methods are relatively time consuming and they need special equipment. Subjective measurements such as the "visloss" were also developed (Aulakh et al., 2013) by the Food and Agriculture Organization of the United Nations (FAO). In these methods, visual scales or scale ratings were used to assess those losses. For many researchers, estimating postharvest losses was not following a holistic approach. Most of the studies have focused on measuring the losses only at the storage steps without incorporating other important stages along the supply chain (such as grading, packaging, transporting and processing), which can also contribute largely to postharvest losses (Aulakh et al., 2013; Van Dijk et al., 2012). Existing methods to estimate postharvest losses are mainly FAO initiatives and based on surveys especially in developing countries (Aulakh et al., 2013; FAO, 2014; Koester, 2013). In addition, recent studies were undertaken by the FAO to estimate food losses using FAO's Food Balance Model (FBM), where food loss is calculated based on the principles of mass flow ($mass_{in}$ = $mass_{out}$) through the value chain process (Gustavsson et al., 2011). In order to quantify these losses, this model uses the pre-set "conversion factor" for each crop, which determines the part of agricultural products that is edible, and multiplies it by the loss percentage in each step of the food supply chain. However these losses have relied on assumptions and estimations; therefore, this is considered a huge "gap" in the knowledge of measuring postharvest losses. There is currently no framework with a consistent and reliable parameter for estimation. Therefore, there is an urgent need for a simple and more reliable measurement system adaptable to other crops.

2.3 FOOD QUALITY MANAGEMENT

2.3.1 Principles and forms

Many industrial products have quality problems, however, food quality is different. Food products are living systems; they continue to be metabolically active after harvesting and during handling. They have restricted shelf life due to numerous biological, chemical and physiological reactions occurring prior to consumption. Food items are commonly known as highly complex systems because of their composition where an abundant amount of macro- and micro-components are present and reacting together. Food products have also multiple quality attributes classified in three main categories mainly safety, health and sensory attributes (Luning et al., 2009). Food quality management is basically composed of food quality and management components. The first component focuses on characterizing the quality attributes of the product from different user perspectives while the second component deals with managing the resources that contribute to achieve this quality. In his book, Luning (2009) stated, "*food quality management consists of goal-oriented decisions resulting in activities which contribute to meeting or even exceeding the quality requirements of customers*". Food quality management is therefore essential to ensure the performance of both product and production quality.

Food companies are being transformed worldwide, given changing consumption patterns and the increasing insistence on food quality and safety. Agri-food chains have been subjected to many pressures in recent years in light of globalization, food recalls, technological innovations, and decreasing consumer trust. This has led many food producers to implement a range of quality management practices notably by monitoring and analyzing major crucial points from farm to fork in order to minimize quality loss and to improve the efficiency of resource use at each stage of the whole chain process (Da Silva et al., 2009). A food production chain is a partnership between farmers, processors and retailers created to manage quality, increase efficiencies and develop differentiated food products (Kushwaha, 2010; Reardon et al., 2009). The ability to provide high quality products depends on the commitment and the cooperation of all these players.

Starting in 1930, quality management has taken the form of statistical reliability in the quality of manufactured goods (Luning et al., 2009; PMBOK, 2013). This statistical approach was then adopted between 1950 and 1980 by many industries, and has contributed to the development of quality assurance systems such as Good Practice Codes (like Good Manufacturing Practices - GMP and Allied Quality Assurance Publications - AQAP). Few years later, the principles of "Hazard analysis and critical control points (HACCP)" were introduced and adopted by the food industry in 1985 due to global concern of food safety and its implications on human health (Batt, 2006). It is a systematic preventive approach to food safety and allergenic, chemical, and biological hazards in production processes that can cause the finished product to be unsafe, and designs measurements to reduce these risks to a safe level (Besterfield et al., 1995). In this manner, HACCP is referred as the prevention of hazards rather than finished product inspection. The HACCP system can be used at all stages of a food chain, from food production and preparation processes including packaging to distribution. In 1987, the International Standards Organization (ISO) standards were first published to ensure that products and services are safe, reliable and of good quality (Besterfield et al., 1995). They are quality management system standards that provide many benefits for agri-food companies including: (1) more efficient resource use, (2) improved risk management and (3) increased customer satisfaction as services and products consistently deliver what they promise.

2.3.2 Quality definitions and perceptions

Defining quality is very difficult and complex, and therefore, there is no single definition that describes quality (Roy, 2001; Shewfelt, 1999). In 1990, Juran defined the quality as "*fitness for use*" (Brocka et al., 1992). Three years later, Deming (1993) stated "*a product or a service possesses quality if it helps somebody and enjoys a good and sustainable market*" (Brocka et al., 1992). ISO also defined quality as "*the degree to which a set of inherent characteristics fulfills requirements*" (Besterfield et al., 1995). A commonly accepted definition is that "*quality is meeting or exceeding customer expectations*" (Luning et al. 2009). Quality has also multiple perceptions based on different views between the end users. It can be seen from a product-based view as a function of a specific measurable variable, from a user-based view as what consumer wants and from a value-based view as the relationship of usefulness or satisfaction to price (Batt, 2006; Luning et al. 2009). Quality is a complex and multidimensional concept that includes several criteria when judging quality. According to Garvin (1984), there are eight principal aspects of products quality: performance, conformance, serviceability, features, reliability, durability, aesthetics and perceived quality; whereas, for Evans and Lindsay (2005) surveyed another eight dimensions of service quality: accuracy, completeness, timeliness, responsiveness, courtesy, expertise, accessibility and time (Ross, 1996). These quality dimensions are applied to any product quality; however, other characteristics may be added when evaluating the quality of a food or an agricultural product (like safety and organoleptic criteria).

2.3.3 Quality management gurus

Walter Shewhart initiated the concept of quality management (Luning et al. 2009). He was internationally recognized as the "Grandfather of Total Quality Management and Continuous Improvement" (PMBOK, 2013). He created the statistical process control (SPC) chart and the PDSA (Plan-Do-Study-Act) cycle to ensure a winning situation between business owners and consumers. Quality management was then modified by Edward Deming who developed the PDCA (Plan-Do-Check-Act) cycle and the Deming's famous 14 points to help companies increase their quality and productivity (Luning et al. 2009). The Deming's philosophy was to increase product quality by reducing the uncertainty and variation in product development and process design (PMBOK, 2013). Dr. Deming concluded that 85% of the quality problems in a company are due to poor management. Another guru, Joseph Juran contributed enormously to quality management (Luning et al. 2009). His philosophy was known as Juran's quality trilogy for management, which involves quality planning, quality control and quality improvement (Besterfield et al., 1995). In 1973, Kaoru Ishikawa founded the "Quality Circles" and the "International Academy for Quality" in Japan (Besterfield et al., 1995). One of his major contributions was the "Cause and Effect" diagram, also called "Fishbone" diagram, where he illustrated how various factors such as equipment, environment, process, people and management, can be linked to potential defects of the final product. Philip Crosby, known also as "the Fun Uncle of the Quality Revolution", made remarkable achievements in quality management (Luning et al., 2009). For him, the quality is equivalent to conformance to requirements. His philosophy came from the idea "*do it right from the first time*", and then the quality comes from prevention not from appraisal. He measured the quality by the cost of non-conformance with a performance standard of "zero defects". Another guru in quality management, Genichi Taguchi, provided a specific tool to improve the product as well as the process by which it is made (Luning et al. 2009; PMBOK, 2013). He stated that quality couldn't be ensured through inspection and rework after production (Taguchi, 1993), but must be built in through the appropriate design of the process and product.

After a thorough literature review, it was found that almost all studies in the non-food sector were relying on the philosophies of those gurus for quality management such as TQM, Lean and Six sigma, however, in the food sector, researchers were applying quality assurance systems such as HACCP, ISO and GMP. The key reason for this implementation was the focus on food safety as primary objective for all food companies and the lack of knowledge and training for other quality management systems among these companies (Dora et al., 2013).

2.4 TAGUCHI APPROACH

2.4.1 Principles and concepts

The Taguchi approach was developed by a Japanese engineer and statistician, Genichi Taguchi, in 1949 (Roy, 2001). Professor Taguchi spent his entire career developing ways to improve the quality of a product. The Taguchi method is an approach associated with robust quality management that combines engineering and statistical methods in order to reduce commodity loss and improve its quality (Ross, 1996; Taguchi, 1993). As mentioned earlier, different people can perceive quality differently. Taguchi has introduced a new dimension of quality: the loss to society caused by a product. According to him, "*quality is the loss imparted to the society from the time a product is shipped*" (Ross, 1996; Roy, 2001). Therefore, the minimum the loss, the maximum the quality of a product obtained. The loss could be any inconvenience and monetary or other loss occurred by the product before or during its use (Barker, 1990). For Dr. Taguchi, a clearly defined measure of quality is essential before any effort is made to improve quality. He declared that the quality of a product is equivalent to its performance characteristics and the ideal value of this characteristic is called "target" (Luning et al., 2009). Maintaining high quality of a commodity will require reducing variations around its target by achieving consistency of performance (Roy, 2001). To attain this consistency, the distance of the population mean from the target should be reduced (Figure 2.1).

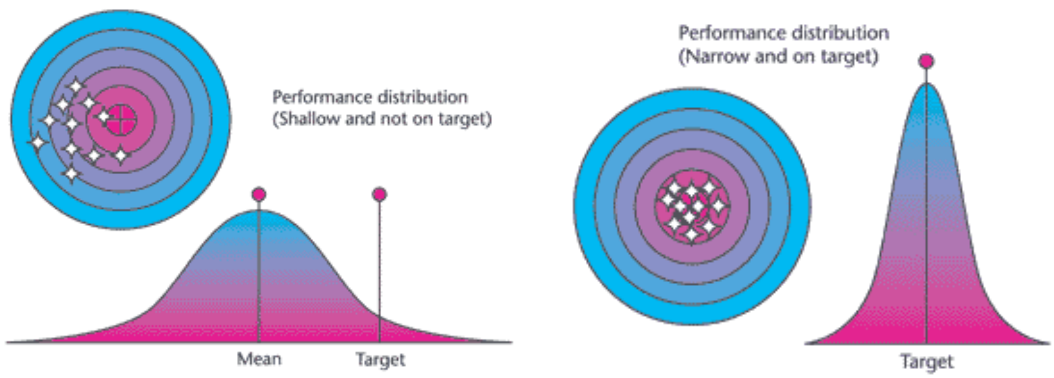

Figure 2.1 Performance consistency of a product as it moves away from the target (Roy, 2001).

In conventional methods, the quality of a product is determined only through inspection at critical steps in a chain where highest loss might occur; however, the overall quality improvement proposed by Taguchi is designed in a way that elements of quality are linked together throughout the process chain and all the links must be equally strong (Bendell et al., 1989). In his work, Taguchi exploits a modified form of "Design of Experiment – DOE" with specific application principles (Roy, 2001). The DOE concept is a statistical tool introduced originally by Sir Ronald A. Fisher in the early 1920s to study the effect of many factors or variables on the results simultaneously and quickly (Roy, 2001). Taguchi then demonstrated that DOE could be used not only to improve quality of a product but also to quantify this improvement in terms of reducing the loss (saving monetary values) generated by this product to the society. In order to analyze the results of an experiment, Taguchi followed basic statistical calculations such as mean and analysis of variance (ANOVA), but combined them with a new approach based on their deviation from the target instead of absolute values (Roy, 2001). Taguchi's method key concepts are three-fold: (1) it can help with the identification of common causes of variation, the most difficult to determine and eliminate during a process, (2) it makes the process and the product robust against their effect at the design stage, and (3) it minimizes the variation in product response while keeping the mean response on target. At the end, the Taguchi approach is also known as a "robust design" due to the fact that the quality of a product is improved by minimizing the effect of variations during the process without eliminating the causes (factors), which in most cases are uncontrollable.

2.4.2 Scope and purpose of usage

To date, the Taguchi approach has been widely and successfully used in various subject areas. Sadeghi et al. (2012) had applied the Taguchi approach in environmental sciences where they assessed soil erosion as affected by soil texture, slope, aspect and vegetation cover. Other researchers (Oztop et al., 2007) used the Taguchi technique in food engineering to optimize the microwave frying process of potato slices. The Taguchi method was also recommended in the biotechnology field to optimize virus yields for vaccine production (Trabelsi et al., 2006). From the literature, the Taguchi approach was found to be successfully applied in construction too to determine the best conditions to obtain the physical properties that will lead to the most durable concretes (Tukmen et al., 2008). This approach was also used in many other research areas including energy (Zeng et al., 2010), aerospace (Singaravelu et al., 2009), sports (Burton et al., 2010) and manufacturing (Dingal et al., 2008; Emadi et al., 2008). This robust quality management approach was mainly able to determine the optimum parameters of a production process and to quantify the quality loss of a manufactured product (Ross, 1996). In his book entitled "Taguchi's Quality Engineering Handbook" (Taguchi et al., 2005a), Professor Taguchi has included more than 90 different applications of his approach in many research fields such as electricity, microbiology, plant production, software development, automobile manufacturing, construction, medicine, robotics, culinary and many others. To the best of our knowledge, no application of this approach to postharvest technology of horticultural commodities has been reported until the present time.

2.4.3 Taguchi's contribution to quality management

2.4.3.1 Quality loss function

The major contribution of Taguchi's approach to quality management is the new concept of "Quality Loss Function" (Roy, 2001). For this, Taguchi developed the loss function curve, usually a parabola as noted in Figure 2.2 (Taguchi et al., 2005b), to quantify quality loss of a commodity. This curve describes the magnitude of loss as the quality moves far or close to its target value. As long as quality deviates from the target value (m), there is "loss". Therefore, he declared that the loss of quality is not only incurred when results do not meet customer specifications. This opposes conventional methods (also called Traditional Goal Post - TGP) for quality management (Taguchi et al., 2005b) where product quality is only defined as "bad" or “good” and as long as the product lies within its specification limits, there is no “loss” (Emadi et al., 2008; Oztop et al., 2007). He then concluded that in order to reduce quality loss of a product, one should reduce the variability around a customer-defined target instead of just meeting customer specifications (Taguchi et al., 2005b). This variability is mainly caused by undesirable external factors (environmental, work, human factors, etc…) throughout the process of that product. Quality loss function is used for three quality characteristics: smaller-the-better, nominal-the-best and larger-the-better (Taguchi et al., 2005b). The nominal-the-best scenario is when there is a fixed target value to reach and any variability around this value is considered unacceptable and a source of loss. The smaller-the-better characteristic is when there is a tendency to minimize the obtained results with a desirable target value of zero. The larger-the-better type of quality loss function is when there is a tendency to maximize the occurrence of some desirable results and the target value being infinity.

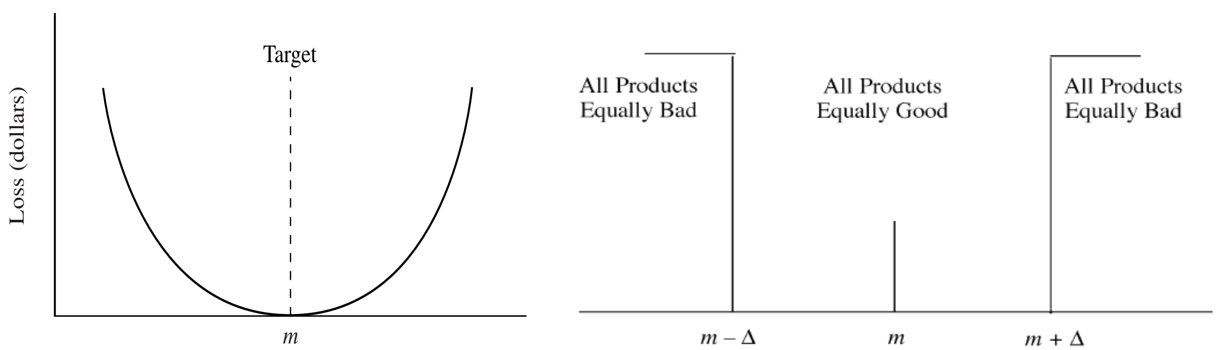

Figure 2.2 Taguchi loss function curve (Left) and Conventional view of quality loss (Right).

Taguchi proposed a mathematical formula called the “quadratic loss function” to quantify the quality loss (Ross, 1996; Taguchi, 1993). The loss due to performance variation is proportional to the square of the deviation of the performance characteristic from its nominal or target value (Taguchi et al., 2005b); therefore, the loss function in case of nominal-the-best quality characteristic is given as (Eq. 3):

$$L = k_L (y - m)^2 \tag{3}$$

Where “L” is the loss, “k_L” is the proportionality or loss constant, “y” is value of quality characteristic and “m” is the target value. When the product’s quality (y) is at its target value (m), the loss (L) is minimum (zero). For other loss functions, the formulas are as follows (Eq. 4 and 5):

$$L = k_L (y)^2 \text{ for smaller-the-better target} \tag{4}$$

$$L = k_L \left(\frac{1}{y}\right)^2 \text{ for larger-the-better target} \tag{5}$$

The important consequence of such function is that the loss follows a continuous pattern and not a sudden step as the quality moves around the target (Barker, 1990). This description of quality demonstrates that making a product within its specification limits does not necessarily guaranty that the product is of good quality and no loss is incurred. Therefore, many scientists have adopted the Taguchi loss function as a robust quality management technique to quantify the most unseen quality losses as affected by minimal variations during a process.

2.4.3.2 Orthogonal arrays

Taguchi used a modified version of experimental design techniques as statistical tools to improve and optimize the design parameters of a process and significantly minimize the overall testing time and experimental costs (Besterfield et al., 1995). When the number of factors and levels increases, application of a full factorial design is very time consuming, expensive and sometimes impossible. To minimize the number of tests required, fractional factorial experiments (FFE) were developed. FFE use only a portion of the total possible combinations to estimate the effects of the main factors on the results. Taguchi then developed a family of FFE matrices that could be utilized in various situations. These matrices are known as orthogonal arrays meaning that these arrays are balanced in such a way to assure that each level of the factors has the same opportunity to influence the results (Roy, 2001). Taguchi has created a number of orthogonal arrays based on the number of factors and their levels. The most common arrays for industrial experiments are two-, three- and four-level factors and their corresponding designations are L-4, L-8, L-12, L-16 and L-32 for two-level arrays; L-9, L-18 and L-27 for three-level arrays; and modified L-16 and L-32 for four-level arrays (Roy, 2001). For further understanding, an experiment of 4 three-level factors (y^x with y = level; x = factor) is considered an L-9 orthogonal array, which means that a full factorial experimental design gives $3^4 = 81$ possible combinations or experimental trials. Using the fractional factorial design in Taguchi approach, only 9 experiments with different combinations are needed.

2.4.3.3 Signal-to-Noise ratio

In his work, Dr. Taguchi has defined the different elements of a typical process including the inputs, the outputs and the factors that can play a major role in determining the final quality of a product. He then divided the factors into two categories namely controllable and uncontrollable factors. Controllable factors are the desirable parameters that the process requires to produce the intended product, whereas uncontrollable factors are the undesirable parameters that are responsible for a significant variability in the process design, which leads to loss of quality in the product (Besterfield et al., 1995). These uncontrollable factors are usually unidentifiable, difficult to control or too expensive to control and referred as "*noise*" factors. In many experiments, these noise factors are environmental variables such as temperature and humidity, and storage conditions (Taguchi et al., 2005c). To analyze further the quality loss of a manufactured commodity, Taguchi developed the concept of robustness where he incorporated the signal-to-noise *(S/N)* ratio to the design of quality (Wang et al., 2012; Zeng et al., 2010). This ratio was criticized several times in literature (Box, 1988; Nair et al., 1992). It helps to assure a design that is robust under the influence of noise factors (Taguchi, 1993). In other words, the best product will only respond to "*signals"* and will be immune to noise factors (Sadeghi et al. 2012). Therefore, the goal of the quality loss reduction effort can be stated as targeting to maximize the signal-to-noise *(S/N)* ratio for the respective product.

As mentioned earlier, the Taguchi approach provides an efficient way to determine the optimum conditions of a process that result in higher quality and minimum loss of a product (Oztop et al. 2007; Trabelsi et al. 2006). Conventional statistical experimental design can determine the optimal conditions of a process according to the "measured values" of the characteristic properties of a product, while Taguchi technique allows choosing the experimental condition having the minimum variability as the "optimal condition" (Sadeghi, et al., 2012). Taguchi (2005a) proposed the following formulas to calculate the S/N ratio based on target type of the commodity (Eq. 6 and 7):

$$\frac{S}{N} = -10Log_{10}\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \text{ for larger-the-better} \tag{6}$$

$$\frac{S}{N} = -10Log_{10}\left(\frac{1}{n}\sum y_i^2\right) \text{ for smaller-the-better} \tag{7}$$

Where “n” is the number of observations or replicates of the particular commodity under the same experimental conditions, and “y” represents the respective quality values of the commodity. In other words, the S/N ratio is a measurement scale to evaluate the process and product performance as affected by noise factors.

Overall, the Taguchi approach is a powerful statistical tool that can offer various improvements in quality management and loss reduction. The Taguchi method mainly focused on designing the quality at very early stages in the process, aiming to design a product and a process that is resistant to major causes of quality reduction. Taguchi approach provides a consistent and an efficient approach to predict the outcome of different process conditions and the identification of the most influenced noise factors on the product quality.

CONNECTING TEXT

The study was embedded in a larger project taken place in the CARICOM region but it focused on two countries namely St. Kitts-Nevis and Guyana. With the aim to enhance postharvest quality management of fresh produce, it was necessary to characterize postharvest practices and losses of locally grown crops at various segments of the supply chain in those countries. The next chapter illustrates the application of two different methods to assess postharvest losses, namely producer household baseline survey and modified count and weight method. This enables to collect data on postharvest handling activities carried out by the farmers and the retailers, and to estimate qualitative and quantitative losses of fresh produce.

CHAPTER 3. CHARACTERIZATION OF POSTHARVEST PRACTICES AND LOSSES OF FRESH PRODUCE ALONG THE CARIBBEAN SUPPLY CHAIN: GUYANA AND ST. KITTS-NEVIS

3.1 ABSTRACT

Inefficient handling and high postharvest losses describe the Caribbean supply chain of fresh fruits and vegetables. In this study, two different approaches to characterize the postharvest practices and losses of key agricultural commodities (tomato, string beans, eggplant, okra and cucumber) were developed for Guyana and St. Kitts-Nevis: (1) producer household surveys (PHS) and (2) modified count and weight (MCW). Results from the PHS baseline surveys revealed that Caribbean farmers sell most of their harvested crops to local markets, keeping the remaining crops for household consumption. In Guyana, the majority of farmers (97%) reported selling their crops at harvest, while in St. Kitts-Nevis, 61% of farmers stored their produce before selling. One plausible explanation for this practice is that farmers delay selling to obtain higher prices based on market demands. While farmers in St. Kitts-Nevis reported 30% postharvest losses of crops due to spoilage, those in Guyana reported considerably less. Results from modified count and weight method revealed that small producers experienced greater postharvest loss compared to large ones due to spoilage and lack of market access. A reasonable explanation to this is the degree of knowledge in high-value crop production between the two types of farmers. As the produce travelled throughout the supply chain, it started to lose significantly ($P < 0.05$) its freshness and its marketable value as well. At the marketing level, small and large retailers in both countries experienced substantial postharvest quantitative and qualitative losses. These losses were due to inappropriate handling and exposure to undesirable environmental conditions.

3.2 INTRODUCTION

Fruits and vegetables play an important role in improving diets. World Health Organization estimated that low fruit and vegetable intake contributed to 1.7 million deaths worldwide annually (WHO, 2012). According to FAO statistics (FAOSTAT, 2013), almost 640 million tons of fruit and more than 1 billion tons of vegetables were harvested worldwide in 2011. Most fruits and vegetables are known to be highly perishable plant produce, they are alive and persist to be active metabolically even after harvesting (Kader & Rolle, 2004). However, their metabolism is different from that of the mother plant growing in its original environment since the harvested produce undergoes varying degrees of stress (Watkins, 2003). Fruits and vegetables must be transported from the field to the table, to arrive in a good condition at the consumer level. The fresh produce supply chain system is a complex web of production, transportation, storage and retailing that moves agricultural products from farm-to-fork through series of activities (Memedovic et al., 2009). The ability to provide high-quality horticultural crops depends on the commitment of all actors in the supply chain. It requires cooperation from the producer to the retailer (Humphrey et al., 2006).

Recent studies commissioned by the United Nations (FAO, 2013) revealed that postharvest losses (PHL) of fresh crops are of considerable interest due to their extremely high values reaching 50% in developed countries where most losses occur at consumption stages and 55% in developing countries where losses happen at production and marketing stages (Gustavsson et al., 2011; Kummu et al., 2012). These losses are defined as any change in the quality (sensory attributes) and quantity (weight and volume) of a produce after harvest that prevents its future use or reduces its marketable value (Kader, 2002).

Crop production in Caribbean countries is considered a vital source of income for many smallholder farmers (Ford, 1992; Kendall et al., 2009). The Caribbean region is characterized by its tropical climate with year-round sunshine, separated into dry and wet seasons (CARICOM Secretariat, 2011). The environmental conditions under which fresh horticultural commodities are produced, transported and displayed have a significant effect on the keeping quality of the foods and the amount that is lost (Florkowski et al., 2014; Lana et al., 2005). The major environmental influences on quality of harvested crops are temperature, humidity and sunlight (Luning et al., 2009). In tropical countries, precooling technologies are limited and below the required capacity (Trotman et al., 2009). In most of those countries, postharvest infrastructures (cold storage facilities, refrigerated transport, packinghouses, etc.) are either scarce or not functioning properly (Reardon et al., 2009).

Careful handling of produce after harvest is important to maintain crop quality (Hodges et al., 2011). Factors that increase postharvest losses in developing countries vary from lack of knowledge and skills to technologies used in harvesting, storage, transportation and marketing (Van Dijk et al., 2012). The majority of food producers and handlers in the Caribbean, lack adequate knowledge and expertise in the application of modern agricultural practices, food hygiene, and good handling practices (Kendall et al., 2009). In most cases, general lack of education on efficient postharvest activities and technologies for fresh produce, leads to rough handling, mechanical damage and food quality loss (FAO, 2007). Moreover, inappropriate packages, which provide little or no protection during handling, transport and storage can also contribute to major postharvest losses of fresh fruits and vegetables (Sivakumar et al., 2011). Produce is often packed in containers with no possible vents access, or usually by using bags, which block the cold air circulation, and thus prevents adequate cooling (Kader, 2005).

The amount of loss differs between crops, location, growing conditions, and along the different segments in the supply chain. Most of the available postharvest loss data are based on estimated numbers and few actual measured data (Buzby et al. 2009). Many existing methods in literature to estimate PHL are based on measuring only weight ratios (Kader, 2003; Kitinoja et al., 2012). Conventional count and weight approaches known as "gravimetric methods" have been used to estimate postharvest losses specifically in grain (Compton et al., 1998; Kitinoja et al., 2012). This is basically a method that takes a sample, separates it into undamaged and damaged portions, counts and weighs each and calculates the percentage weight loss (Aulakh et al., 2013). Subjective measurements have also been developed and implemented by many researchers. In these methods, visual scales or scale ratings were used to assess those losses known as "visloss" (Aulakh et al., 2013).

On a similar note, Gustavsson et al. (2011) reported that postharvest losses of fruits and vegetables in Latin America and the Caribbean (LAC) were estimated at 20% at the production level and up to 30% at the marketing level (including storage, distribution and retailing). Commonly existing methods to assess PHL in the Caribbean are mainly based on household surveys. A recent document was prepared by the Inter-American Institute for Cooperation on Agriculture (IICA) on the challenges and opportunities of postharvest losses in LAC (IICA Secretariat, 2013). IICA conducted a large survey to estimate these losses. In the Caribbean region, greatest postharvest losses occurred in fresh fruits and vegetables among other horticultural commodities (35% for tomato and 52% for peppers). Results also revealed that there was no scientific and consistent information on PHL in the region and the main factors contributing to these losses were inappropriate handling and exposure to undesirable environmental conditions for the harvested crops.

3.3 OBJECTIVES

This study was undertaken in the Caribbean to characterize postharvest practices and losses during production and marketing of locally grown fruits and vegetables. This work included two major objectives: (1) to assess postharvest handling practices and losses of fresh horticultural commodities on-farm using producer household surveys and (2) to determine, identify and measure postharvest losses of fresh produce along the supply chain segments using a modified count and weight method.

3.4 MATERIALS AND METHODS

3.4.1 Study sites

This study was conducted in the Caribbean Community (CARICOM) countries, of Guyana and St. Kitts-Nevis. Guyana is bordered by Suriname to the east, Brazil to the south and southwest, Venezuela to the west, and by the Atlantic Ocean to the north. The Federation of St. Kitts and Nevis is a two-island country located in the Leeward Islands. Two different study sites in each country were selected. Local communities from the geographical regions of Parika/Black Bush Polder and Mansion/Stapleton were involved from Guyana and St. Kitts-Nevis, respectively. The selection of participants, field activities, collection of samples and evaluation of postharvest losses were conducted in collaboration with the research partners: (1) National Agricultural Research and Extension Institute (NAREI) in Guyana and (2) Ministry of Agriculture and Marine Resources (MAMR) in St. Kitts-Nevis.

3.4.2 Experimental design

3.4.2.1 Producer household survey method (PHS)

The postharvest handling practices and loss data were obtained from a baseline survey designed by Thompson-Colón et al. (2013). The survey instrument was composed of a 10-module questionnaire and targeted farmers operating small holding farms in selected project countries (Annexe 1). Due to logistical and budgetary concerns, local communities were selected with the assistance of local agents. Respondents were drawn from master lists of smallholder farmers who had registered with local government institutions and organizations. The PHS data collection procedures were similar across both project countries and consisted of in-person, paper-and-pencil interviews (PAPI) conducted with the farmers at their homes or farms (United Nations, 2005). A total of 395 questionnaires were successfully completed among the study sites. Surveys were administered based on farmers' consent to participate securing an ethical engagement with local communities. Interviewers were asked to read a short script included in the questionnaire before the start of the interview; the script explained the confidentiality agreement and the participant's right to refuse at any time.

Interviews with household members were divided into three main sections: (1) the first section focused on assessing activities associated with their farming experience on a yearly basis; this section allowed to identify the types and the density of crops produced and harvested during the last 12 months period, (2) the second part of the survey consisted of collecting information on the percentage of crops freshly harvested and sold in local markets, as well as postharvest quality changes of these crops due to spoilage and storage conditions on-farm, and (3) the last section of the survey enabled to assess the handling practices performed by the farmers' prior to selling their produce in the markets; these practices include grading and types of containers used to carry the produce. For data analysis, Bar Chart statistics were conducted using JMP version 11 software (SAS Inc., USA).

3.4.2.2 Modified count and weight method (MCW)

3.4.2.2.1 Protocol design and implementation

A field-based data collection protocol to measure postharvest quality and quantity losses of five key horticultural crops (tomato, string bean, eggplant, cucumber and okra) was developed. This protocol included information on the participants, sampling size, field study kits (color charts, refractometer, thermometer, calliper, etc…) and studied quality attributes. These crops were selected on their degree of perishability and susceptibility to losses, their seasonal availability, and their economic importance for local farmers.

The supply chain of fresh produce in Guyana and St. Kitts-Nevis was grouped into three major segments including production, marketing and consumption. At the production or farm level, farmers were divided into two groups namely small and larger scale farms. A production cycle is usually defined as the period from the beginning of harvest in a given farm to the end of harvest when the crop can no longer produce (Dixon et al., 2001). Three sets of data from the same farmer and for the same produce were collected during the same production cycle. A total of three small farmers and three large farmers in each country were selected randomly to participate in this work. At the marketing or retail level, retailers in St. Kitts-Nevis were also divided into two groups of small and larger scale. The small-scale retailers typically purchased small quantities of produce and did not use any temperature control system, although they used umbrellas to protect their crops from the sunlight, whereas the large-scale retailers normally purchased larger quantities of produce and used cold storage and refrigerated shelves in their operations. In Guyana, the supply chain network of fresh commodities was slightly different. Distributors known also as "wholesalers" were also involved in this chain. They purchased crops from the farmers and sold them back to retailers. At the retail level, sampling was conducted at the point when a retailer purchased the produce and continued every day until all the same produce was sold (typically three consecutive days). A total of three small retailers and three large retailers in both Guyana and St. Kitts-Nevis were selected randomly to participate in this study. At the consumption level, only one kitchen center in St. Kitts-Nevis was investigated in this network. This center prepared lunch for students in schools under a school-feeding program established and managed by the local government. The entire experiment was conducted in three replicates over a year.

3.4.2.2.2 Assessment of postharvest losses and quality attributes

For every study crop, a unit package (sample size) was chosen based on the size and weight of the produce (Table 3.1). Immediately after collecting the samples from different segments in the supply chain, they were transported to laboratory facilities belonging to the research partner in each country for further quality evaluation. Qualitative postharvest losses were assessed as follows: Visual quality was self-evaluated for individual fruit using a nine point hedonic scale for the parameters indicating symptoms of deterioration and limits of marketability. A quality index (QI) summarizing all these parameters was determined using the quality description in Table 3.2

and the total score for each parameter was registered. Color attribute was evaluated using rating scale method as shown in Table 3.3. Firmness and Brix measurements were conducted for individual fruit using a handheld FT 011 penetrometer (QA Supplies, Virginia, USA) and a Brix/RI digital refractometer (QA Supplies, Virginia, USA), respectively. In addition, quantitative postharvest losses were evaluated based on the percentage of bruised, diseased, dehydrated and rejected fruits of the same unit package.

Table 3.1 General characteristics of selected crops used for this study.

Crop	Unit package size (fruit)	Diameter size (mm)	Mass (g)
Tomato	10	72 to 81	93 to 105
Eggplant	10	63 to 76	342 to 412
Okra	15	18 to 23	23 to 29
String Bean	15	5 to 8	5 to 7
Cucumber	10	49 to 63	282 to 342

Table 3.2 Full description of quality index scales of study crops (Kader et al., 2010).

Quality index	Quality	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 marketability
3	Poor	Serious deterioration, limit of usability
1	Extremely Poor	Not usable

Table 3.3 Rating scales for color attribute of different produce.

Crop	Color Rating
Tomato	1 = Green; 2 = Breaker; 3 = Turning; 4 = Pink; 5 = Light Red; 6 = Red
Eggplant	1 = Bright; 2 =Dull; 3 = Brownish
Okra	1 = Yellow; 2 = Slight Green; 3 = Green; 4 = Bright Green
String Bean	1 = Yellow; 2 = Slight Green; 3 = Green; 4 = Dark Green
Cucumber	1 = Bright; 2 = Dull

To evaluate the postharvest losses of the study crops and the effect of handling practices of different segments along the supply chain in both Guyana and St. Kitts-Nevis on produce quality, an analysis of variance (ANOVA) followed by a Tukey-Kramer HSD test for comparison of means was conducted using JMP version 11 software.

3.5 RESULTS AND DISCUSSION

3.5.1 Producer household survey

3.5.1.1 Cropping systems

In both countries, the majority of the farmers (more than 50% in Guyana) had plots of land between 2 to 5 acres. A large number of farmers were growing up to 9 crops in St. Kitts-Nevis. However, in Guyana, almost 72% of farmers planted between 3 and 5 different crop varieties. This agricultural strategy was used to ensure enough quantity of diverse crops to supply the market demand. Crop production density is considered a "Good Agronomical Practice" in terms of pest infestation reduction, crop rotation, nutrient cycling and environmental unprecedented changes tolerance (Batt, 2006). The results also showed that crops from six different classification groups (using FAO classification) were grown by farmers with an emphasis on vegetables and melons in both Guyana and St. Kitts-Nevis. As shown in Figure 3.1, these classifications included vegetables-melons, fruits-nuts, oilseeds, roots-tubers, beverage-spice, and leguminous.

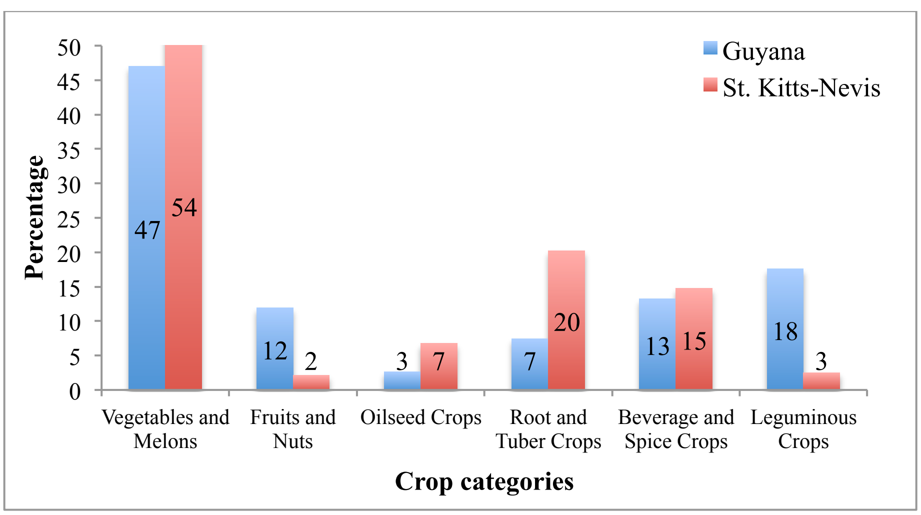

Figure 3.1 Types of crops harvested during the last 12 months period

3.5.1.2 Postharvest crop loss

As shown in Figure 3.2, up to 95% of the harvested crops were sold to local markets in Guyana, whereas in St. Kitts-Nevis only 65% of the produced commodities were sold. Another remarkable finding was the high percentage of spoilage in St. Kitts-Nevis (30%), where some produce was completely lost on-farm and became unmarketable. On a different note, there was minimal report of storing crops after harvest in Guyana (3%), but in St. Kitts-Nevis over half of the harvested crops (61%) were being stored at the farm level (Figure 3.3). One plausible explanation for this practice is that farmers in St. Kitts-Nevis delay selling to obtain higher prices based on market demands (Baudron et al., 2012). There is a marked correlation between the spoilage of harvested produce for small farmers and their storage activity on-farm, which compounds the problem of postharvest losses arising from limitations in storage technology under inadequate conditions of temperature, humidity and light. Household members consumed the remaining harvested crops.

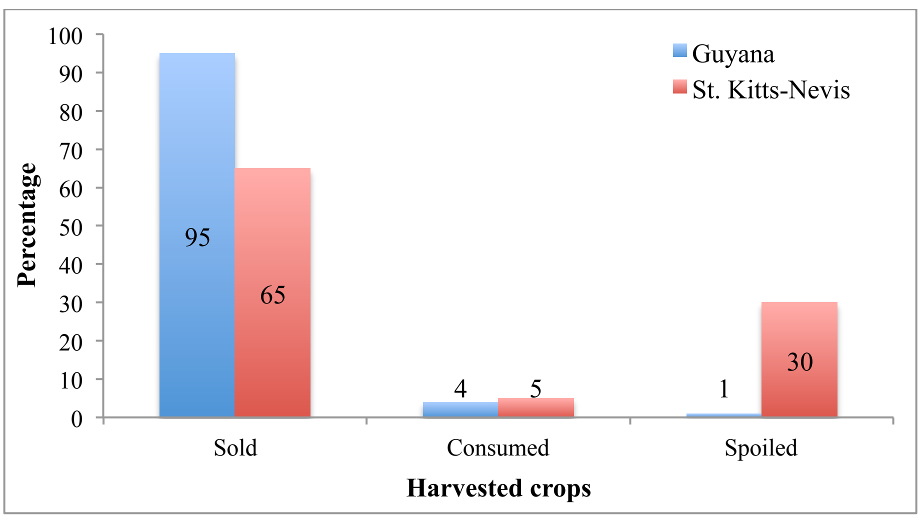

Figure 3.2 Percentage of crops sold, consumed and spoiled on-farm after harvesting

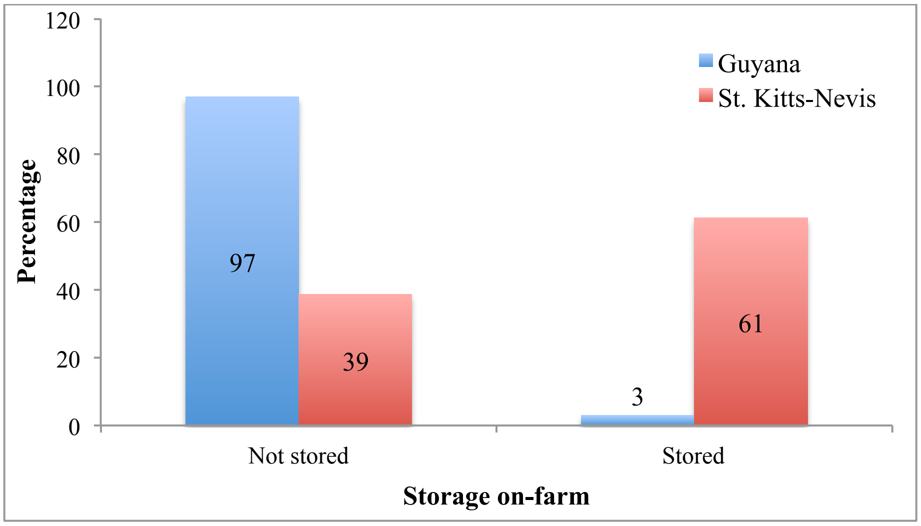

Figure 3.3 Percentage of harvested crops that were stored by farmers before selling

3.5.1.3 Preparation activities for fresh market

As indicated in Figure 3.4, the majority of farmers interviewed reported using large bags as the main field container for their crops, followed by crates and boxes. In Guyana, 88% of selected farmers used only bags to pick up their crops from the field. In contrast, 25% of farmers also used carton boxes in St. Kitts-Nevis. Careful supervision of field packing is needed to avoid harmful physical injuries that sometimes do not appear immediately but will dramatically reduce the quality of the harvested produce later on (FAO/WHO, 2010).

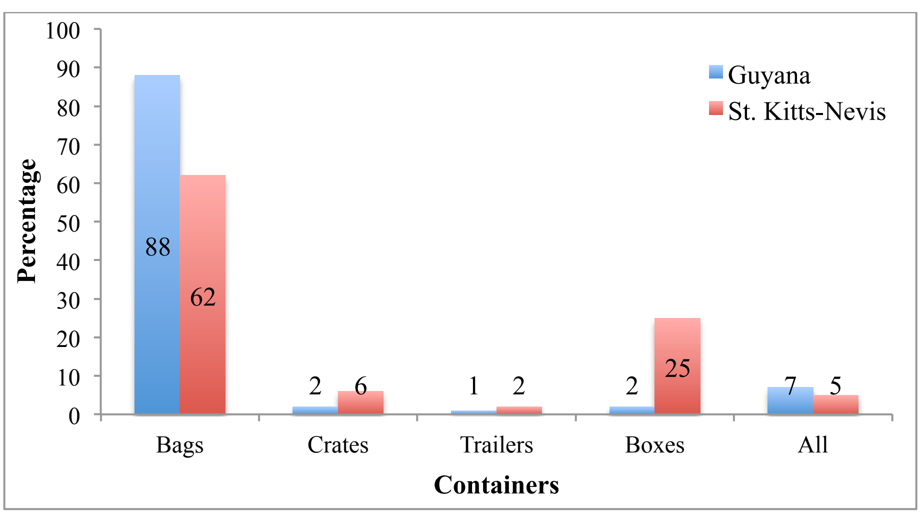

Figure 3.4 Types of containers used by farmers for harvested crops

Where there are poor storage conditions, selling the crops at the nearest place to the field is highly recommended (Florkowski et al., 2014). The distance between the field and the selling point should be minimized to ensure high quality and reduce postharvest losses of freshly harvested crops (Hodges et al., 2011). Up to 88% of the farmers interviewed in Guyana (Figure 3.5) were selling their crops at the farm gate, whereas in St. Kitts-Nevis, large quantities of the crops were sold at wholesale, retail and supermarkets. Consequently, this increased the chances of spoilage. These results supported the above discussion related to Figure 3.2, where the maximum spoilage percentage was revealed to be higher in St. Kitts-Nevis and was reported considerably less in Guyana.

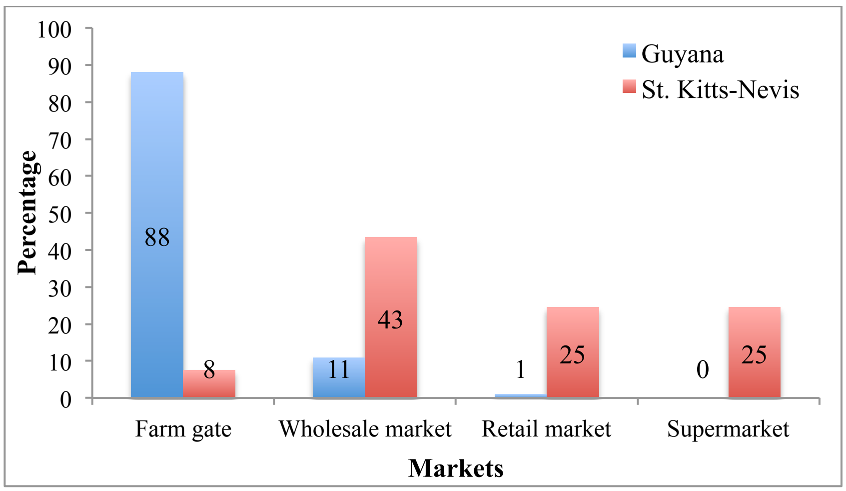

Figure 3.5 Marketing places used by farmers to sell their harvested crops

Another important field activity, which took place during the preparation of harvested produce for fresh market was grading. Hand grading can be used to segregate produce by color, size and grade (Kader, 2002). This activity is subjective and requires a lot of time and effort resulting in high postharvest losses (Florkowski et al., 2014), since over-grading on-farm and in the packinghouse based on strict guidelines that have more to do with appearance (color, size, shape) than nutritional value or eating quality, leads to higher discards of edible produce. As demonstrated in Figure 3.6, only 17% of the selected farmers in Guyana were grading all the time. In St. Kitts-Nevis, double this number of farmers (34%) conducted grading operations after harvesting, which resulted in higher percentage of losses, similar to what was found previously from Figure 3.2.

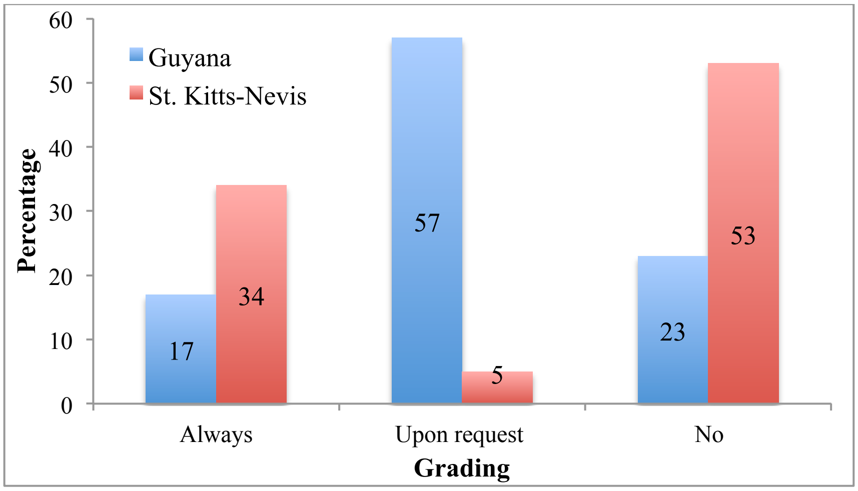

Figure 3.6 Grading activity of harvested crops on-farm

3.5.2 Modified count and weight

3.5.2.1 Supply chain mapping

Figures 3.7 and 3.8 showed the supply chain maps in both Guyana and St. Kitts-Nevis. In both countries, farmers were divided into two main categories: subsistence and commercial farmers. In the first category, farmers have relatively limited farming experience with respect to producing "high-value" crops such as tomato, string beans, cucumber, eggplant and okra. In the second category, farmers have good agronomical experience in growing perishable commodities. They had wide knowledge in the area of crop production in terms of plantation requirements, pesticide and fertilizer usage, harvesting schedule and appropriate postharvest handling practices. On a similar note, small-scale retailers, called also "street markets", bought their crops directly from farmers and sold them in kiosks. These vendors worked in open areas where temperature and humidity were not controlled. The freshly harvested produce was not cleaned before it was displayed under the sunlight for most of the day. Any remaining commodities were inappropriately packed and stored in small trucks during the night. Marketing activities for large retailers differed between the two countries. In St. Kitts-Nevis, fresh fruits and vegetables were sold in supermarkets. These vendors were operating in closed areas where environmental conditions were controlled and monitored most of the day. Upon reception, fresh produce was cleaned, graded and packed in different sizes, then displayed on refrigerated shelves. Unsold commodities were adequately handled and stored in cold chambers overnight. In Guyana, large retailers sold their crops in "public markets" under non-refrigerated but shaded conditions with slightly improved handling practices compared to street markets in St. Kitts-Nevis in terms of modes of packaging, cleaning and displaying.

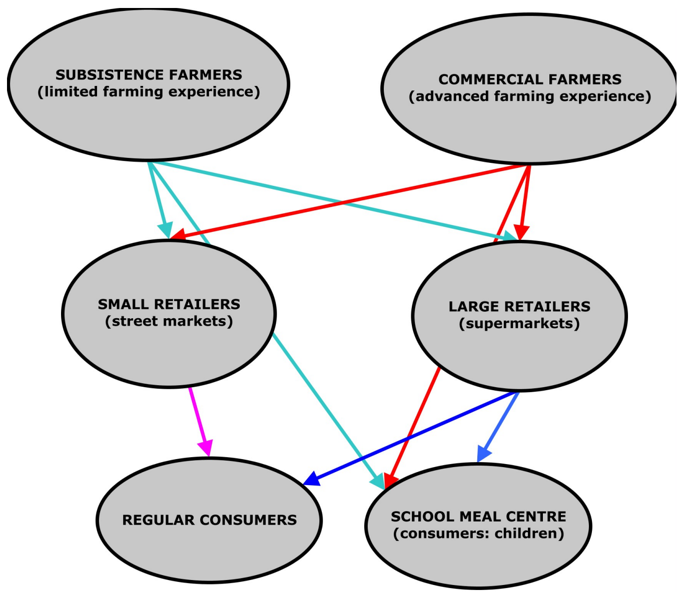

Figure 3.7 Postharvest supply chain map of fresh crops in St. Kitts-Nevis

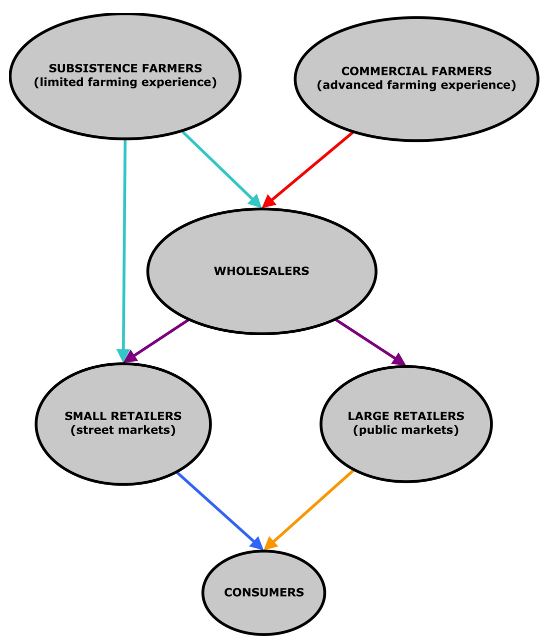

Figure 3.8 Postharvest supply chain map of fresh crops in Guyana

3.5.2.2 Postharvest qualitative and quantitative loss

Results from the "Modified Count and Weight" method revealed that both countries experienced significant ($P < 0.05$) postharvest qualitative and quantitative losses of selected produce among different segments of the supply chain as well as between various participants within the same segment. Furthermore, under similar handling practices, the extent of postharvest loss varied widely amongst different horticultural crops. This was mainly due to the biological and chemical composition of each produce and its response to the surrounding environment (Watkins, 2003).

As shown in Table 3.4, significantly more qualitative postharvest losses ($P < 0.05$) occurred at the small farms compared to large ones for all crops in terms of quality index and firmness. A reasonable explanation for this is the degree of knowledge in high-value crop production between the two types of farmers. As the produce travelled throughout the supply chain, it started to lose significantly ($P < 0.05$) its freshness and its marketable value as well. Tomatoes gained in red color and turned softer in texture same as eggplant and okra became firmer. The results also showed a significant increase ($P < 0.05$) in quality loss at the marketing stage (retailers). Three days after purchasing, the quality index had decreased for almost all crops in both countries. However in St. Kitts-Nevis, the overall quality was better maintained at the supermarkets compared to street and public markets. In this work, the Brix or sugar content remained fairly stable in all crops during postharvest handling activities.

Table 3.5 showed the percentage of quantitative postharvest losses at various segments for each study crop. At the farm level, higher losses ($P > 0.05$) occurred with small farmers, with tomato estimates of 2.07% bruised and 5.28% diseased; string beans estimates of no loss; okra estimates of 5.00% bruised and 5.73% diseased; eggplant estimates of 1.67% diseased; and cucumber estimates of 3.88% bruised, 2.61% diseased and 1.68% dehydrated. At the retail level, street and public markets experienced greater postharvest losses ($P < 0.05$) for almost all selected crops, with tomato estimates of 32.75% bruised, 16.66% diseased, 30.00% dehydrated and 20.51% rejected or completely lost; string beans estimates of 5.37% diseased, 8.88% dehydrated and 6.45% rejected; okra estimates of 9.69% bruised and 20.46% dehydrated; eggplant estimates of 13.17% bruised, 3.88% diseased and 68.27% dehydrated; and cucumber estimates of 4.44% bruised and 1.21% dehydrated. These losses were mainly due to inappropriate postharvest handling and storage of fresh produce under undesirable environmental conditions.

Table 3.4 Postharvest quality loss of study crops in Guyana and St. Kitts-Nevis.

Crop	Color	Quality index	Firmness (N)	Brix (%)
Tomato				
SF	4.60^{b*}	8.82^{a}	6.02^{a}	3.42^{a}
LF	4.41^{b}	8.61^{a}	5.82^{ab}	3.47^{a}
SR	5.05^{ab}	6.45^{bc}	2.83^{c}	3.48^{a}
LR	5.37^{ab}	7.37^{b}	4.28^{bc}	3.67^{a}
String beans				
SF	3.00^{a*}	8.60^{ab}	1.14^{b}	na
LF	3.00^{a}	8.82^{a}	1.17^{b}	na
SR	3.00^{a}	7.64^{b}	1.72^{ab}	na
LR	3.00^{a}	7.65^{b}	1.18^{b}	na
Okra				
SF	2.51^{a*}	6.98^{bc}	1.98^{b}	na
LF	2.80^{a}	8.04^{ab}	2.08^{ab}	na
SR	3.40^{a}	5.84^{c}	2.22^{ab}	na
LR	3.76^{a}	5.70^{c}	2.27^{a}	na
Eggplant				
SF	1.00^{a*}	7.86^{a}	7.38^{a}	na
LF	1.00^{a}	7.16^{ab}	8.14^{a}	na
SR	1.28^{a}	5.36^{b}	6.29^{b}	na
LR	1.31^{a}	5.41^{b}	7.27^{a}	na
Cucumber				
SF	1.10^{a*}	7.81^{ab}	1.86^{a}	2.30^{a}
LF	1.00^{a}	8.36^{a}	1.96^{a}	2.33^{a}
SR	1.42^{a}	7.16^{b}	1.91^{a}	2.42^{a}
LR	1.39^{a}	7.62^{ab}	1.92^{a}	2.35^{a}

* Values in the same column with the same letter are not significantly different at $\alpha = 0.05$
SF=small farmer; LF=large farmer; SR=small retailer; LR=large retailer.

Table 3.5 Percentage of quantity loss of study crops in Guyana and St. Kitts-Nevis.

Crop	Bruised (%)	Diseased (%)	Dehydrated (%)	Rejected (%)
Tomato				
SF	2.07^{c*}	5.28^{b}	0.00^{b}	0.00^{b}
LF	0.67^{c}	5.58^{b}	0.00^{b}	0.00^{b}
SR	32.75^{a}	16.66^{a}	30.00^{a}	20.51^{a}
LR	13.60^{bc}	7.22^{b}	0.00^{b}	6.11^{b}
String beans				
SF	0.00^{a*}	0.00^{b}	0.00^{b}	0.00^{b}

LF	0.00^{a}	0.00^{b}	0.00^{b}	0.00^{b}
SR	0.00^{a}	5.37^{a}	8.88^{a}	6.45^{a}
LR	0.00^{a}	2.96^{ab}	3.79^{b}	2.75^{b}
Okra				
SF	5.00^{ab*}	5.73^{ab}	0.00^{b}	0.00^{a}
LF	1.66^{b}	5.50^{ab}	0.00^{b}	0.00^{a}
SR	9.95^{a}	0.00^{b}	20.41^{a}	0.00^{a}
LR	9.69^{a}	0.00^{b}	20.46^{a}	0.00^{a}
Eggplant				
SF	0.00^{b*}	1.67^{a}	0.00^{b}	0.00^{a}
LF	0.00^{b}	1.68^{a}	0.00^{b}	0.00^{a}
SR	13.17^{a}	0.55^{a}	63.38^{a}	0.00^{a}
LR	10.55^{a}	3.88^{a}	68.27^{a}	0.00^{a}
Cucumber				
SF	3.88^{a*}	2.61^{a}	1.68^{a}	0.00^{a}
LF	1.68^{a}	0.00^{a}	0.00^{a}	0.00^{a}
SR	4.44^{a}	0.00^{a}	1.21^{a}	0.00^{a}
LR	0.00^{a}	0.00^{a}	1.11^{a}	0.00^{a}

* Values in the same column with the same letter are not significantly different at $\alpha = 0.05$
SF=small farmer; LF=large farmer; SR=small retailer; LR=large retailer.

3.6 CONCLUSIONS

This research study attempted to identify the major postharvest quality management hurdles that different segments in the supply chain are facing in the Caribbean and their effects on postharvest losses. States in the Caribbean region have limited local food availability and diversity and therefore limiting intake of fresh fruits and vegetables by local communities. A clear pathway to ensure the availability of food is to minimize the postharvest losses (PHL). High percentage of the crops harvested in St. Kitts-Nevis and Guyana is lost due to on-farm spoilage, sunlight exposure, high temperatures and inappropriate handling at the retail level. There is also a serious problem with regard to market access for small farmers, which compounds the problem of postharvest losses arising from limitations in postharvest technology.

CONNECTING TEXT

The previous chapter demonstrates that the main drivers of postharvest loss in many developing countries are the exposure of the fresh produce to undesirable environmental conditions and inefficient handling. The major environmental factors affecting the quality of the crops include the temperature, the humidity and exposure to direct light. In CARICOM countries, cold storage facilities are limited and below the required capacity and sometimes not even practiced. It is often difficult to ensure constant environmental conditions during postharvest handling of fresh produce. Therefore, in the following chapter, different scenarios of simulated storage are developed to study the effect of temperature and light fluctuations and wrapping materials on quality attributes in dark purple eggplant, which is considered a staple food commodity in the Caribbean region.

CHAPTER 4. QUANTIFYING QUALITY CHANGES IN DARK PURPLE EGGPLANT AS AFFECTED BY FLUCTUATING STORAGE CONDITIONS AND WRAPPING MATERIALS

4.1 ABSTRACT

Produce quality can be irreversibly damaged by exposure to fluctuating temperature and light when moving along various segments in the supply chain. Quality loss of fresh fruits and vegetables are of considerable interest due to their extremely high value, which exceed 50% in some developing countries. In this work, different storage scenarios and their effect on eggplant quality were investigated. Under isothermal conditions, two temperatures (10 and 30°C) were chosen under the partial presence (12 hrs/day) and complete absence of light. Under non-isothermal storage, four different combinations of temperatures and light were studied. These combinations represented all segments of the supply chain of fresh fruits and vegetables starting at the producer, followed by the distributor, the retailer and end up at the consumer level. Major losses occurred during storage at 30°C in the presence of light. In the case of unwrapped eggplants, quality losses during a 10-day storage period were as follows: 85.5% for firmness, 21% for weight loss, 27.96% for color and 89% for visual quality index. However, when crops were wrapped using food grade polyethylene film, quality losses were reduced significantly ($P < 0.05$) with the exception of the color attribute. Compared to the same storage conditions as unwrapped eggplants, quality losses for wrapped produce were 49.7% for firmness 2.23% for weight loss, 21.69% for color and 44.44% for quality index. Under non-isothermal storage conditions, higher losses happened during the 77-hour period of storage. At the end of the entire storage duration, the measured quality loss for unwrapped samples were 75.62% for firmness, 11.02% for weight loss, 10.19% for color and 61.11% for quality index. These losses were reduced significantly ($P < 0.05$) by wrapping the fresh produce during storage and the percent quality loss were as follows: 19.43% for firmness, 0.84% for weight loss, 7.31% for color and 22.22% for quality index. Kinetic models were used to provide a structural framework for quantitatively describing and predicting these losses.

4.2 INTRODUCTION

Fresh fruits and vegetables are an essential part of human's daily diet (Florkowski et al., 2014). The environmental conditions under which fresh horticultural commodities are produced, transported and displayed have a major effect on the keeping quality of the foods and the amount that is lost. Such losses are minimised by proper temperature and light management at every link within the supply chain (Hodges et al., 2011; Hoogerwerf et al., 1994). Moreover, storing the crop at fluctuating temperatures was demonstrated to be the driver behind accelerated respiration and transpiration rates, which can cause further deterioration of the postharvest quality of the produce (Florkowski et al., 2014). Consequently, the rate of water loss from the fresh produce increases causing irreversible weight loss that cannot be regained when placed back into a high humidity environment (Moretti et al., 2010). Other studies carried out by Sanz et al. (2009), showed that light was also a major cause for the deterioration of fresh commodities (like asparagus) due to acceleration in the physiological activities. According to other researchers (Ayala et al., 2009; Cervera et al., 2007), lighting exposure caused an increase in respiration rate and changes in the overall appearance of minimally processed green vegetables.

Eggplant (*Solanum melongena* L.), commonly known also as aubergine, is considered to be among the 30 commonly produced and consumed horticultural crops worldwide (Concellón et al., 2007; Florkowski et al., 2014). It is best grown in tropical and sub-tropical areas (Concellón et al., 2012; Loose et al., 2014) and has high economic and nutritional values worldwide (FAO, 2013; Okmen et al., 2009). Beside its medicinal properties including the inhibition of the formation of blood vessels responsible for tumour growth and metastasis (Matsubara et al., 2005), eggplant contains a large amount of polyphenols, vitamins and minerals (Boulekbache-Makhlouf et al., 2013). In many countries in Asia and Latin America, the majority of eggplant fruits are cultivated and harvested by small-holder farmers and are considered as a vital source of income for them (Hanson et al., 2006). Eggplant, like many other fresh plant produce, is highly perishable and continues to be metabolically active even after harvesting (Kader et al., 2004). Usually eggplants are egg-shaped or globular and have dark green calix, firm texture and dark purple skin (Gross et al., 2014). At the international level, the dark purple eggplant is the most commercially consumed fruit among the eggplant varieties (Zaro et al., 2014a).

Quality perception is very complex (Luning et al., 2009). A commonly accepted definition by the International Standard Organisation (ISO, 2014) is that "*quality is a desirable characteristic that a product or service must have*". In the case of fresh fruits and vegetables, the consumer's quality perception is generally focused on quality attributes such as appearance, color, size, shape, firmness and freshness (Florkowski et al., 2014). Appearance is the first quality attribute assessed by the consumer and a key factor in buying or rejecting the fresh produce (Florkowski et al., 2014). Color is also a determining parameter when purchasing fruits and vegetables. In the case of eggplant, the dark purple color reflects the antioxidant content (anthocyanin) in the fruit (Mishra et al., 2012). When evaluating the texture of a fresh commodity, firmness is equivalent to the maturity stage or the degree of freshness of that commodity (Kader, 2002). For crops like eggplant, tomato and cucumber, consumers have an expectation of a firm quality product that could last longer before consumption. However, crops such as string beans for example; should be harvested at their early maturity stages in order to assure a soft product because firmer string beans would not be consumable as they become fibrous and hard to digest.

Numerous authors have shown that using wrapping films could play a major role in reducing postharvest losses of fresh produce during storage and therefore, extending their shelf-life (Janave et al., 2005; Xiao et al., 2014b). In research on mango fruits, Janave et al. (2005) stated that food grade films created certain barriers between the food system and their surroundings, therefore, the fruits retained around 40% of their chlorophyll content and a 50% reduction of their weight loss was observed compared to unwrapped fruits. Consequently, the shelf life of wrapped mangoes was extended by 15 days and the ripening process was slowed down. Other studies conducted by Bouzo et al. (2012) revealed that wrapping films decreased respiration and transpiration rates of fresh fig fruits and hence prolonged the storage life and quality appearance.

Postharvest storage conditions can foster many chemical composition changes in fresh eggplant (Florkowski et al., 2014; Matsubara et al., 2005). The measurement of appropriate kinetic parameters, such as reaction rate constant and activation energy for these changes, enables the estimation of the magnitude of change in a given food component during storage and prior to final consumption (Heldman, 2011). The kinetic analysis of quality attributes has been extensively investigated in a wide variety of fresh commodities. Nourian et al. (2003) documented that first-order prediction models for physical (color and firmness) and chemical (ascorbic acid, total soluble solids and pH) quality attributes were a good fit for the experimental data of potato when stored at different temperatures. Other authors (Cruz et al., 2009) reported that zero order models best described the color data obtained during cold storage of watercress. It is often very difficult to ensure constant environmental factors during postharvest handling of fruits and vegetables, therefore, the continuous exposure of fresh horticultural crops to fluctuating temperature and light during handling is the challenge facing stakeholders in many countries that lack refrigeration and other supporting postharvest technologies.

4.3 OBJECTIVES

The objective of this research was to study the effect of temperature and light fluctuations and wrapping materials during postharvest storage on quality attributes in dark purple eggplant. The specific objectives were to: (1) assess postharvest losses over time during storage under several temperature and light combinations and wrapping materials, (2) quantify these losses using kinetic models, and (3) study the dependence of temperature and light on quality degradation.

4.4 MATERIALS AND METHODS

4.4.1 Plant material preparation

Fresh eggplants were obtained from a local, year-round, greenhouse supplier (Lufa farms, Montreal, Canada). Right after harvesting, the samples were labeled and separated into experimental units of similar quantity for further analysis. These crops were then divided into two groups, namely "with wrapping film" and "without wrapping film" (Thermo Fisher Scientific Inc, Montreal, Canada) (Appendix 3).

4.4.2 Experimental set-up

Controlled environment chambers (Conviron Inc., PGR15, Manitoba, Canada) were used in the study (Appendix 2). With an internal capacity of 2.2 m^3, the chambers were fully programmable to monitor set factors (temperature and light). The chamber was capable of maintaining temperatures in the range between 10 and 45°C. Airflow inside the unit was distributed uniformly upward using an air distribution plenum (Conviron, 2014) that allowed up to 0.5 m^3/min of air exchange. Light intensity in the chamber was maintained up to 875 micromoles/m^2/s or 64,750 lux using fluorescent and incandescent lamps. This is the typical average of light intensity during a sunny day.

Under constant storage conditions (SC), samples of eggplant were stored at 10 and 30^oC for 10 days with 90±5% RH with two different light scenarios, namely "complete darkness" and an "interval of 12 hours of direct light per day" for each temperature setting. A total of four different storage combinations of temperature and light were conducted as follow: SC1 = 10^0C (with light); SC2 = 30^0C (with light); SC3 = 10^0C (without light); SC4 = 30^0C (without light).

Under fluctuating conditions, the storage of eggplant was simulated based on real situations occurring during the handling process of fresh produce in many countries around the world (Figure 4.1). After harvesting, the eggplant samples were stored at 25^oC for 2 hours with no light exposure (S1). This step was similar to the activity carried out by farmers in the field, where they place their crop under shade after harvesting. The following step (S2) was to store the eggplant for 3 hours under light, which simulated the transportation of the fresh produce to the market using open trucks. Step 3 corresponded to the marketing stage of the harvested commodity for a typical duration of three consecutive days under fluctuating conditions of temperature and light between day and night. Therefore, the eggplant samples were stored at 30^oC with light for 12 hours and at 20^oC with no light for another 12 hours. This step (S3) lasted for 72 hours. The final step (S4) illustrated conditions similar to what happened at the consumption level where the produce was stored at low temperature (10^oC) in the absence of light for a maximum duration of 6 days (144 hours). The entire experiment was conducted in triplicate.

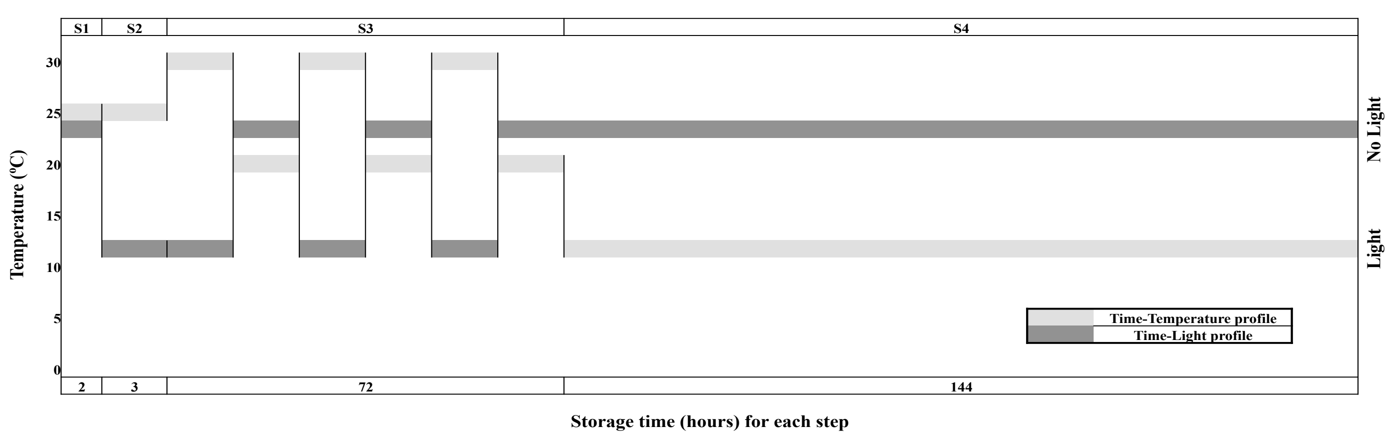

Figure 4.1 Schematic diagram of fluctuating environmental conditions during storage

4.4.3 Color measurement

The color of studied samples was expressed in CIELAB color space using a Minolta Spectrophotometer (CM-3500d, Japan) where L* defines lightness, a* describes the red/green coordinate and b* the yellow/blue value. The equipment was calibrated against standard ceramic white and black tiles. The total color difference (ΔE) was stated as a single value using the following equation:

$$\Delta E = \sqrt{(\Delta L^2) + (\Delta a^2) + (\Delta b^2)} \qquad (1)$$

where $\Delta L = L^* - L^*_{standard}$; $\Delta a = a^* - a^*_{standard}$; $\Delta b = b^* - b^*_{standard}$; and the standard $L^*a^*b^*$ values were defined as the initial color values of the freshly harvested produce. Triplicate readings at different places on the produce were taken for individual samples to obtain a better representation of its actual color.

4.4.4 Texture analysis

Firmness or texture evaluation was measured using the Instron Universal Testing Machine (Model 4502, Instron, Canton, MA, USA) (Appendix 4). A compression test was carried out with 5 mm diameter probe, a crosshead speed of 5 mm/min and a maximum load cell of 50N. For the purpose of this study, the firmness was defined in terms of applied force (F) or load on the surface of the commodity and was expressed in Newton (N). Load-displacement plots were then obtained and firmness corresponding to maximum load (N) was calculated. A total of three readings were acquired for each sample and an average firmness was registered.

4.4.5 Weight loss evaluation

Loss of weight in fresh eggplant during postharvest handling was measured using the formula:

$$WL = 100 * \left(W_i - W_f\right) / W_i \qquad (2)$$

where WL was the weight loss (%), W_i and W_f were the initial (t = 0) and the final weight of the produce calculated before and after treatment.

4.4.6 Quality index rating

Quality index (QI) was assessed for individual produce using a nine point hedonic scale for the subsequent parameters: symptoms of deterioration and limits of marketability. A quality index for eggplant summarizing all these parameters was determined (Table 4.1) and a score for each sample was given.

Table 4.1 Full description of quality index scales of eggplant.

Quality Index	Quality	Description
9	Excellent	Calyx of freshly dark green color, turgid appearance. Glossy skin and dark black in color. Firm in texture. Absence of major handling defects. Absence of decay.
7	Good	Green calyx, slightly wilting appearance. Skin reasonably glossy and black in color. Slight loss of firmness. Presence of minor handling defects. Absence of decay.
5	Average	Pale green calyx, wilted or slightly dry and brownish in color at its end. Dull skin and lightly browning. Slight softness in texture. Presence of decay and major handling defects.
3	Poor	Very pale calyx and brown in color, severe wilting or partly drying. Major browning in skin. Soft in texture. Presence of remarkable decay and major handling defects.
1	Unmarketable	Brown calyx, complete wilting or drying. Skin very brown in color. Very soft in texture. Presence of extensive decay and severe handling defects.

4.4.7 Kinetic modeling and data analysis

Under isothermal storage conditions, zero and first order kinetic equations are expressed as follows:

$$C_t = C_0 - kt \tag{3}$$

$$\frac{C_t}{C_0} = \exp^{-kt} \tag{4}$$

where C_t is the measured quality parameter (color, firmness, quality index and weight loss) at time t, C_0 is the initial quality before any storage, t is the storage time and k is the rate constant at temperature T.

Equations 3 and 4 were fitted to the experimental data. Appropriate model was chosen based on the highest R^2. The temperature-dependence of the rate constant k was assumed to follow the Arrhenius equation (Eq. 5):

$$k = k_{ref} \exp\left[\frac{-E_a}{R}\left(\frac{1}{T_i} - \frac{1}{T_{ref}}\right)\right] \tag{5}$$

where k_{ref} is the reaction rate at reference temperature (T_{ref}), E_a is the activation energy of the reaction (J/mol), R is the universal gas constant (8.314 J/mol.K) and T_i is the absolute temperature (K). The reference temperature used was 30°C.

Under non-isothermal conditions, the quality attributes can be predicted for a given time by equation 6 and 7:

$$C_t = C_0 - k_{ref} \int_0^t \exp\left[\frac{-E_a}{R}\left(\frac{1}{T_i} - \frac{1}{T_{ref}}\right)\right] dt \tag{6}$$

$$\frac{C_t}{C_0} = \exp^{-k_{ref} \int_0^t \exp\left[\frac{-E_a}{R}\left(\frac{1}{T_i} - \frac{1}{T_{ref}}\right)\right] dt} \tag{7}$$

By introducing an effective temperature (T_{eff}) term as demonstrated by Giannakourou et al. (2003) and defined as the constant temperature at which the same quality change resulted from the same time duration as the temperature fluctuated along the storage, the quality changes for the entire storage duration of studied crops as influenced by fluctuating temperature and light can then be predicted using equations 8 and 9:

$$C_{t_{total}} = C_0 - k_{eff} t_{total} \tag{8}$$

$$\frac{C_{t_{total}}}{C_0} = \exp^{-k_{eff} t_{total}} \tag{9}$$

where k_{eff} is the value of the rate constant at the effective temperature. Therefore, $k_{eff}\, t_{total}$ was calculated using equation 10:

$$k_{eff} t_{total} = k_{ref} \sum_i \left(\exp\left[\frac{-E_a}{R} \left(\frac{1}{T_i} - \frac{1}{T_{ref}} \right) \right] t_i \right) \tag{10}$$

An analysis of ANOVA followed by a Tukey-Kramer HSD test for comparison of means was conducted using JMP version 11 software.

4.5 RESULTS AND DISCUSSION

4.5.1 Effect of environmental factors on quality parameters

In this study, the storage at 10^{o}C represented the optimum conditions for commercial storage recommended for eggplant (Gross et al., 2014); whereas, the storage at 30^{o}C corresponded to the average annual temperature that best characterize tropical countries where temperature abuse during postharvest handling is more frequent. The results showed that quality parameters of eggplants were influenced by temperature and light during postharvest storage.

At complete darkness, there was a consistent degradation of firmness with softer samples ($P > 0.05$) stored at 30^{o}C compared to 10^{o}C (Figure 4.2a). These results are in agreement with other studies, which demonstrated that storage at higher temperature further decreased the firmness in fresh vegetables (Liu et al., 2014; Lopez et al., 2010). Numerous studies concluded that the extent of firmness degradation during postharvest storage varied between crops. Pyrotis et al. (2011) showed that the loss of firmness in stored strawberry increased by 0.6 N with 1^{o}C increase in temperature. Other studies demonstrated that the firmness of tomato fruits decreased exponentially during storage at higher temperatures (Lana et al., 2005). Similarly, the percent weight loss of eggplant was higher ($P > 0.05$) when stored at 30^{o}C under the absence of light (Figure 4.2b). During this storage period, eggplant samples lost between 9 to 14.5% of their initial weight (at harvesting). Storage at lower temperature (10^{o}C) in the absence of light slowed down the weight loss to the initial weight and could be recommended for eggplant storage while maintaining higher quality and longer shelf life. Weight loss is both a quantitative and a qualitative loss and is usually associated with moisture loss that causes wilting, shrivelling and softening of the external texture of the crop (FAO, 2007; Hung et al., 2011). Preserving the color during the postharvest handling of eggplant is an important practice in quality management. Anthocyanin compounds in eggplant are responsible for providing the dark purple color on the outside peel of the eggplant fruit (Sun et al., 1990). Therefore, reducing the loss of those color pigments is crucial during storage. Figure 4.2c showed the results of total color difference (ΔE) compared to the initial color value (at time 0). Storage in complete darkness at both temperatures caused some color loss in eggplants, however, the color difference was not significant ($P > 0.05$). A similar trend was observed for quality index degradation during storage (Figure 4.2d). In the absence of light, storage at lower temperature resulted in slower rate of quality deterioration ($P > 0.05$) and a better quality index was registered compared to higher temperature.

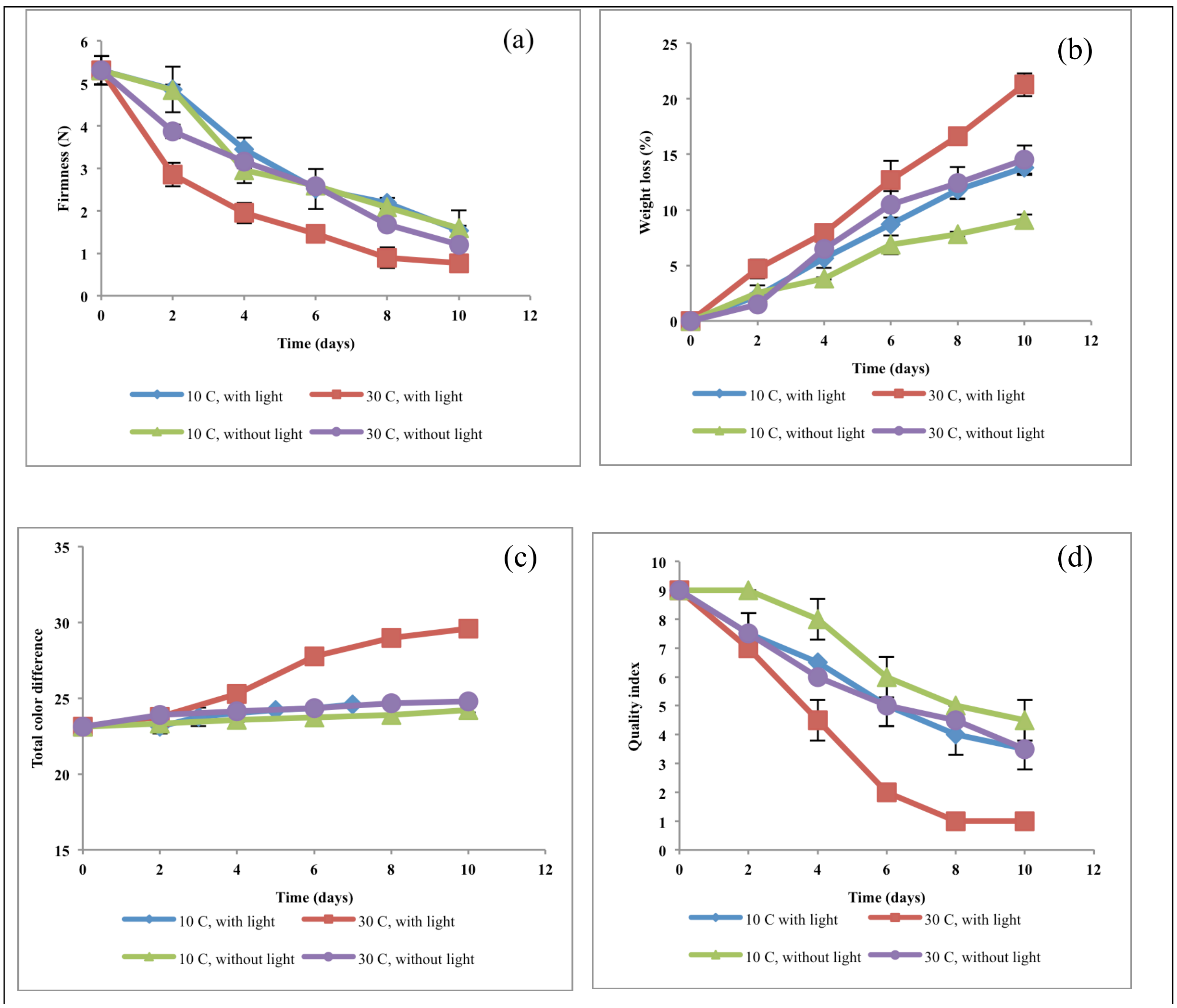

Figure 4.2 Quality attribute responses during storage of unwrapped eggplants.

Under light conditions, there was a higher rate of quality deterioration of eggplant over time. The firmness of eggplant samples decreased from 5.31 N to 0.77 N (85.5% loss). These results in Figure 4.2a revealed that light, combined with elevated temperatures, had accelerated ($P > 0.05$) the softening process of stored eggplant. As mentioned previously, light could speed-up the metabolic and physiological activities of the plant cells. Similar results on the influence of light were demonstrated by Martinez-Sanchez et al. (2011), where they stored fresh Romaine lettuce under complete darkness and partial light conditions. As seen in Figure 4.2b, storing the eggplants under light at 30^{o}C has further increased the weight loss up to 21% ($P > 0.05$). A plausible explanation is that during storage, light exposure is responsible for stomata opening which increases further the weight loss of the produce through transpiration (Martinez-Sanchez et al., 2011). In terms of color, a significant difference ($P < 0.05$) in color was observed after 10 days of storage at 30^{o}C in the presence of light (Figure 4.2c). Studies conducted by Fennema et al. (1996) revealed that anthocyanin is very susceptible to high temperature and direct light exposure. Other studies performed by Xiao et al. (2014a) stated that lycopene, anthocyanin and carotenoid were very unstable when exposed to solar radiation and showed higher stability in the dark. The loss of color in fresh fruits and vegetables is mainly due to the occurrence of oxidation during storage (Sanz et al., 2009). In the presence of light, this oxidation process is called photo-oxidation (Tiwari et al., 2013). In terms of quality index (Figure 4.2d), the eggplant samples have lost their overall quality ($P < 0.05$) only after 6 days of storage at 30^{o}C with light and became unmarketable at day 8 (QI = 1). These results are in agreement with the recommended conditions of 10^{o}C in dark conditions for the commercial storage of eggplant (Gross et al., 2014).

4.5.2 Effect of wrapping material on keeping quality

Analysis of variance showed that wrapping influenced the quality of eggplants during storage. Wrapping film behaved as a barrier between the surface of the plant produce and the surrounding environment. Quality losses were reduced significantly ($P < 0.05$) when the crops were wrapped with the exception of color. In the case of unwrapped eggplants, these losses during 10-day storage at 30^{o}C with light, were as follows: 85.5 % for firmness, 21 % for weight loss, 27.96 % for color and 89 % for visual quality index. Under the same storage conditions (SC2 = 30^{o}C with light), quality losses for wrapped produce were 49.7 % for firmness, 2.23 % for weight loss, 21.69 % for color and 44.44 % for quality index (Figure 4.3). Food grade polyethylene film helped in maintaining the firmness quality under all storage conditions with firmer produce at lower temperature (Figure 4.3a). Similar results were published by Maftoonazad et al. (2008), where they showed the beneficial effect of packaging on firmness retention of avocado stored under various temperatures. Similarly, little weight loss was observed with wrapped eggplant due to the barrier effect to water vapor movement caused by the wrapping film (Bouzo et al., 2012). The crop turgor was maintained during the entire duration of the storage as shown in Figure 4.3b. From Figure 4.3c, the difference in color between wrapped and unwrapped samples was not significant ($P > 0.05$). This finding is in accordance with a previous study carried out by Olarte et al. (2009) on broccoli and cauliflower where the packaging film did not influence the retention or degradation of the color coordinates. Conversely, a study conducted by Maftoonazad et al. (2008), stated a significant reduction in color difference between wrapped and unwrapped avocado. Figure 4.3d also revealed that the overall visual quality of studied eggplants was significantly maintained during the entire storage period. At the 10-day storage period, a score of 5 was registered at 30^{o}C under light exposure compared to a score of 1 for unwrapped produce under the same storage conditions (SC2).

For all quality attributes, the wrapping effect was equivalent to storing the unwrapped eggplant samples at 10^{o}C in complete darkness. Therefore, food grade polyethylene film could be a promising solution to reduce postharvest losses and maintaining the quality of fresh produce among the supply chain segments especially in countries where controlling the temperature and light effect is difficult to address with handling practices.

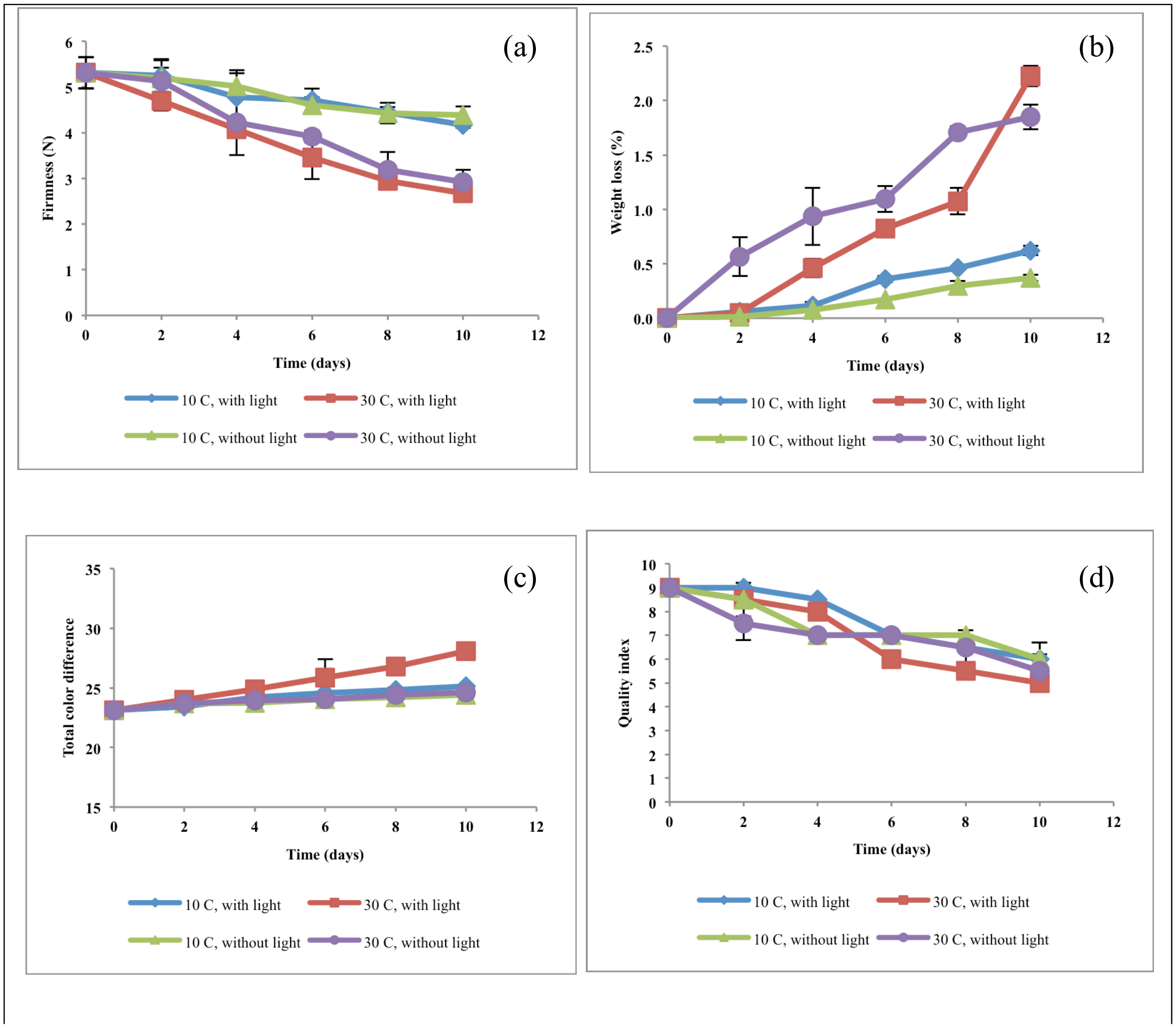

Figure 4.3 Quality attribute responses during storage of wrapped eggplants.

4.5.3 Changes of quality attributes during storage

4.5.3.1 Firmness and quality index changes

Changes in texture and visual quality of unwrapped and wrapped eggplant during storage at constant conditions are presented in Tables 4.2 and 4.3. The experimental data fitted the first order reaction model (Eq. 4) well for all four storage conditions. During storage, both firmness and quality index attributes decreased over time at a rate that depended on temperature and light exposure. Among all storage conditions, the quality degradation was faster at 30^{o}C in the presence of light for both unwrapped and wrapped eggplants. However, the food grade polyethylene film slowed down the firmness deterioration by threefold ($k_{unwrapped}$ = 0.191/day and

$k_{wrapped}$ = 0.071/day) and the quality index by fourfold ($k_{unwrapped}$ = 0.252/day and $k_{wrapped}$ = 0.064/day) during the 10-day storage. Using Arrhenius formula (Eq. 5) with $T_{30°C}$ as reference temperature, the activation energy was calculated. In the study, two different "Ea" were obtained considering the light factor. In theory, a chemical reaction occurs within the food system when sufficient energy is available. The results in Tables 4.2 and 4.3 revealed that the energy needed to start the firmness degradation in the presence of light were Ea = 14.56 and 38.70 kJ/mol for unwrapped and wrapped eggplants, respectively. Similarly, for overall quality index, the activation energy were Ea = 12.57 and Ea = 33.70 kJ/mol, respectively. In the absence of light, higher Ea values for firmness (15.41 kJ/mol for unwrapped samples and 41.80 kJ/mol for wrapped samples) and quality index (19.55 kJ/mol for unwrapped samples and 41.84 kJ/mol for wrapped samples) were recorded, respectively. From the results, it could be concluded that exposure to light has a negative influence on maintaining firmer and high quality produce and should be carefully considered during postharvest quality management of fresh fruits and vegetables. Once again, the wrapping material used in the study proved to be highly efficient in maintaining the quality during storage, since it slowed down the rate of the deterioration process.

Table 4.2 Kinetic parameters of unwrapped eggplant at constant storage conditions.

Quality attributes	Storage Conditions	C_0	C_{eq}	Kinetic parameters		
				k(day^{-1})	R^2	Ea (kJ/mol)
Firmness	SC1	5.31	1.53	0.127	0.98	14.56
	SC2	5.31	0.77	0.191	0.97	
	SC3	5.31	1.59	0.124	0.97	15.41
	SC4	5.31	1.20	0.144	0.98	
Weight loss	SC1	0.00	13.81	1.459	0.99	12.91
	SC2	0.00	21.27	2.095	0.99	
	SC3	0.00	9.06	0.854	0.96	32.02
	SC4	0.00	14.53	1.601	0.95	
Total color difference	SC1	23.10	24.57	0.106	0.99	33.12
	SC2	23.10	29.56	0.766	0.95	
	SC3	23.10	24.22	0.099	0.98	60.06
	SC4	23.10	24.77	0.117	0.98	
Quality index	SC1	9.00	3.50	0.098	0.99	12.57
	SC2	9.00	1.00	0.252	0.95	

	SC3	9.00	4.50	0.078	0.94	19.55
	SC4	9.00	3.50	0.092	0.99	

SC1 = 10^{0}C (with light); SC2 = 30^{0}C (with light); SC3 = 10^{0}C (without light); SC4 = 30^{0}C (without light).

Table 4.3 Kinetic parameters of wrapped eggplant at constant storage conditions.

Quality attributes	Storage Conditions	C_0	C_{eq}	Kinetic parameters		
				k(day^{-1})	R^2	Ea (kJ/mol)
Firmness	SC1	5.31	4.17	0.024	0.96	38.70
	SC2	5.31	2.67	0.071	0.99	
	SC3	5.31	4.37	0.022	0.95	41.80
	SC4	5.31	2.91	0.064	0.97	
Weight loss	SC1	0.00	0.62	0.073	0.97	43.64
	SC2	0.00	2.22	0.248	0.91	
	SC3	0.00	0.37	0.046	0.98	60.11
	SC4	0.00	1.85	0.167	0.96	
Total color difference	SC1	23.10	25.13	0.200	0.94	70.57
	SC2	23.10	28.11	0.506	0.99	
	SC3	23.10	24.42	0.094	0.97	73.01
	SC4	23.10	24.60	0.111	0.98	
Quality index	SC1	9.00	6.00	0.045	0.93	33.70
	SC2	9.00	5.00	0.064	0.94	
	SC3	9.00	6.00	0.037	0.88	41.84
	SC4	9.00	5.50	0.041	0.90	

SC1 = 10^{0}C (with light); SC2 = 30^{0}C (with light); SC3 = 10^{0}C (without light); SC4 = 30^{0}C (without light).

Under non-isothermal conditions, the effective reaction rates "k_{eff}" multiplied by the cumulative storage time "t_{total}" at each storage period, as illustrated in Figure 4.1, was calculated from Eq. 10 and presented in Tables 4.4 and 4.5. At time = 2 hours, the firmness and quality index loss occurred at slower rates. At time = 5 hours, the loss continued in an increasing rate due to light effect. At the end of step 3 (77 hours), the quality degradation was much faster due to the effect of the fluctuating temperature and light during every 12-hour period. During the last storage period (221 hours), the loss occurred at a slower rate at 10^{o}C in complete darkness. It is important to mention that the wrapping film was beneficial to slow down the degradation rate throughout the entire storage duration.

Table 4.4 Kinetic parameters of unwrapped eggplant at fluctuating storage conditions.

Quality attributes	Storage period (hours)	C_0	C_{eq}	Kinetic parameters
				$k_{eff}\ t_{total}$
Firmness	2	5.66	5.50	0.014
	5	5.66	5.32	0.035
	77	5.66	3.20	0.553
	221	5.66	1.38	1.297
Weight loss	2	0.00	0.30	0.141
	5	0.00	0.42	0.381
	77	0.00	5.03	5.560
	221	0.00	11.02	10.684
Total color difference	2	23.10	23.14	0.039
	5	23.10	23.20	0.098
	77	23.10	24.86	1.675
	221	23.10	25.46	2.268
Quality index	2	9.00	9.00	0.016
	5	9.00	8.50	0.041
	77	9.00	5.00	0.633
	221	9.00	3.50	1.101

Table 4.5 Kinetic parameters of wrapped eggplant at fluctuating storage conditions.

Quality attributes	Storage period (hours)	C_0	C_{eq}	Kinetic parameters
				$k_{eff}\ t_{total}$
Firmness	2	5.66	5.54	0.004
	5	5.66	5.48	0.011
	77	5.66	5.03	0.177
	221	5.66	4.56	0.309
Weight loss	2	0.00	0.02	0.014
	5	0.00	0.03	0.038
	77	0.00	0.63	0.575
	221	0.00	0.84	0.851
Total color difference	2	23.10	23.13	0.028
	5	23.10	23.18	0.078
	77	23.10	24.33	1.173

	221	23.10	24.79	1.737
Quality index	2	9.00	9.00	0.004
	5	9.00	9.00	0.011
	77	9.00	8.00	0.180
	221	9.00	7.00	0.402

4.5.3.2 Weight loss and color changes

Under constant storage conditions, the experimental data fit a zero order model (Eq. 3) well as shown in Tables 4.2 and 4.3. Weight loss and color difference increased over time at different rates based on the storage conditions. Maximum loss was observed with unwrapped samples stored at higher temperature with light exposure (k_{WL} = 2.095/day and k_{TCD} = 0.766/day). As mentioned earlier, combining these two environmental factors together will irreversibly damage the fresh produce, hence, increasing its quality loss. When wrapping the eggplant, the rate of weight loss was reduced by eightfold compared to unwrapped samples ($k_{unwrapped}$ = 2.095/day and $k_{wrapped}$ = 0.248/day). The minimum rate for weight loss (k = 0.046/day) was registered with wrapped produce and storage at 10^{o}C in the dark. In contrast, wrapping material did not have any major effect on color attribute and the results revealed a slight reduction in the deterioration rate (at SC2) compared to unwrapping ($k_{unwrapped}$ = 0.766/day and $k_{wrapped}$ = 0.506/day). Using a similar calculation with other quality attributes, the activation energy for weight loss during light exposure were Ea = 12.91 and 43.64 kJ/mol for unwrapped and wrapped eggplant, respectively, whereas during the storage in darkness, Ea = 32.02 and 60.11 kJ/mol were needed to start the reactions within the food system. In terms of total color difference, Ea = 33.12 and 70.57 kJ/mol for unwrapped and wrapped samples, respectively, were obtained in the presence of light (Tables 4.2 and 4.3), however, in complete darkness, the activation energy needed was lower, with Ea = 60.06 and 73.01 kJ/mol, respectively. It could also be concluded that higher temperature and exposure to direct light accelerated the quality degradation, while lower temperature with the absence of light and wrapping the produce maintained better quality during storage.

Tables 4.4 and 4.5 showed the changes in quality of eggplant as affected by fluctuating environmental factors during handling. For both weight loss and color difference, the degradation process was much faster during the third storage period (77 hours) where most of temperature and light fluctuation occurred. Applying wrapping films reduced the weight loss during storage but did not change the deterioration rate in terms of color.

4.5.4 Prediction of quality loss

Studying kinetics was necessary to predict the changes in postharvest quality attributes and the influence of temperature and light on the studied crop during storage. Table 4.6 presented the cumulative percent quality loss of predicted versus measured values of different quality parameters obtained at fluctuating conditions. The majority of losses happened during the 77-hour period of storage. At the end of the entire storage duration, the observed quality loss for unwrapped samples were 75.62% for firmness, 11.02% for weight loss, 10.19% for color and 61.11% for quality index. These losses were reduced significantly ($P < 0.05$) through wrapping the fresh produce during storage. The percent quality losses were as follows: 19.43% for firmness, 0.84% for weight loss, 7.31% for color and 22.22% for quality index. The experimental data obtained at fluctuating conditions were plotted against the prediction model values (Eq. 8 and 9). Predicted quality loss was in line with observed data for studied eggplant. These results confirmed the validation of the predictive models in response to the variable environmental factors used in the study.

Table 4.6 Cumulative percent quality loss of predicted against observed values obtained under fluctuating conditions.

Quality attributes	Storage period (hours)	Percent quality loss (Unwrapped)		Percent quality loss (Wrapped)	
		Observed	Predicted	Observed	Predicted
Firmness	2	2.92	1.39	2.12	0.40
	5	6.01	3.44	3.18	1.09
	77	43.55	42.48	11.13	16.22
	221	75.62	72.66	19.43	26.58
Weight loss	2	0.30	0.14	0.02	0.01
	5	0.42	0.38	0.03	0.04
	77	5.03	5.56	0.63	0.58
	221	11.02	10.68	0.84	0.85
Total color difference	2	0.15	0.27	0.13	0.09
	5	0.44	0.41	0.36	0.27
	77	7.59	6.46	5.32	4.67

	221	10.19	11.62	7.31	8.74
Quality index	2	0.00	1.59	0.00	0.40
	5	5.56	4.02	0.00	1.09
	77	44.44	46.90	11.11	16.47
	221	61.11	66.75	22.22	33.10

4.6 CONCLUSIONS

In this study, the quantification of postharvest losses of the quality attributes in dark purple eggplant as affected by constant and fluctuating storage temperature and light was presented. Higher losses occurred at 30^{o}C under light exposure during a 10-day period. Storage at higher temperatures further decreased the quality in fresh vegetables. The lower storage temperature (10^{o}C) delayed the quality changes over time. Similarly, light has a great influence on degrading quality, which was the same as high temperature under complete darkness. The utilisation of wrapping material extended shelf life and maintained the quality of studied samples during the entire storage duration. Kinetic models were very useful for measuring and predicting the magnitude of change in quality attributes during constant and fluctuating storage. This study presented an important tool that allowed the closing up of major data gaps in the knowledge of quantifying postharvest quality changes of fresh eggplant as affected by temperature and light abuse during handling practices, aiming to recommend best strategies to reduce postharvest losses of fruits and vegetables.

CONNECTING TEXT

Other important quality parameters to consider in fresh fruits and vegetables are the health promoting attributes known as phytochemicals. The next chapter is designed to investigate the effect of fluctuating environmental factors on total phenolic content in freshly harvested eggplant and cucumber, another high value crop for the local population in the Caribbean. This chapter is useful to quantify postharvest quality loss from the perspective of health attributes rather than conventional quality parameters such as color, firmness, weight loss and visual quality index.

CHAPTER 5. INFLUENCE OF FLUCTUATING ENVIRONMENTAL FACTORS ON TOTAL PHENOLIC CHANGES IN EGGPLANT AND CUCUMBER DURING POSTHARVEST STORAGE

5.1 ABSTRACT

In tropical countries, fresh vegetables travelling from “farm-to-fork” are continuously exposed to different environmental conditions of temperature and solar radiation that seriously affect their phytochemical composition and consequently, their overall postharvest quality. Phytochemicals in plants are known for their potential health benefits, providing consumers with valuable antioxidant, anti-inflammatory, and anti-cancer benefits. In this work, freshly harvested eggplants and cucumbers were bought from a local supplier and stored for 10 days in controlled chambers at different combinations of constant and fluctuating temperature and light. Crude extracts of freeze-dried produce were used to determine the total phenolic contents (TPC) using the Folin-Ciocalteu method, then, these reactions were monitored spectrophotometrically. Applying kinetic models, it was possible to quantify phytochemical changes over time. Exposing vegetables to high temperature (30^{o}C) and direct light was found to significantly degrade their phenolic compound content. However, a rise in TPC ($P < 0.05$) was observed when the crops were maintained at 10^{o}C in the absence of light. In addition, storage at fluctuating environmental conditions was found to be the main driver to worsen the phenolic degradation in fresh eggplant (49.7% loss) and cucumber (83.8% loss). This study was useful in advancing knowledge on characterizing postharvest quality loss of fresh horticultural commodity from the perspective of health attributes rather than conventional sensory parameters such as color, firmness and weight loss; and aiming to effectively quantify postharvest losses of fresh produce along the supply chain in a more holistic manner.

5.2 INTRODUCTION

Fruits and vegetables play important roles in human diets and health. The World Health Organization estimated that low fruit and vegetable intake contributed to 1.7 million deaths worldwide annually (WHO, 2012). Food insecurity in many countries has taken the form of chronic non-communicable diseases (NCDs), including cancer, heart problems and diabetes. Consequently, there has been a global awareness of the beneficial effects of consuming fresh fruits and vegetables in order to alleviate the risk of those diseases. Various studies have shown strong evidence of the protective effects of plant foods against cancer and cardiovascular illness. Therefore, these foods are recognized for their health-promoting effects beside their nutritional contributions (Alarcón-Flores et al., 2014; Kaur et al., 2014; Mukherjee et al., 2013). Fruits and vegetables are rich in phytochemicals or phytonutrients, which act as antioxidants when consumed due to their ability to scavenge free oxygen radicals released in the human body under oxidative stress and thus protect cell membranes from oxidative damage (Tiwari et al., 2013).

Many researchers have proved the existence of an extensive range of phytochemicals in fruits and vegetables (Boivin et al., 2009). These phytochemicals are typically grouped according to function, chemical structure and also on the targeted source. Phytochemicals in fresh commodities are mainly ascorbic acid, carotenoids and phenolic/polyphenol compounds (Xu et al., 2009). Among the vegetables, eggplant (*Solanum melongena* L.) and cucumber (*Cucumis sativus* L.) provide a wide variety of health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer benefits due to their high content of antioxidant nutrients (Mukherjee et al., 2013; Okmen et al., 2009). They are best grown in tropical and sub-tropical areas (with some cucumbers also grown in temperate areas); therefore, they are grown in many countries in the world (Ismail et al., 2010). In 2012, FAO statistics revealed a global production of 48 and 65 MT for eggplant and cucumber, respectively (FAOSTAT, 2013). Commonly known as aubergine, eggplants are egg-shaped or globular (Gross et al., 2014) and have a bright green calyx, firm texture and dark purple skin. Cucumber fruit belongs to the Cucurbitaceae plant family and depending on the cultivar, high quality cucumber fruit should be dark green and firm with no wrinkled ends (Gross et al., 2014).

Quality is an important factor in the production and marketing of horticultural crops. When evaluating quality, several parameters in terms of external appearance can play a major role including color, firmness and weight loss, however, the phytochemical attribute is receiving much attention recently in both developed and developing societies. Although the consumption of fresh fruits and vegetables rich in phytochemicals has been proven to defend against chronic deseases, the stability of these compounds can vary a lot when the food product undergoes postharvest storage prior to consumption (Tiwari et al., 2013). Both eggplant and cucumber are highly perishable and their phenolic content can be affected by postharvest handling practices (Agarwal et al., 2012; Boulekbache-Makhlouf et al., 2013; Mishra et al., 2012). Factors such as temperature and direct light during transportation and storage can determine the synthesis, retention or breakdown of those plant-derived organic compounds (Tiwari et al., 2013). Carotenoids are very sensitive to temperature, light and packaging materials; therefore, they can degrade heavily during storage and processing (Namitha & Negi, 2010). Studies conducted by Fennema et al. (1996) also revealed that anthocyanin is very susceptible to high temperature and direct light exposure. The rate of phytochemical changes in fresh produce depends on environmental conditions and duration during storage (Shin et al., 2007). Many studies reported that the exposure to undesirable temperatures could exacerbate postharvest phytochemical loss during the handling process (Nath et al., 2011; Padda & Picha, 2008). These compounds are unstable at higher temperatures (between 25 and 40^{o}C) and relatively stable at lower temperatures (between 4 and 10^{o}C) (Tiwari et al., 2013). Results published by Concellón et al. (2012) showed that minor changes in phenolic antioxidants occurred when dark purple eggplant was stored at 0^{o}C for 14 days compared to a significant accumulation of these organic compounds when stored at 10^{o}C. Beside temperature, exposure to direct light has shown a significant influence on the overall stability of phytonutrients during storage. It is commonly known that phytochemicals are susceptible to degradation due to the occurrence of oxidation during storage (Sanz et al., 2009). In the presence of light, this oxidation process is called photo-oxidation (Tiwari et al., 2013). Studies performed by Xiao et al. (2014a) stated that lycopene, anthocyanin and carotenoid were very unstable when exposed to solar radiation and showed higher stability in the dark.

Postharvest storage conditions can foster many chemical composition changes in eggplant and cucumber (Florkowski et al., 2014). These changes occur at different rates, depending on the exposure of the commodity to external environments and the intensity of environmental factors during storage. Kinetic models provide a structural framework for quantitatively describing these changes (Heldman, 2011). The measurement of appropriate kinetic parameters such as reaction rate constant and activation energy for these changes enables the estimation of the magnitude of change in a given food component during storage and prior to final consumption. The kinetic analysis of phenolic compounds has been extensively investigated in a wide variety of fresh commodities. Cruz et al. (2009) documented that first-order prediction model for ascorbic acid fitted well the experimental data of watercress when stored at different fluctuating cold temperatures. Other studies reported that kinetic parameters were also obtained through first-order models, where the Arrhenius equation was used for temperature-dependence (Kirca & Cemeroglu, 2003; Pinheiro et al., 2013).

Among the many techniques widely used to quantify the phytochemical content in food and biological products, the non-chromatographic UV-VIS spectrophotometric method has proven to be the most simple, quick and inexpensive when not detecting individual phenolic compounds (Tiwari et al., 2013). This method counts on the ability of the phytochemicals to absorb light in the ultraviolet (UV) and the visible range of the spectrum (Samtha et al., 2012), or the ability of producing chromophores after reacting with other reagents (Tiwari et al., 2013). This approach is based on one representative compound or standard for quantification, with the total concentration of the phytochemicals in the plant extract is expressed in terms of equivalent to this standard using a calibration curve. For example, when measuring the total phenolic content (TPC) according to the Folin-Ciocalteu (FC) method, gallic acid, a naturally phenolic antioxidant found in plant foods, is usually used as a standard representing the group of polyphenols in the studied crops. These polyphenols react with specific FC reagents to form a blue complex that can be quantified by spectrophotometry (Ainsworth & Gillespie, 2007; Sanchez-Rangel et al., 2013).

Research on postharvest quality management is experiencing remarkable growth with the emphasis on health-promoting attributes rather than traditional sensory parameters such as color and firmness.

5.3 OBJECTIVES

The general objective of this study was to investigate the influence of fluctuating environmental factors such as temperature and light, on the phytochemical content of freshly harvested cucumber and eggplant. The specific objectives were to: (1) evaluate changes in the total phenolic content of eggplant and cucumber as influenced by storage conditions, and (2) describe these changes using a kinetic modelling approach.

5.4 MATERIALS AND METHODS

5.4.1 Plant material preparation

Fresh cucumbers and eggplants were obtained from a local year-round greenhouse supplier (Lufa farms, Montreal). Right after harvesting, the samples were labeled and separated into experimental units of similar quantity for further analysis.

5.4.2 Experimental set-up

Controlled environment chambers (Conviron Inc., PGR15, Manitoba, Canada) were used in the study. With an internal capacity of 2.2 m^3, the chambers were fully programmable to monitor set factors (temperature and light). The chamber was capable of maintaining temperature in the range between 10 and 45^oC. Airflow inside the unit was distributed uniformly upward using air distribution plenum (Conviron, 2014) that allowed up to 0.5 m^3/min of air exchange. Light intensity in the chamber was maintained up to 875 micromoles/m^2/s or 64750 lux using fluorescent and incandescent lamps. This is a typical average of sunlight intensity during a sunny day.

Under constant storage conditions (SC), samples of eggplant and cucumber were stored at 10 and 30^oC for 10 days with 90±5% RH. Experiments were conducted under 2 different light scenarios namely complete darkness and an interval of 12 hours of direct light per day for each temperature setting. A total of four different storage combinations of temperature and light were conducted as follow: SC1 = 10^0C (with light); SC2 = 30^0C (with light); SC3 = 10^0C (without light); SC4 = 30^0C (without light). The storage at 10^oC represented the optimum conditions for commercial storage recommended for studied crops (Gross et al., 2014); whereas, the second temperature (30^oC) corresponded to the average annual temperature that best characterize tropical countries where temperature abuse during postharvest handling is more frequent.

Under fluctuating conditions, the storage of cucumber and eggplant was simulated based on real situations occurring during the handling process of fresh produce in many countries around the world (Figure 5.1). After harvesting, the crop samples were stored at 25^oC for 2 hours with no light exposure (S1). This step was similar to the activity carried out by farmers in the field, where they place their crop under shade after harvesting. The following step (S2) was to store the cucumber and the eggplant for 3 hours under light, which simulated the transportation of the fresh produce to the market using open trucks. Step 3 corresponded to the marketing stage of the harvested commodity for a typical duration of three consecutive days under fluctuating conditions of temperature and light between day and night. Therefore, the crop samples were stored at 30^{o}C with light for 12 hours and at 20^{o}C with no light for another 12 hours. This step (S3) lasted for 72 hours. The final step (S4) illustrated conditions similar to what happened at the consumption level where the produce was stored at low temperature (10^{o}C) in the absence of light for a maximum duration of 6 days (144 hours). The entire experiment was conducted in triplicate.

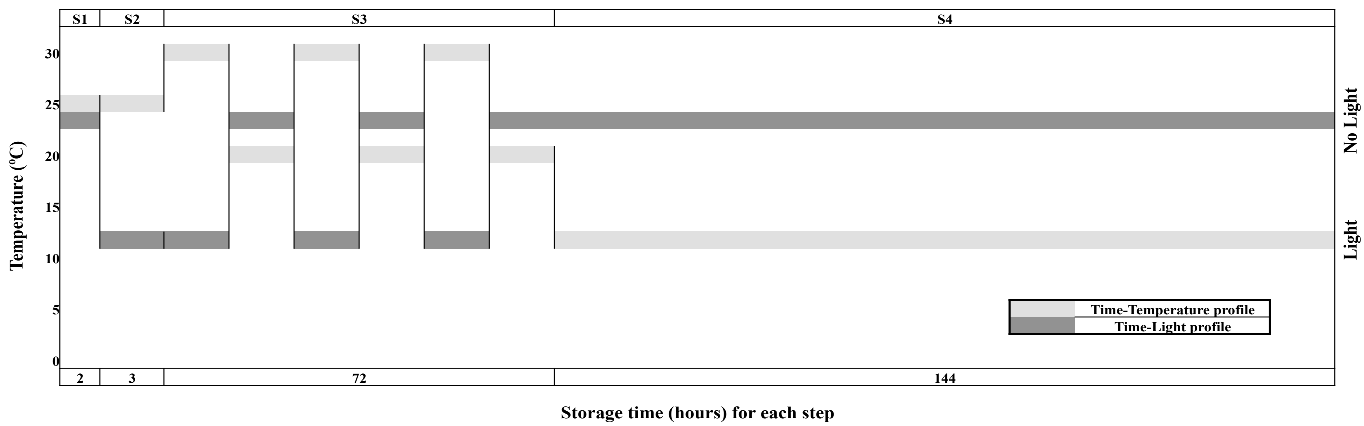

Figure 5.1 Schematic diagram of fluctuating environmental conditions during storage

5.4.3 Samples and chemicals preparation

Immediately after storage, eggplant and cucumber samples were sliced into thin pieces with a sharp knife (~30 g for each crop) and placed at -80^{o}C until used for further analysis. Methanol, acetone and sodium carbonate anhydrous (Na_2CO_3) were bought from Thermo Fisher Scientific Inc. (Montreal, Canada). Folin-Ciocalteu's phenol reagent and gallic acid were purchased from Sigma-Aldrich Co. (Montreal, Canada).

5.4.4 Methanolic/Acetonic extraction

Frozen samples of eggplant and cucumber were freeze-dried using freeze-dryer (Modulyod-115; ThermoSavant, Holbrook, NY, USA) until equilibrium at -52^{o}C (48 hrs) (Appendix 6). Dried samples were then pulverized into fine powder using a mortar and a pestle. After that, 100 mg portions of pulverized dried sample were placed into 15 ml plastic tubes. Then, 4 ml of solvent (methanol 90% for cucumber and acetone 90% for eggplant) were added (Boulekbache-Makhlouf et al., 2013). The mixture was bath-sonicated (Branson Ultrasonic Inc., 5510, USA) for 45 min with ice and then vortexed manually. The solution was then centrifuged at 3500 rpm for 15 min at 4^{o}C (Jouan CR4.22, bench-model, Canada). First supernatant was collected in clean tubes and the pellet was re-extracted by adding 1 ml solvent and centrifuged again. A second supernatant was then collected and added to the first one. Finally, clear supernatants of both eggplant and cucumber dry weight (DW) extracts were stored at -20^{o}C for further analysis.

5.4.5 Determination of total phenolic content

The total phenolic content of both crop extracts was quantified following the technique of Singleton and Rossi (1965) by using the Folin-Ciocalteu assay with few modifications. Clear supernatant of 100 µl was added to 2 ml distilled water and 200 µl of Folin-Ciocalteu phenol's reagent (2N). After few minutes, the solution was mixed with 1 ml of Na_2CO_3 (10%) and incubated in the dark at room temperature for 60 min. The absorbance was then read at 765 nm using UV-Vis spectrophotometer (UV1; Thermo Fisher Scientific Inc, Canada) (Appendix 5). Total phenolic content was obtained by a linear equation using gallic acid as the standard (y = 2.2892x + 0.0042, R^2 = 0.99). Each sample's extract was measured in triplicate and an average value was recorded. Finally, the total phenolic content of eggplant and cucumber was determined as a milligram gallic acid equivalent (GAE. mg/ml extract).

5.4.6 Data and statistical analysis

Changes in phytochemical content of cucumber and eggplant as affected by different storage conditions were analyzed. For all storage conditions, zero, first and second order reactions were plotted against time (days) and the highest coefficient of determination (R^2) was obtained from a linear regression analysis, thus providing the accuracy of the first order kinetic model.

Under isothermal conditions, a fractional kinetic model described by equation 1 was used to quantify phytochemical change. The average retention of TPC at a given time was determined using the following formula:

$$\frac{C_t}{C_0} = \exp^{-kt} \qquad (1)$$

where C_t is the measured quality parameter (TPC) at time t, C_0 is the initial quality before any storage, t is the storage time and k is the rate constant at temperature T.

The temperature-dependence of the rate constant "*k*" followed the Arrhenius equation (Eq. 2):

$$k = k_{ref} \exp\left[\frac{-E_a}{R}\left(\frac{1}{T_i} - \frac{1}{T_{ref}}\right)\right] \tag{2}$$

where k_{ref} is the reaction rate at reference temperature (T_{ref}), E_a is the activation energy of the reaction (J/mol), R is the universal gas constant (8.314 J/mol.K) and T is the absolute temperature (K). The reference temperature used was 30^{o}C.

By substituting equation 2 into equation 1, the general model that expresses the phytochemical changes (loss or accumulation) due to temperature and light effect can be described as follows (Eq. 3):

$$\frac{C_t}{C_0} = \exp^{-k_{ref}\exp\left[\frac{-E_a}{R}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]t} \tag{3}$$

Under non-isothermal conditions, the total phenolic content can be predicted for a given time by equation 4:

$$\frac{C_t}{C_0} = \exp^{-k_{ref}\int_0^t \exp\left[\frac{-E_a}{R}\left(\frac{1}{T_i}-\frac{1}{T_{ref}}\right)\right]dt} \tag{4}$$

By introducing the term of effective temperature (T_{eff}) as demonstrated by Giannakourou et al. (2003) and defined as the constant temperature at which the same quality change resulted from the same time duration as the temperature fluctuated along the storage, the total phytochemical changes for the entire storage duration of studied crops as influenced by fluctuating temperature and light can then be predicted using the equation 5:

$$\frac{C_{t_{total}}}{C_0} = \exp^{-k_{eff}t_{total}} \tag{5}$$

where k_{eff} is the value of the rate constant at the effective temperature. Therefore, $k_{eff}\, t_{total}$ was calculated using equation 6:

$$k_{eff} t_{total} = k_{ref} \sum_i \left(\exp\left[\frac{-E_a}{R} \left(\frac{1}{T_i} - \frac{1}{T_{ref}} \right) \right] t_i \right) \tag{6}$$

An analysis of ANOVA followed by a Tukey-Kramer HSD test for comparison of means was conducted using JMP version 11 software.

5.5 RESULTS AND DISCUSSION

5.5.1 Effect of storage temperature and light on total phenolics

Figures 5.2 and 5.3 showed the phytochemical concentration of freshly harvested dark purple eggplant and cucumber fruits under different storage conditions. Under complete darkness, TPC decreased during high storage temperature. After 10 days at 30^{o}C, phenolic contents decreased from 0.33 to 0.18 mg GAE/ml eggplant extract (44.5% loss) and from 0.09 to 0.06 mg GAE/ml cucumber extract (37% loss). However, an opposite trend was significantly observed ($P < 0.05$) in the absence of light when crops were stored at 10^{o}C. An accumulation of 33 and 90% for eggplant and cucumber, respectively, was recorded at day 10, compared to the initial concentration. These results were in agreement with other studies demonstrating that storage temperature is a key parameter for the degradation or the retention of phytochemicals in vegetables (Zaro et al., 2014b). Therefore, maintaining optimum temperature conditions during storage is extremely important to promote health-benefit attributes in postharvest quality management of fresh produce. Studies have also shown that the stability of phenolic compounds greatly depended on undesirable temperatures. Studies carried out by Concellón et al. (2012) and Zaro et al. (2014a) showed that there was an increase in phenolic content of eggplant cultivars stored at 10^{o}C for 14 days and this accumulation was correlated to chlorogenic acid biosynthesis, a bioactive compound at this temperature. Others have reported lower stability of potato and radish anthocyanin at 25^{o}C compared to 2^{o}C (Tiwari et al., 2013). It was noticed that kinetics of some antioxidants present in these crops followed much faster reaction rates at higher temperatures as well as quadratic model under 25^{o}C and linear model at 2^{o}C.

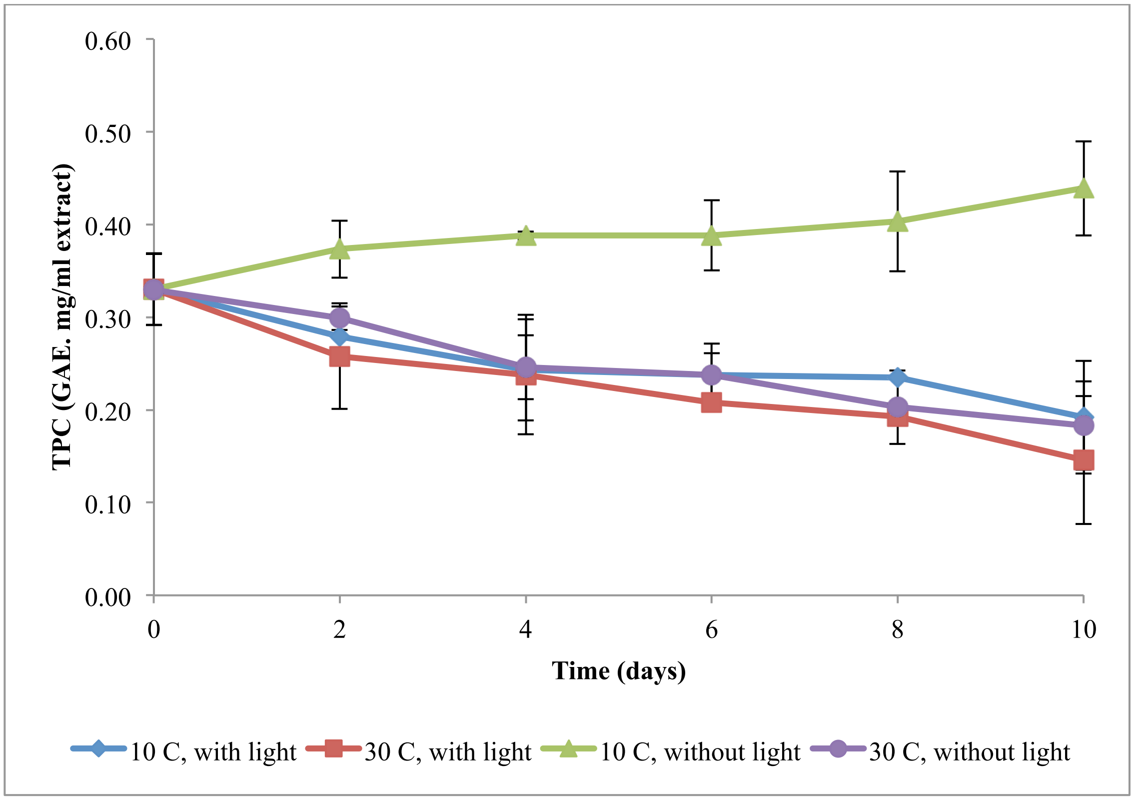

Figure 5.2 Total phenolic content at constant storage conditions for eggplant

Figures 5.2 and 5.3 revealed also the results of TPC as affected by direct exposure to light during storage. Under isothermal conditions (10^{o}C), there was a significant break-down ($P < 0.05$) in phenolic concentration due to photo-oxidation with light. In the case of eggplant, the phytochemical content degraded by 42%, while in cucumber, around 35% loss was observed after 10 days of storage. On a different note, there was a continuous drop of TPC when produce was stored at 30^{o}C. A greater loss ($P > 0.05$) of phytochemicals (56 and 52%) was noticed under direct exposure of light compared to 45 and 37% degradation under complete darkness in both eggplant and cucumber, respectively. Similarly under 10 and 30^{o}C with exposure to light, the results revealed a continuous decrease of phytonutrients of both crops with no significant difference between the two storage conditions. Therefore, exposure of fresh crops to light for 12 hrs/day at both 10 and 30^{o}C has a great influence on degrading phytochemical content same as high temperature (30^{o}C) under complete darkness. A similar conclusion has been reported by Lin et al. (2005) and Nachtigall et al. (2009) where they demonstrated that lycopene destruction was more severe due to light effect than to high temperature.

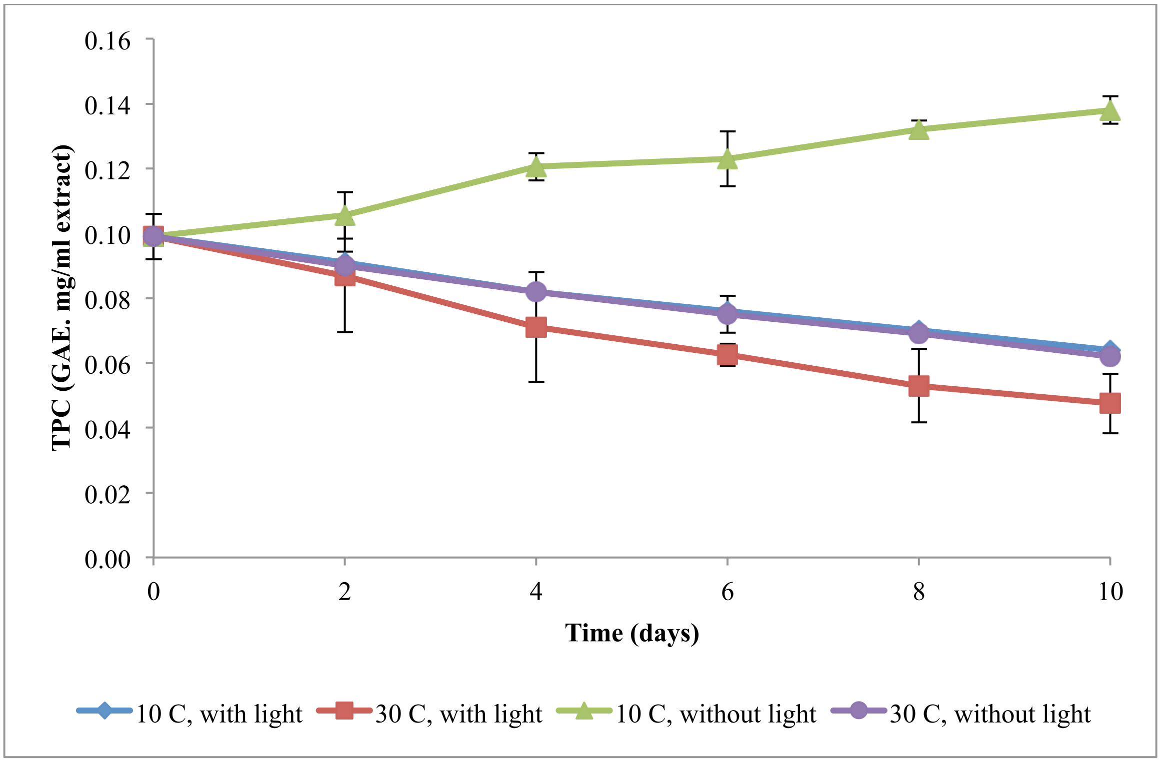

Figure 5.3 Total phenolic content at constant storage conditions for cucumber

It is often difficult to ensure constant storage conditions during postharvest handling of fresh commodities. In many countries, fresh fruits and vegetables experience severe stress along the postharvest process due to fluctuating temperature and direct sunlight. Consequently, this results in major qualitative and quantitative losses. Figure 5.4 illustrated the phytochemical behavior of fresh eggplant and cucumbers as they moved from farm to fork. During the first two hours of storage (S1), TPC decreased by almost 2 and 6% for eggplant and cucumber, respectively. A continuous degradation of phenolic compounds occurred when the crops were exposed to light for a subsequent three hours (S2) with higher loss (~15%) in the case of cucumber. The results also demonstrated a significant ($P < 0.05$) degradation of total phenolics after 3 consecutive storage days (S3) of fluctuating temperature and light with a corresponding phytochemical loss for eggplant and cucumber ranging from 50 to 84%. After that, when the produce was stored in darkness at 10^{o}C for another 6 days (S4), phenolic antioxidants were significantly ($P < 0.05$) built up to 86 and 92% of the initial concentrations for both eggplant (0.285 mg GAE/ml extract) and cucumber (0.091 mg GAE/ml extract).

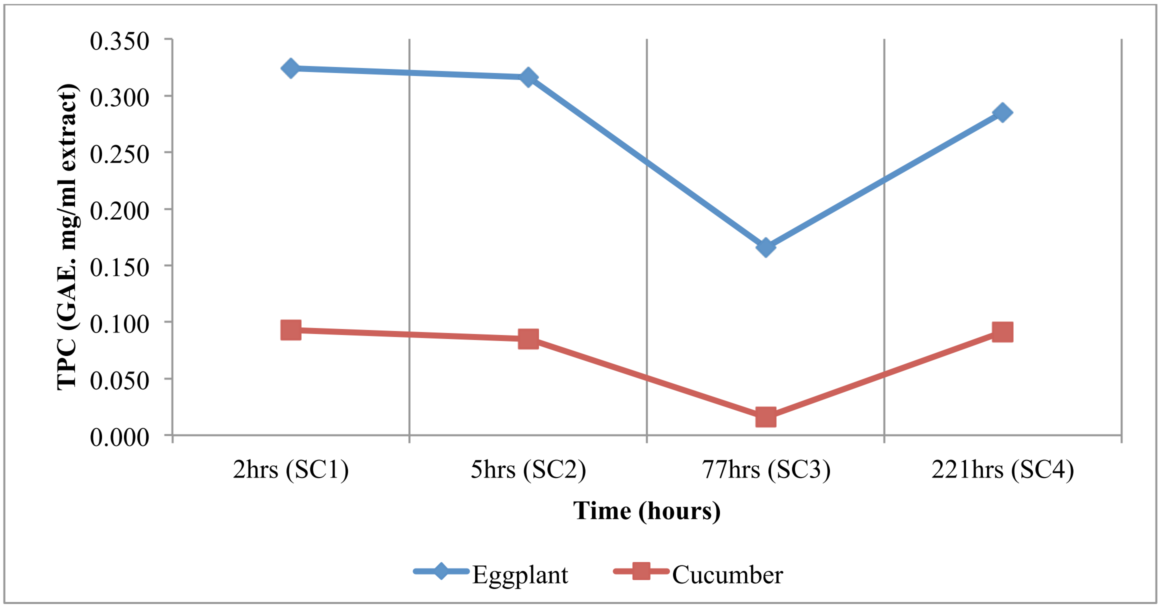

Figure 5.4 Total phenolic content at fluctuating storage conditions for eggplant and cucumber.

Fluctuating the temperature and light along the supply chain process has been always associated with major quality loss of fresh food commodities. This statement is in agreement with a study carried out by Cruz et al. (2009) where they concluded that temperature abuse was the main problem affecting food quality during storage and a lower and constant temperature was needed to minimize food quality losses. Finally, the present work showed that the phytochemical content of eggplant and cucumber fruits was greatly affected by postharvest storage temperatures and light. The synthesis observed at 10^{o}C in the absence of light considerably increases the nutritional value of the produce and the benefits related to the consumption of antioxidants (Concellón et al., 2012).

5.5.2 Phytochemical changes during storage

5.5.2.1 Kinetic analysis at constant conditions

Studying kinetics was necessary to predict the change in postharvest health attributes and the influence of temperature and light on the phytochemical content of studied crops during storage. Table 5.1 showed the kinetic parameters of eggplant and cucumber at both studied temperatures 10 and 30^{o}C obtained under the absence and the presence of light. Experimental data of TPC fitted well the first order reaction model (Eq. 1). During storage (SC1, SC2 and SC4), the total phenolic concentration in both eggplant and cucumber was decreased gradually over time at a rate depending on the temperature and light exposure. For both crops, the degradation was faster at 30^{o}C under direct light ($k_{eggplant}$ = 0.073/day; $k_{cucumber}$ = 0.075/day). It was also important to mention that the phenolic content was degrading at almost similar rate when crops were stored at 10^{o}C with light and 30^{o}C without light. Therefore, this concluded that even at lower temperature, direct exposure of light has the same impact on phytochemical loss as higher temperature. On a different note, total phenolic content was gradually increased with time at a slower reaction rate during storage at 10^{o}C under complete darkness ($k_{eggplant}$ = 0.024/day; $k_{cucumber}$ = 0.034/day).

Table 5.1 Kinetic parameters of eggplant and cucumber at constant storage conditions.

Storage Conditions	C_0	C_{eq}	Kinetic parameters		
			k (day^{-1})	R^2	Ea (kJ/mol)
Eggplant					
SC1	0.330	0.192	0.046	0.906	16.05
SC2	0.330	0.146	0.073	0.961	
SC3	0.330	0.439	0.024	0.889	39.94
SC4	0.330	0.183	0.059	0.981	
Cucumber					
SC1	0.099	0.064	0.044	0.998	19.62
SC2	0.099	0.048	0.075	0.994	
SC3	0.099	0.138	0.034	0.961	28.84
SC4	0.099	0.062	0.046	0.999	

SC1 = 10^{0}C (with light); SC2 = 30^{0}C (with light); SC3 = 10^{0}C (without light); SC4 = 30^{0}C (without light).

An Arrhenius equation describing the temperature-dependence (Eq. 2) with $T_{30}{}^{o}C$ as reference temperature was used to calculate the activation energy for both studied crops. In the study, two different "Ea" were obtained for each produce considering the light factor. The results (Table

5.1) revealed that energy needed to start the phenolic concentration change within the food system was Ea = 16.05 and 19.62 kJ/mol for eggplant and cucumber, respectively. In contrast, higher Ea values were recorded in the absence of light (39.94 kJ/mol for eggplant and 28.84 kJ/mol for cucumber). Once again, this concluded that exposure to light was a major environmental factor to be carefully considered during postharvest quality management of fresh fruits and vegetables.

5.5.2.2 Kinetic analysis at fluctuating conditions

Kinetic parameters determined under isothermal conditions were used to establish kinetic models under fluctuating temperature and light. Under non-isothermal storage, the effective reaction rates "k_{eff}" multiplied by the cumulative storage time "t_{total}" at each step in Figure 5.1, was calculated and presented in Table 5.2. At the first stage of the storage (time = 2 hours), the phytochemical loss occurred at slower rates ($k_{eff}\,t_{total}$ = 0.046 and 0.051) resulting in predicted TPC loss of 4.5 and 5% for eggplant and cucumber, respectively. However, at the end of the second stage (time = 5hours), phenolic degradation under the same temperature of 25°C was higher ($k_{eff}\,t_{total}$ = 0.128 and 0.133) due to light effect with phenolic losses of about 12% for both crops. After 77 hours of variable storage conditions of temperature and light, between 84 and 86% loss resulted for eggplant and cucumber, respectively, with $k_{eff}\,t_{total}$ = 1.860 and 2.019. When the produce was stored for 144 hours at 10°C in completed darkness, an accumulation of phenolic antioxidants was observed and a predicted loss of 35% for eggplant and 1.4% for cucumber of the initial concentration was observed ($k_{eff}\,t_{total}$ = 0.430 and 0.014). Concellón et al. (2012) also found an increase of phenolic antioxidant values to harvest when the dark purple American eggplant samples were maintained at 10°C after 5 and up to 14 days of storage. Based on Table 5.2, the extent of phytochemical behaviour varied a lot between crops; therefore, an accurate prediction of the TPC changes as affected by temperature and light fluctuation is always a function of estimated kinetic parameters determined under isothermal conditions (Cruz et al., 2009).

Table 5.2 Kinetic parameters and predicted TPC loss of eggplant and cucumber at fluctuating storage conditions.

Storage period (hours)	C_0	C_{eq}	Kinetic parameters	Predicted TPC loss (%)
			$k_{eff}\ t_{total}$	
Eggplant				
2	0.330	0.324	0.046	4.49
5	0.330	0.316	0.128	12.01
77	0.330	0.166	1.860	84.43
221	0.330	0.285	0.430	34.94
Cucumber				
2	0.099	0.093	0.051	4.97
5	0.099	0.085	0.133	12.45
77	0.099	0.016	2.019	86.72
221	0.099	0.091	0.014	1.39

5.5.3 Comparison of TPC loss

In this experiment, fresh eggplant and cucumber fruits were stored for 10 days under various conditions. Under fluctuating temperature and light, the majority of TPC loss occurred during the first 77 hours (equivalent to day 4 under isothermal conditions) of storage that corresponded to early stages in the supply chain (production and marketing stages) where most of postharvest losses are frequent in many countries around the globe (especially in developing societies). This storage duration corresponded to almost day 4 under constant conditions. Figure 5.5 showed the percent loss of phenolic content in both eggplant and cucumber under the four constant conditions compared to fluctuating storage. The results revealed that highest losses occurred under variable storage temperature and light followed by losses at a constant temperature of 30^{o}C with direct exposure to sunlight. In other words, temperature and light abuses during postharvest handling and prior to consumption of fresh horticultural commodities increased phytochemical losses by two- to three-fold for eggplant and cucumber, respectively. Therefore, the impact of fluctuating environmental factors was detrimental to phytonutrients of fresh produce during postharvest storage.

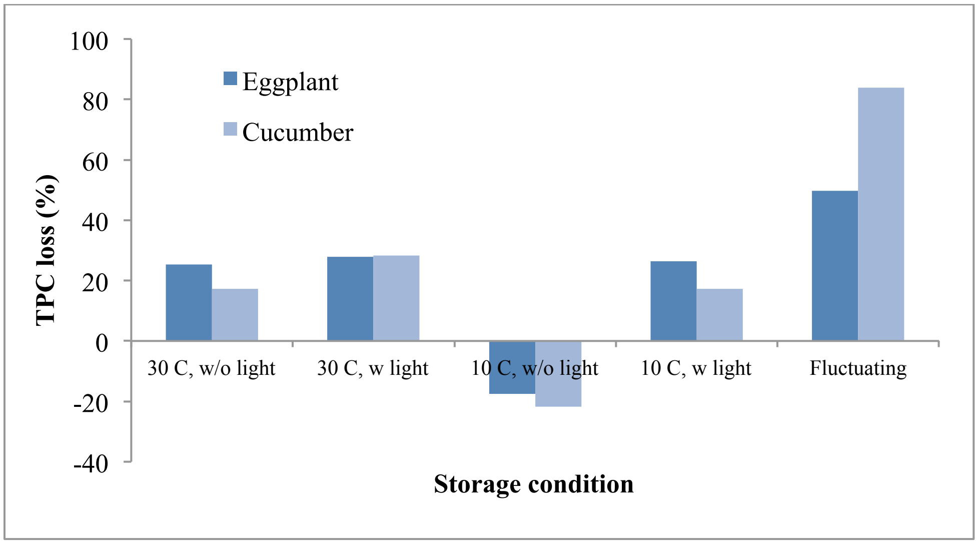

Figure 5.5 Comparison of TPC percent loss after 77 hours of storage to harvest for both eggplant and cucumber as affected by constant and fluctuating storage conditions.

5.6 CONCLUSIONS

The environmental conditions under which fresh crops are produced, transported and displayed have a significant effect on the keeping quality of the food and the amount that is lost. Exposure to light showed a similar influence on retention and/or degradation of phytochemical content same as high temperature. Furthermore, fluctuating conditions right after harvesting and during the handling process caused greater phytonutrient losses than constant storage at 30^{o}C in the presence of light. Therefore, enhancing postharvest quality management from farm to fork through maintaining low temperature of 10^{0}C with complete darkness can significantly reduce postharvest phytonutrient quality loss. Finally, kinetic models were quite useful in predicting the degradation of the total phenolic content of fresh commodities during storage and commercialization and therefore allowed for a better assessment of quality at each step along the supply chain.

CONNECTING TEXT

As seen in the literature review, quality is a multidimensional concept and can be defined differently by different people. The previous chapters described the effect of fluctuating environmental factors on quality changes during storage and quantified the quality loss of fresh produce from a consumer's perspective. Taguchi has introduced a new dimension of quality: the loss to society caused by a product. In the following chapter, the Taguchi approach, known as a robust quality management tool, is applied as a new technique to measure the postharvest quality loss of fresh cucumber.

CHAPTER 6. A NEW METHOD TO QUANTIFY POSTHARVEST QUALITY LOSS OF CUCUMBER USING THE TAGUCHI APPROACH

6.1 ABSTRACT

At the present time, the literature does not offer any methodology for an effective and reliable measurement of postharvest losses of fresh produce. The aim of this study was to use the Taguchi approach to quantify postharvest quality loss of cucumber as affected by environmental factors (temperature, light, humidity) over time. The experimental design included the 4 three-level factors and an L-9 orthogonal array. The Taguchi loss function was used to quantify quality loss of fresh cucumber after each storage combination. The results revealed that fresh cucumber lost some of its quality attributes as early as immediately after harvesting. With a firmness of 15.68 N, the loss was equivalent to 13.68 units. However, at 7.68 N firmness, the loss value was increased by almost 4 times (56.98 units). In terms of quality index, it was noticed that even when the score was high (QI = 9 points), the produce had lost 8.74 units of its quality. In theory, the only time when the loss is equal to zero is when the cucumber fruit is still attached to its mother plant. When the quality index dropped to 1.67 points, the loss was increased by almost 30 times more (loss = 254.91 units). The results showed how large the extent of loss could be when fresh cucumber is stored under undesirable conditions. The percent influence of studied factors on each quality attribute was also determined. For the overall quality, 46.5% of loss was due to time, followed by 18% due to temperature and 11.5% due equally to light and humidity. Finally, using a measure of goodness-of-fit of linear regression, Taguchi predictions fitted the observed data. This confirmed the ability of the Taguchi technique to predict postharvest quality loss of fresh produce in response to different combinations of factors and their levels.

6.2 INTRODUCTION

Cucumber fruit (*Cucumis sativus* L.) belongs to the Cucurbitaceae plant family that can be cultivated in subtropical and tropical environments; therefore, they are grown in many countries of the world (Gross et al., 2014; Ismail et al., 2010). Fresh consumption of this crop provides a variety of health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer benefits (Mukherjee et al., 2013). According to FAO statistics, the global production of cucumber was 65MT in 2012 grown in an area of 2,109,650 ha (FAOSTAT, 2013). Cucumber is a highly perishable crop and the environmental conditions under which cucumber is produced, transported and displayed have a significant effect on the keeping quality of this food and the amount that is lost.

The major environmental influences that change the quality of cucumber include temperature, relative humidity and light (Luning et al., 2009; Shin et al., 2007). The main quality issues in cucumber during postharvest handling are mainly fruit discoloration due to loss of chlorophyll pigments, shrivelling or wilting caused by loss of moisture which affects the firmness of the produce and physiological deterioration due to undesirable temperature (Manjunatha et al., 2014). Storage of cucumber at low temperature (10^{o}C) was shown to induce chilling injuries (Dhall et al., 2012; Zhang et al., 2015). Other research studies have shown that for each increase of 10^{o}C, the rate of degradation will increase by 2 to 3 times (Kader, 2002). Relative humidity is another environmental factor that can cause serious losses of the fresh commodity (Hung et al., 2011). Laurin et al. (2005) revealed that the storage of Beit Alpha cucumber under undesirable humidity results not only in direct quantitative losses (weight loss) but also qualitative losses such as wilting, shrivelling and softening. Light is also one of the most important factors affecting the phytonutrient content in many plant products that are rich in antioxidants (such as cucumber). It can cause harmful effects on produce quality (Alcock et al., 2013; Xiao et al., 2014a). Depending on the cultivar, high quality cucumber fruit should be dark green and firm with no wrinkled ends (Gross et al., 2014). The suggested conditions for commercial storage of fresh-market cucumbers are less than 14 days at 10 to 12^{o}C and 95% RH (Florkowski et al., 2014; Gross et al., 2014).

Currently there is no methodology for the effective and reliable measurement of postharvest losses of fresh produce. Not much progress has been made in this direction. During the past 30 to 40 years, research investigations were focused on developing technologies to increase the productivity of food and only few researchers were engaged in minimizing postharvest losses (Aulakh et al., 2013; Buzby et al., 2009). This is mainly due to problems related to the complexity of the concept of postharvest loss, the absence of reliable and accurate data on postharvest losses, major gaps in the knowledge of measuring these losses and the multiple definitions of quality loss (Hodges et al., 2011). For many researchers, estimating postharvest losses was not following a holistic approach. Most of the studies have focused on measuring the losses only at the storage steps without incorporating other important stages along the supply chain (such as grading, packaging, transporting and processing), which can also contribute largely to postharvest losses (Aulakh et al., 2013; Van Dijk et al., 2012). Existing methods to estimate postharvest losses are mainly Food and Agriculture Organization of the United Nations (FAO) initiatives and based on surveys especially in developing countries (Aulakh et al., 2013; FAO, 2007, 2014; Koester, 2013). In addition, recent studies were undertaken by the FAO to estimate food losses using FAO's Food Balance Model (FBM), where food loss is calculated based on the principles of mass flow ($mass_{in} = mass_{out}$) through the value chain process (Gustavsson et al., 2011). In order to quantify these losses, this model uses the pre-set "conversion factor" for each crop, which determines the part of agricultural products that is edible, and multiplies it by the loss percentage in each step of the food supply chain. However these losses have relied on assumptions and estimations; therefore, this is considered a huge "gap" in the knowledge of measuring postharvest losses.

The Taguchi approach has been successfully used by researchers in various subject areas including environmental sciences (Sadeghi et al., 2012), food engineering (Oztop et al., 2007), biotechnology (Trabelsi et al., 2006), aerospace (Singaravelu et al., 2009), sports (Burton et al., 2010), construction (Tukmen et al., 2008), energy (Zeng et al., 2010) and many others. This approach was applied as a valuable statistical tool to determine the optimum parameters of a production process and to quantify the quality loss of a manufactured product (Dingal et al., 2008; Ross, 1996). However, to the best of our knowledge, no application of this approach to postharvest technology has been reported until the present time. Considered as a pioneer in quality management, Genichi Taguchi has combined engineering and statistical methods in order to quantify commodity loss and improve its quality (Luning et al. 2009; Ross, 1996; Taguchi, 1993). For this, Taguchi proposed a mathematical formula called the "quadratic loss function". He stated that maintaining the high quality of a commodity would require reducing variations around a "target" by achieving consistency of performance (Roy, 2001). As long as quality deviates from the target specifications, there is “loss”. This opposes conventional methods for quality management where product quality is only defined as “bad” or “good” and as long as the product lies within its specification limits, there is no “loss” (Emadi et al., 2008; Oztop et al., 2007). In this research study, Taguchi’s approach was expected to help with the identification of the most influenced environmental factors on the product quality, to provide a robust and consistent method to measure the most unseen quality losses during postharvest handling of fresh crops and to minimize the variation in product response caused by environmental factors while keeping the mean response close to target.

6.3 OBJECTIVES

The objectives of this work were: (1) to quantify postharvest quality loss of freshly harvested cucumber using the Taguchi approach, and (2) to predict intrinsic quality attributes as affected by environmental or uncontrollable factors as the produce moved from farm to fork.

6.4 MATERIALS AND METHODS

6.4.1 Plant material and storage simulation

Built on a rooftop, Lufa Farms, a local supplier in Montreal, Canada, provided year-round fruits and vegetables grown in a commercial large-scale agriculture greenhouse. Right after harvesting, fresh cucumbers were labeled and separated into experimental units of similar quantity. A storage simulation experiment was carried out afterwards in controlled environment chambers (Conviron Inc.) to evaluate the postharvest quality of fresh produce stored under different conditions of temperature (T), relative humidity (RH) and light according to the Taguchi design. With an internal capacity of 2.2 m^3, the chambers were fully programmable to monitor the set factors without the need for constant adjustment. Specially designed to provide a temperature range between 10 and 45^0C, airflow inside the unit was distributed uniformly upward using an air distribution plenum (Conviron, 2014) that allowed up to 0.5 m^3/min of air exchange. Using fluorescent and incandescent lamps, the light intensity reached up to 875 micromoles/m^2/s or 64750 lux, which is a typical average of light intensity during a sunny day.

6.4.2 Experimental design

A Taguchi experimental design was developed and carried out using the JMP v.11 statistical software. Since the Taguchi technique is a form of a "design of experiment" (DOE), the first step in this experiment was to select the key environmental factors along with their levels. These factors were responsible for causing variability around the quality target of cucumbers fruits along the supply process. For the purpose of this study, four factors including storage temperature (^oC), storage time (days), exposure to direct light related to the presence or absence of luminosity during 12hrs/day and relative humidity (%) were selected as demonstrated in Table 6.1. Those factors and their equivalent levels were selected based on other studies conducted by the authors in the Caribbean. According to the Taguchi design, an experiment involving 4 three-level factors and an L-9 orthogonal array was suggested. A full factorial experimental design gives 3^4 = 81 possible combinations or experimental trials. Using fractional factorial in the Taguchi approach, only 9 experiments with different combinations were needed and conducted as shown in Table 6.2. To seek out the best combinations of factors/levels among the many alternatives, the JMP statistical software was used. The entire experiment was conducted in three replicates.

Table 6.1 Selected factors and their levels recommended for this study (cucumber).

Factor	Level		
	1	2	3
A: Temperature (^0C)	10	20	30
B: Time (days)	1	5	10
C: Relative Humidity (%)	75	85	95
D: Light	No Light	12 hrs. Light / no Light	Light

Table 6.2 Different combinations according to Taguchi L-9 orthogonal array (cucumber).

Test	Combination				Factor			
					Temperature	Time	Humidity	Light
Test 1	1	1	1	1	10	1	75	No
Test 2	1	2	2	2	10	5	85	No/Yes
Test 3	1	3	3	3	10	10	95	Yes
Test 4	2	1	2	3	20	1	85	Yes
Test 5	2	2	3	1	20	5	95	No
Test 6	2	3	1	2	20	10	75	No/Yes

Test 7	3	1	3	2	30	1	95	No/Yes
Test 8	3	2	1	3	30	5	75	Yes
Test 9	3	3	2	1	30	10	85	No

6.4.3 Quality loss function

As mentioned earlier, the loss function is a statistical tool that Taguchi developed to measure the quality loss of a commodity caused to a society when its leaves the production. In this work, loss function was used to measure the quality loss of fresh cucumber after harvesting. Quality attributes for cucumber, such as weight loss and total color difference, have "smaller the better (SB)" quality characteristics since the reduction of postharvest loss is greater when the produce still maintains its fresh color and loses less moisture during handling. However, quality parameters like firmness and quality index were best desired to have "larger the better (LB)" type of measurement because the consumer will always prefer to purchase a firmer and higher quality cucumber. Therefore, the mathematical formulas proposed by Taguchi (Ross, 1996; Taguchi, 1993) were as follow (Eq. 1 and 2):

$$L = k_L (y)^2 \text{ for smaller the better target} \tag{1}$$

$$L = k_L \left(\frac{1}{y}\right)^2 \text{ for larger the better target} \tag{2}$$

where "k_L" is the proportionality constant and "y" is the studied quality attribute (color difference, firmness, quality index or weight loss).

In all his work, Taguchi expressed the loss in monetary terms. However, for the purpose of this study, the word "*loss*" means the loss of quality and is expressed in unit scale. Using linear interpolation analysis with a minimum value of 1 and maximum value of 100, calculated values were plotted against $(1/y)^2$ and $(y)^2$ separately and the value of k_L (slope in this case) was determined from each plot. The quality loss was then calculated for any value of "y" based on the constant value of "k_L".

6.4.4 Percent influence

An analysis of variance was conducted using the JMP v.11 statistical software. It was necessary to determine how much influence each environmental factor caused on the quality attributes of the studied cucumber. This analysis is normally called a percent influence (P_i). The percent influence is a function of sum of squares for each factor (Ross, 1996). It was used as an indicator of the power of each factor to increase or decrease variability around the target (Ross, 1996). The total and factor sum of squares were the fundamental calculations computed by ANOVA. The percent influence (P_i) of each factor on the quality was then calculated based on the following formula (Ross, 1996; Sadeghi et al., 2012):

$$P_i = \frac{S_F - \left(V_e \times f_F\right)}{S_T} \times 100 \qquad (3)$$

where S_F is the sum of squares of a particular factor, V_e is the variance for the error term, f_F is the degree of freedom of a particular factor and S_T is the total sum of squares of all factors.

6.4.5 Quality evaluation

Quality is an important factor in the production and marketing of horticultural products. When evaluating quality, several methods can play an important role, but the only accurate test of quality is the feedback of the buyer. For cucumber, consumers look at several quality parameters, such as good external appearance known also as quality index, color, firmness, and weight loss, before making the decision to purchase. Both initial (used as control) and final qualities after each storage combination were evaluated.

The quality index (QI) for individual produce was assessed for the parameters of symptoms of deterioration and limits of marketability using a nine point hedonic scale. A quality index (Table 6.3) for cucumber summarizing all these parameters was determined and the total score for each parameter was calculated.

Table 6.3 Full description of quality index scales of cucumber by Kader *et al.* (2010).

Quality Index	Quality	Description
9	Excellent	Bright green color; firm, crisp and turgid.
7	Good	Minor defects present but not objectionable. Drying of cut stem surface. Gives slightly in middle when compressed.
5	Average	No longer crisp and turgid; gives easily in middle when compressed. Water loss apparent on stem and blossom ends.
3	Poor	Soft, with slight shrivelling near ends. May show irregular yellowing or paleness of green color.
1	Unmarketable	Soft and flabby. Noticeable shrivelling at ends. May show irregular yellowing.

The color of studied samples was expressed in CIELAB color space using a Minolta Spectrophotometer (CM-3500d, Japan) where L* defines lightness, a* describes the red/green coordinate and b* the yellow/blue value. The equipment was calibrated against standard ceramic white and black tiles. The total color difference (ΔE) was stated as a single value using the following equation:

$$\Delta E = \sqrt{(\Delta L^2) + (\Delta a^2) + (\Delta b^2)} \tag{4}$$

where $\Delta L = L^* - L^*_o$; $\Delta a = a^* - a^*_o$; $\Delta b = b^* - b^*_o$; and the $L^*_o a^*_o b^*_o$ values were defined as the initial color values of the freshly harvested produce. Triplicate readings were taken for each of the individual samples to obtain a better representation of its color.

Weight loss (WL), another important quality attribute, was quantified using the formula:

$$WL = 100 * \left(W_i - W_f\right) / W_i \tag{5}$$

where W_i and W_f were the initial and the final weight of the produce calculated before and after treatment.

Firmness or texture evaluation was measured using the Instron Universal Testing Machine (Model 4502, Instron, Canton, MA, USA). A compression test was carried out with 5 mm diameter probe, a crosshead speed of 5 mm/min and a maximum load cell of 50N. For each replicate of the experiment, a total of three readings were acquired for every sample and an averaged firmness was registered.

6.5 RESULTS AND DISCUSSION

6.5.1 Quantification of quality loss

The first step in quantifying the quality loss was to calculate the proportionality constant "k_L" for different quality attributes. Table 6.4 shows the relationship between calculated values obtained by interpolation and values of $(1/y)^2$ and $(y)^2$ and their losses for LB and SB respectively. As seen, the coefficient of determination R^2 is close to 1 for all quality attributes indicating that the regression line perfectly fits the observed data. Values of the constant "k_L" were then determined which corresponds to the slope in each linear equation. For firmness and quality index, values of "k_L" were 3363.80 and 708.09, respectively whereas for weight and color, they were 0.04 and 0.12, respectively.

Table 6.4 Values of the proportionality constant "k_L" for each quality attribute.

Quality attribute	Linear equation	R^2	k_L
Firmness	$L = 3363.8(1/y)^2 - 4.7779$*	0.99	3363.8
Quality Index	$L = 708.09(1/y)^2 + 2.0768$	0.87	708.09
Weight loss	$L = 0.0411(y)^2 + 1.0359$	0.99	0.04
Color difference	$L = 0.1243(y)^2 + 1.4372$	0.97	0.12

*L is the measured loss and y is the studied quality attribute

Substituting "k_L" values in equations 1 and 2, the quantity of loss was then found for all quality parameters in all 9 experiments used in the Taguchi design as demonstrated in Table 6.5 and illustrated in Figure 6.1. The results revealed that even at the very early stages after harvesting (test 1), the fresh cucumber had lost some of its quality, mainly in terms of firmness (loss = 13.68 units) and quality index (loss = 8.74 units). This loss continued at an exponentially increasing rate as long as the produce was exposed to undesirable environmental conditions during handling process. In theory, the only time when the loss is equal to zero is when the cucumber fruit is still attached to its mother plant and a minimum loss occurs when the produce is placed under its optimum conditions. According to Taguchi, loss increases as long as the distance of the population mean from the target increases (Wang et al., 2012). From the literature, the Taguchi approach provides an efficient way to determine the optimum conditions of a process that result in higher quality and minimum loss of a product (Oztop et al. 2007; Trabelsi et al. 2006). For this, another study was carried out by the authors, where the Taguchi approach was applied to establish the optimum conditions of the postharvest storage of cucumber and the corresponding target values for each quality attribute obtained when the produce was stored under these conditions. Therefore, the target values of cucumbers were 16.95 N, 9 points, 0.57% and 0.71 for firmness, quality index, weight loss and color difference, respectively.

Table 6.5 Values of loss for observed quality attribute used in L-9 Taguchi tests.

Test	Firmness (N)	Loss	Quality Index	Loss	Weight Loss (%)	Loss	Color Difference	Loss
1	15.68	13.68	9	8.74	0.6	0.01	0.74	0.07
2	8.82	43.27	5.33	24.89	20.78	17.75	7.93	7.81
3	12.06	23.12	4	44.26	11.91	5.83	3.16	1.24
4	15.79	13.49	7.33	13.17	0.9	0.03	2.66	0.88
5	7.68	56.98	6	19.67	23.99	23.65	6.7	5.57
6	7.95	53.27	3	78.68	22.44	20.7	11.13	15.39
7	14.03	17.08	7	14.45	2.6	0.28	4.89	2.98
8	8.66	44.82	1.67	254.91	34.82	49.84	8.71	9.42
9	7.17	65.37	3.33	63.73	23.12	21.96	2.53	0.8

The Taguchi loss function was applied to cucumber quality characteristics where larger is better in the case of firmness and quality index, and smaller the better in case of weight loss and total color difference. As illustrated in the first 2 plots of Figure 6.1, in case of the LB target, only the left side of the curve was applicable, whereas in the other 2 plots, in case of the SB target, the right side of the curve was relevant. At firmness equal to 15.68 N, the loss was equivalent to 13.68 units. However, when the cucumber had lost its firmness by half (7.68 N), the loss value was increased by almost 4 times (56.98 units). In terms of quality index, it was noticed that even when the score was high (QI = 9 points), the produce had also lost 8.74 units of its quality. A plausible explanation of this was that in many cases quality index was assessed subjectively based on rating scales. However, in reality the produce had undergone some losses even though it was difficult to detect during the quality evaluation. This was a great indicator that the Taguchi approach can provide a robust and consistent method to measure the most unseen quality losses during postharvest handling of fresh fruits and vegetables. Moreover, the graph showed that when the quality index dropped to 1.67 points, the loss was increased by almost 30 times more (loss = 254.91 units). This indicated how large the extent of loss could be when the fresh cucumber was stored under undesirable conditions and was affected by undesirable environmental factors.

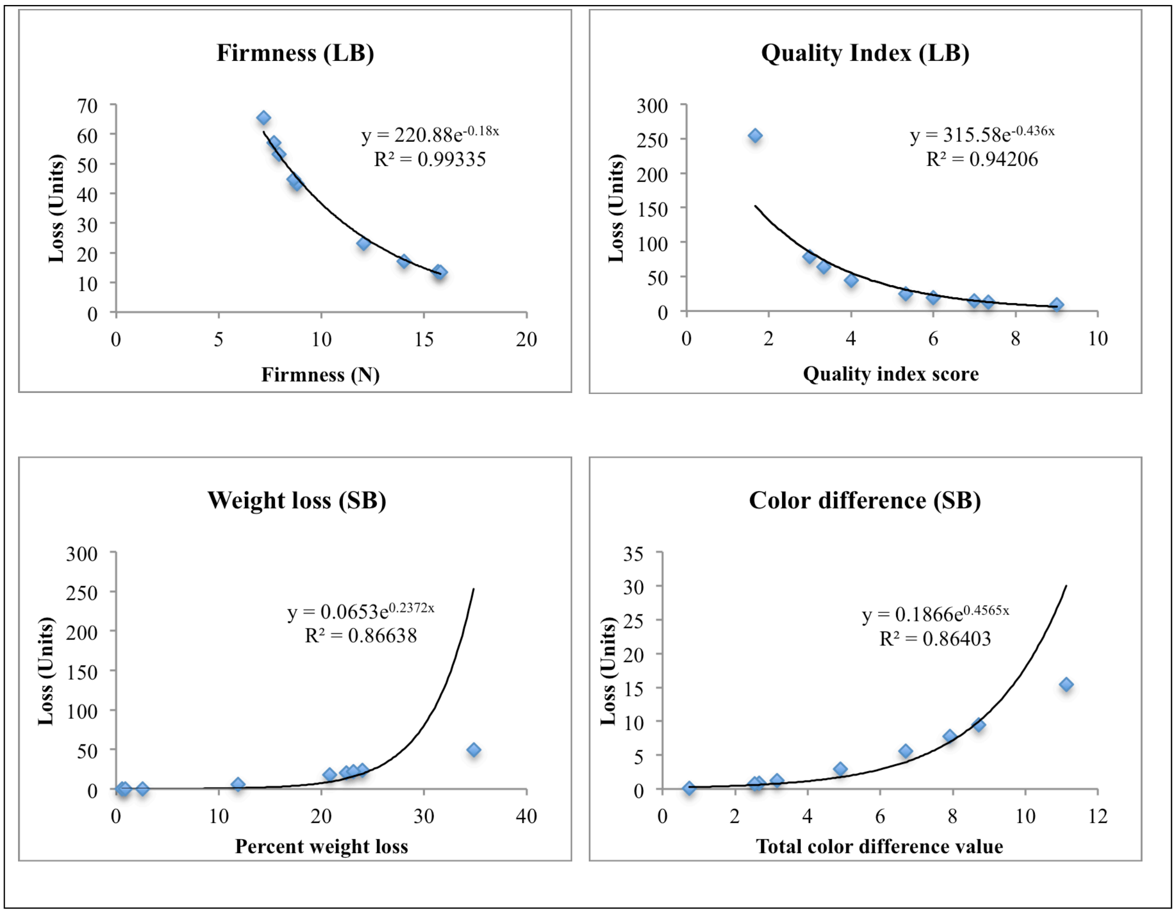

Figure 6.1 Taguchi quadratic loss functions obtained for all quality attributes. (LB=larger the better, SB=smaller the better)

A similar scenario with a lower extent of loss was observed for weight and color attributes. As the percent weight loss and the total color difference increased, the loss increased too. A remarkable increase in loss was noticed at higher values of both quality attributes, which revealed for the second time the amount of damage caused to a produce's quality through a continuous increase in weight loss and color change. The Taguchi technique proved its validity one more time by consistently quantifying the quality loss of a fresh produce.

6.5.2 Percent influence

The environmental conditions under which fresh horticultural commodities are produced, transported and displayed have a significant effect on the keeping quality of the foods and the amount that is lost. Therefore, the quality retention or degradation of cucumber was directly related to the percent influence of extrinsic factors investigated in this study. As presented in Table 6.6, the factor "time" was the main driver causing quality loss of cucumber. Hence, the handling process duration for fresh fruits and vegetables should be kept at its minimum in order to maintain high quality (Kader et al., 2004). The firmness attribute was influenced at 77.5% by time followed by approximately 9.5% for both temperature and light. According to the results, the factor humidity had a negligible influence on firmness of fresh cucumber. In terms of the quality index parameter, 46.5% of loss was due to time, followed by 18% due to temperature. In this study, results also revealed that light and relative humidity had both almost an equal influence (~11.5%) on the keeping quality of the produce. Besides, it is important to mention that around 12% of the quality index loss was due to other factors that happened during postharvest process. These factors could be handling practices or errors occurred during the experiments. Weight loss seemed to be affected mostly by time with 60.07%, followed by 29.10% due to humidity. Temperature and light were shown to have less influence on increasing the weight loss of the cucumber studied. On a different note, light appeared to have a major influence in maintaining color of cucumber, thus, continuous exposure of the crop to direct light was responsible by about 34% in increased color loss during storage. Time was the major factor causing color loss with 45% followed by 17% for temperature. Finally, the percent influence of environmental factors on quality loss differs between crops, geographies, growing conditions, and along the different segments in the supply chain.

Table 6.6 Percentage influence (P_i) and analysis of variance calculations of environmental factors for each quality attribute studied.

Quality Attribute	Factor	Sum of Squares	Variance	F Ratio	Pi (%)
Firmness	Temperature	18.41	9.20	49.90	9.57
	Time	146.37	73.18	396.82	77.43
	Humidity	2.78	1.39	7.52	1.28
	Light	17.68	8.84	47.93	9.18
	Other/Error	3.32	0.18		2.54
Quality Index	Temperature	111.56	55.78	20.83	18.14
	Time	277.98	138.99	51.91	46.57
	Humidity	75.99	37.99	14.19	12.06
	Light	71.71	35.85	13.39	11.33
	Other/Error	48.20	2.68		11.89
Weight Loss	Temperature	424.10	212.05	14.91	7.32
	Time	3465.70	1732.85	121.88	60.07
	Humidity	1680.01	840.00	62.39	29.10
	Light	181.07	90.54	6.37	3.11
	Other/Error	15.77	0.88		0.39
Total Color Difference	Temperature	225.66	112.83	54.98	16.71
	Time	595.90	297.95	145.19	44.63
	Humidity	13.08	6.54	3.19	0.68
	Light	454.53	227.27	110.74	33.97
	Other/Error	36.94	2.05		4.02

6.5.3 Quality prediction

Predicting food quality degradation is considered an important step for stakeholders to make better decisions regarding the control and reduction of postharvest quality loss of fresh produce. Using the Taguchi approach, it was possible to predict quality outcomes of different combinations of factors/levels and to generate the corresponding prediction expressions. Using ANOVA, it was possible to calculate a measure of goodness-of-fit of the linear regression. Figure 6.2 illustrated the Taguchi predictions versus the measured values of combinations used in this study for each quality attribute. For all four plots, the values of R^2 were between 0.92 and 0.98, which provided a good measure of how well the observed data were matching with the statistical model.

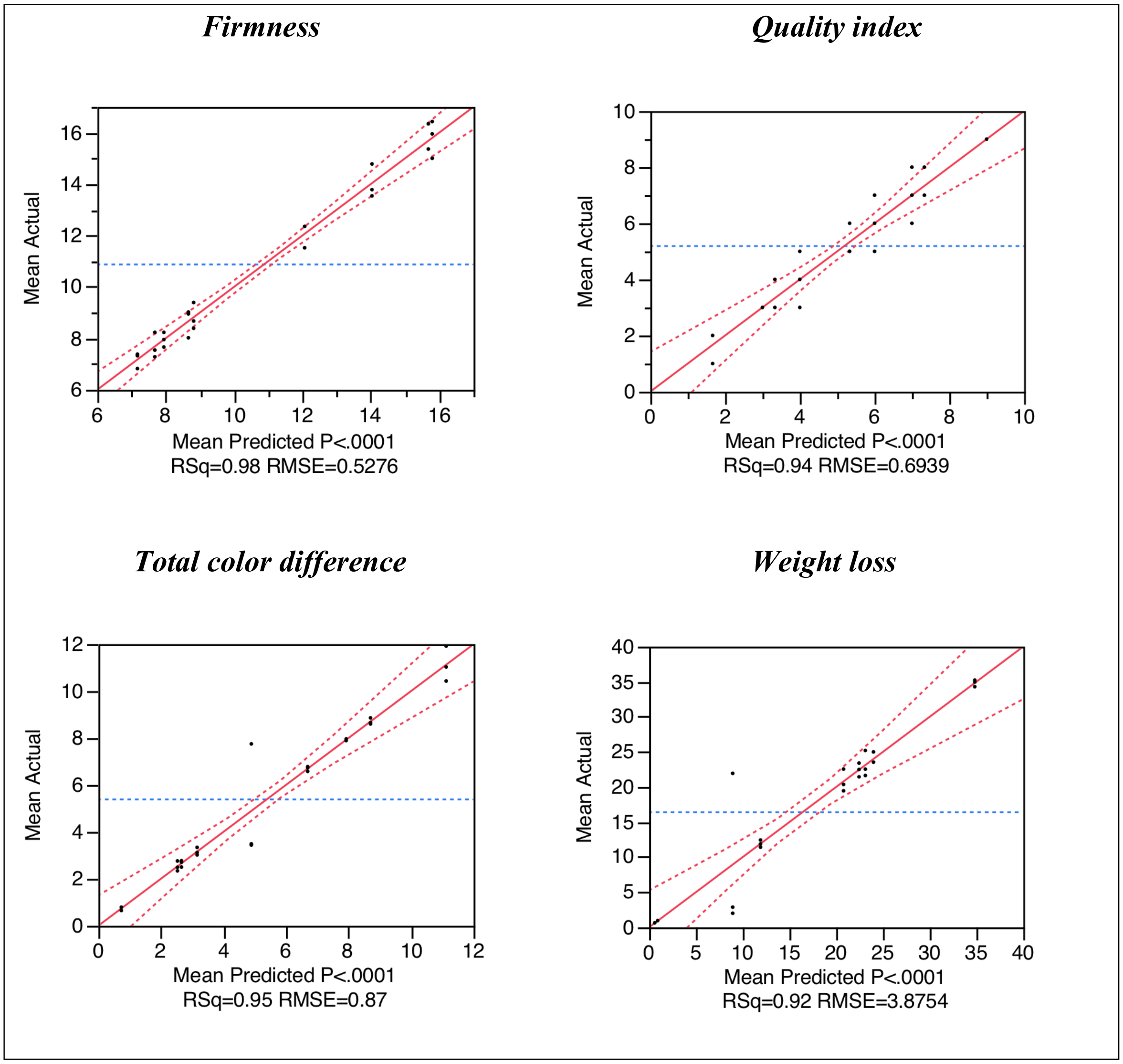

Figure 6.2 Plots of Taguchi predictions against actual (measured) values used in this analysis.

Consequently, the Taguchi method was able to predict the quality of cucumber at different storage conditions; therefore, it can be used effectively as a method for predicting the outcome in other storage and supply chain settings aimed at enhancing food quality and curtailing postharvest losses of fresh produce. Using the JMP statistical software, the prediction expressions were determined as follows:

$$Firmness = 10.87 + \left| \begin{array}{l} "1" \Rightarrow +1.31 \\ "2" \Rightarrow -0.39 \\ "3" \Rightarrow +0.91 \end{array} \right| \left[Temperature\ level \right] + \left| \begin{array}{l} "1" \Rightarrow +4.29 \\ "2" \Rightarrow -2.48 \\ "3" \Rightarrow -1.81 \end{array} \right| \left[Time\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -0.11 \\ "2" \Rightarrow -0.27 \\ "3" \Rightarrow +0.38 \end{array} \right| \left[Humidity\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -0.69 \\ "2" \Rightarrow -0.60 \\ "3" \Rightarrow +1.30 \end{array} \right| \left[Light\ level \right]$$

$$Quality\ Index = 5.18 + \left| \begin{array}{l} "1" \Rightarrow +0.92 \\ "2" \Rightarrow +0.26 \\ "3" \Rightarrow -1.18 \end{array} \right| \left[Temperature\ level \right] + \left| \begin{array}{l} "1" \Rightarrow +2.59 \\ "2" \Rightarrow -0.85 \\ "3" \Rightarrow -1.74 \end{array} \right| \left[Time\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -0.63 \\ "2" \Rightarrow +0.15 \\ "3" \Rightarrow +0.48 \end{array} \right| \left[Humidity\ level \right] + \left| \begin{array}{l} "1" \Rightarrow +0.92 \\ "2" \Rightarrow -0.07 \\ "3" \Rightarrow -0.85 \end{array} \right| \left[Light\ level \right]$$

$$Total\ Color\ Difference = 5.38 + \left| \begin{array}{l} "1" \Rightarrow -1.44 \\ "2" \Rightarrow +1.44 \\ "3" \Rightarrow -0.01 \end{array} \right| \left[Temperature\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -2.62 \\ "2" \Rightarrow +2.39 \\ "3" \Rightarrow +0.22 \end{array} \right| \left[Time\ level \right] + \left| \begin{array}{l} "1" \Rightarrow +1.47 \\ "2" \Rightarrow -1.01 \\ "3" \Rightarrow -0.46 \end{array} \right| \left[Humidity\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -2.06 \\ "2" \Rightarrow +2.06 \\ "3" \Rightarrow -0.54 \end{array} \right| \left[Light\ level \right]$$

$$Weight\ Loss = 16.38 + \left| \begin{array}{l} "1" \Rightarrow -5.29 \\ "2" \Rightarrow -0.61 \\ "3" \Rightarrow +5.90 \end{array} \right| \left[Temperature\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -12.91 \\ "2" \Rightarrow +10.14 \\ "3" \Rightarrow +2.76 \end{array} \right| \left[Time\ level \right] + \left| \begin{array}{l} "1" \Rightarrow +2.89 \\ "2" \Rightarrow -1.45 \\ "3" \Rightarrow -1.44 \end{array} \right| \left[Humidity\ level \right] + \left| \begin{array}{l} "1" \Rightarrow -0.49 \\ "2" \Rightarrow +0.99 \\ "3" \Rightarrow -0.51 \end{array} \right| \left[Light\ level \right]$$

Each predicted quality attribute was a function of all four studied factors including temperature, time, humidity and light. So by selecting the level for each factor in this research, it was possible to calculate the predicted quality of the stored cucumber. These models could also be used to predict the resulting quality for other combinations not used in the Taguchi L-9 orthogonal arrays. As mentioned earlier, the full factorial design for this study is composed of 81 experiments, however, only 9 were recommended by the Taguchi design. Accordingly, using those prediction equations, the cucumber quality could be predicted for the remaining 72 different combinations. These results confirmed the ability of the Taguchi technique to predict postharvest quality loss of any other crop in response to different combinations of factors and their levels.

6.6 CONCLUSIONS

For the first time, the Taguchi approach was used as a new technique to quantify postharvest quality loss of cucumber during the handling process. This approach made it possible to quantify the loss for all combinations used in this experiment and to demonstrate how large the magnitude of loss could be when fresh cucumbers were stored under undesirable conditions of environmental factors. Using this approach, the percent influence of studied factors on each quality attribute was also determined permitting to pinpoint the main causes of produce's quality degradation. Furthermore, the Taguchi method has proven its robustness for predicting the outcome quality of stored cucumber for any factor/level combinations used in this study. This work has provided an important tool that allows for the closing of major gaps in the knowledge for measuring postharvest losses of fresh produce and the prediction of the outcome of different storage and distribution conditions, aiming to increase fresh-market food availability and to enhance postharvest quality management.

CONNECTING TEXT

The preceding chapter demonstrated the ability of Taguchi's approach to quantify postharvest quality loss of fresh produce and to show how large the magnitude of loss could be when the crop is stored under undesirable conditions of environmental factors. For this, it was necessary to enhance quality loss management aiming to reduce the loss and maintain high and consistent quality of the produce. In the next chapter, Taguchi technique is applied to optimize postharvest handling of eggplant by reducing the variability into the product caused by environmental factors.

CHAPTER 7. OPTIMIZATION OF POSTHARVEST HANDLING OF EGGPLANT USING THE TAGUCHI TECHNIQUE

7.1 ABSTRACT

Fresh fruits and vegetables are highly perishable plant produce and can undergo varying degrees of stress during postharvest handling process if exposed to undesirable environmental conditions, resulting in major qualitative and quantitative losses. Quality is a complex multidimensional parameter; therefore, quality loss is typically more difficult to reduce than quantitative. For the first time, Taguchi's approach was used as a novel technique to optimize postharvest handling process to minimize quality loss of fresh eggplant (*Solanum melongena* L.). To date Taguchi's approach has been widely and successfully used in various subject areas such as: aerospace, communications, environment, construction, energy, materials manufacturing, mechanical engineering, food processing and dental science. No application of Taguchi's approach to postharvest quality loss has been reported until the present time. This approach was able to quantify the quality for all combinations of environmental factors and their corresponding levels used in this experiment and were expressed in terms of Signal-to-Noise ratios. For each quality attribute, the highest ratio was determined which corresponded to the least variability of the noise factors (T, RH, Light & time) around the desired target of this attribute. Taguchi's method was proven to be able to identify optimum conditions of uncontrollable factors throughout the handling process of eggplant. The technique could enhance postharvest quality management from field to fork and alleviate quality loss of fresh fruits and vegetables. Finally, Taguchi's technique could be recommended as a robust design of quality in postharvest technology and could be applied to many other crops exposed to various environmental conditions.

7.2 INTRODUCTION

Fresh fruits and vegetables are living systems that continue to be active metabolically after harvest (Gajewski et al. 2009; Kader et al. 2004). They readily lose their quality if not handled properly as they move from farm to fork. Eggplant (*Solanum melongena* L.), commonly known also as aubergine, is best grown in tropical and sub-tropical areas (Concellón et al. 2007; Loose et al. 2014) and is considered among the most important horticultural crops in terms of its economic and nutritional values worldwide (FAO, 2013; Okmen et al. 2009). According to recent statistics from the Food and Agriculture Organization (FAO), the global production of eggplant was 48MT in 2012 occupying an area of 1,853,023 ha. Usually eggplants are egg-shaped or globular and have bright green calyces, firm texture and dark purple skins (Gross et al. 2014). They are highly perishable plant produce and can undergo varying degrees of stress during the postharvest handling process if exposed to undesirable environmental conditions, resulting in major quality and quantity losses (Gajewski et al. 2009; Ghidelli et al. 2014). The major environmental influences that affect the quality of foods include temperature, humidity and direct sunlight exposure (Luning et al. 2009). In tropical countries, cold storage facilities are limited and below the required capacity. Long-term storage is not practiced for most kinds of fruits and vegetables (Smith et al. 2000; Van Dijk et al. 2012). In most tropical countries, postharvest infrastructure (cold storage facilities, refrigerated transport, packinghouses, etc.) are either scarce or not functioning properly.

Temperature can be detrimental for the quality of fresh produce (Concellón et al. 2007). Kader (2002) stated that temperature is the major environmental factor that affects the deterioration rate of non-chilling sensitive commodities. For each increase of 10^0C above optimum conditions, the rate of degradation increases by 2 to 3 times. Exposing harvested commodity to elevated temperature can initiate a favorable environment for pathogens to grow and cause serious safety issues for consumers. Moreover, storing crops at high temperatures was demonstrated to be the driver behind accelerated respiration and transpiration rates, which can further deteriorate the postharvest quality of the produce. Precooling the commodity immediately after harvest can alleviate the effect of high temperature on crop losses and extend their shelf life (Cortbaoui et al. 2005; Vigneault et al. 2007). Relative humidity is another environmental factor that can cause serious quality loss to fresh commodities. The rate of water loss from the fruits and vegetables is greatly dependent on the percent of moisture present in the surrounding air; the lower the relative humidity the higher the water loss (Kader, 2002; Watkins, 2003). Undesirable humidity results not only in direct quantitative losses (weight loss) but also in qualitative losses such as wilting, shrivelling and softening (FAO, 2007; Hung et al. 2011). The recommended commercial storage for eggplant is set generally for less than 14 days at 10-12^0C and 90 to 95%RH (Gross et al.

2014). Light is also one of the most important factors affecting the phytonutrient content in many produces rich in antioxidants (like eggplant) and can cause harmful effects on produce quality (Alcock et al. 2013; Xiao et al. 2014a). Sanz et al. (2009) have shown that accelerated degradation in quality and reduced shelf life was observed with stored asparagus under continuous lighting conditions. Further studies carried out by other researchers (Braidot et al. 2014; Martinez-Sanchez et al. 2011) revealed that light could also promote browning of fresh-cut lettuce.

Quality has multidimensional perspectives that underlines the various definitions and concepts of quality based on different views among end users (Luning et al. 2009). Quality can be seen from a product-based view as a function of a specific measurable variable, from a user-based view as what the consumer wants and from a value-based view as the relationship of usefulness to price (Batt, 2006; Luning et al. 2009). Defining quality is very difficult and complex and, therefore, there is no one definition that describes quality (Luning et al. 2009; Roy, 2001). A commonly accepted definition is that "*quality is meeting or exceeding customer and consumer expectations*" (Luning et al. 2009). In the case of fresh fruits and vegetables, the consumer's quality perception is mainly focused on intrinsic quality attributes such appearance, color, size, shape, firmness and freshness (Florkowski et al. 2014). Food quality management is therefore essential to ensure the performance of a product and production quality. The concept of quality management was initiated by Walter Shewhart and modified by Edward Deming to help companies increase their quality and productivity (Luning et al. 2009). The Deming's philosophy was to increase product quality by reducing the uncertainty and variation in product development and process design (PMBOK, 2013). In addition to other philosophers such as Juran and Crosby, another guru in quality management, Genichi Taguchi, provided a specific tool to improve the product as well as the process by which it is made (Luning et al. 2009; PMBOK, 2013).

The Taguchi method is an approach associated with robust quality management that combines engineering and statistical methods in order to reduce commodity loss and improve its quality (Ross, 1996; Taguchi, 1993). Taguchi stated that maintaining the high quality of a commodity would require reducing variations around the "target" by achieving consistency of performance (Roy, 2001). For him, every commodity has a target value. Therefore, minimizing quality loss of a product could be achieved through reducing the variability around a target instead of just meeting customer specifications. For the purpose of this study, this variability is caused by environmental factors (temperature, light and relative humidity) throughout the postharvest handling process of the fresh produce. The Taguchi technique is a form of “design of experiment” or DOE (Roy, 2001). For this, Taguchi has developed several fractional factorial experiments (FFE) matrices that could be used for special applications. This method has generally been adopted to optimize the design parameters of a process and significantly minimize the overall testing time and experimental costs. Taguchi showed that FFE could be used not only to maintain quality, but also to quantify it (Roy, 2001). For this purpose, he created a number of special orthogonal arrays, each of which is used for a number of experimental situations (Maghsoodloo et al. 2004).

To analyze the quality loss of a commodity, Taguchi had developed the signal-to-noise *(S/N)* ratio (Ross, 1996; Roy, 2001; Wang et al. 2012). This ratio helps to assure a design that is robust under the influence of noise or environmental factors (Taguchi, 1993). In other words, the best product will only respond to signals and will be immune to noise factors (Sadeghi et al. 2012). Therefore, the goal of the quality loss reduction effort can be stated as targeting to maximize the signal-to-noise *(S/N)* ratio for the respective product.

To date the Taguchi approach has been widely and successfully used in various subject areas. Sadeghi et al., (2012) had applied the Taguchi approach in environmental sciences where they assessed soil erosion as affected by soil texture, slope, aspect and vegetation cover. Other researchers (Oztop et al., 2007) used the Taguchi technique in food engineering to optimize the microwave frying process of potato slices. The Taguchi method was also recommended in the biotechnology field to optimize virus yields for vaccine production (Trabelsi et al., 2006). From the literature, the Taguchi approach was found to be successfully applied in construction too to determine the best conditions to obtain the physical properties that will lead to the most durable concretes (Tukmen et al., 2008). This approach was also used in many other research areas including energy (Zeng et al., 2010), aerospace (Singaravelu et al., 2009), sports (Burton et al., 2010) and manufacturing (Dingal et al., 2008; Emadi et al., 2008). No application of the Taguchi approach to postharvest quality loss has been reported until the present time. This research study attempted to use the Taguchi technique to reduce the variations of extrinsic factors (temperature, relative humidity, and light) over time on characteristic properties or intrinsic quality attributes of eggplant by optimizing postharvest handling process to maintain the highest quality and minimize losses.

7.3 OBJECTIVES

The main objective of this study was to enable the identification of optimum environmental conditions to minimize postharvest loss along the food supply process. This was achieved through (1) finding the highest signal-to-noise ratio for different storage combinations using the Taguchi approach and (2) acquiring the best factor/level combinations for each quality attribute for eggplant.

7.4 MATERIALS AND METHODS

7.4.1 Plant material and storage simulation

Samples were obtained from Lufa farms (Montreal, Canada), a local year-round supplier of fruits and vegetables. The samples were labeled and separated into experimental units of similar quantity for further analysis. A storage simulation experiment was carried out afterwards in controlled environment chambers (Conviron Inc., PGR15, Manitoba, Canada) to evaluate postharvest quality loss of fresh produce stored at different conditions of temperature (T), relative humidity (RH) and light according to the Taguchi design. With an internal capacity of 2.2 m^3, the chambers were fully programmable to monitor set factors (temperature and light). The chamber was capable of maintaining temperature in the range between 10 and 45^oC. Airflow inside the unit was distributed uniformly upward using air distribution plenum (Conviron, 2014) that allowed up to 0.5 m^3/min of air exchange. Light intensity in the chamber was maintained up to 875 micromoles/m^2/s or 64750 lux using fluorescent and incandescent lamps. This is the typical average of light intensity during a sunny day.

7.4.2 Experimental design

The Taguchi experimental design was developed and carried out using the JMP v.11 statistical software. The first step in this design of experiment (DOE) was to select the key environmental factors along with their levels. These factors were responsible for causing variability around the quality target of each produce during the handling process. For the purpose of this study, four factors including storage temperature (^0C), age of produce corresponding to the time of storage (days), exposure to direct light related to the presence or absence of luminosity during 12 hrs/day and relative humidity or RH (%) were selected. As demonstrated in Table 7.1, three different levels were chosen for each factor as follow: temperature (10, 20 and 30^{o}C), relative humidity (75, 85 and 95%), daily light (0, 12 and 24 hours) and time (1, 5 and 10 days). Based on Taguchi's technique, the experiment used 4 three-level factors and an L-9 orthogonal array. A full factorial experimental design gives 3^4 = 81 possible combinations or experimental trials. Using the fractional factorial in Taguchi's approach, only 9 experiments with different combinations were needed and conducted as shown in Table 7.2. To seek out the best design among many combinations, the JMP statistical software was used. The entire experiment was conducted in three replicates.

Table 7.1 Selected factors and their levels recommended for this study (eggplant).

Factor	Level		
	1	**2**	**3**
A: Temperature (^{0}C)	10	20	30
B: Time (days)	1	5	10
C: Relative Humidity (%)	75	85	95
D: Light	No Light	12 hrs. Light / no Light	Light

Table 7.2 Different combinations according to Taguchi L-9 orthogonal array (eggplant).

Test	Combination				Factor			
					Temperature	**Time**	**Humidity**	**Light**
Test 1	1	1	1	1	10	1	75	No
Test 2	1	2	2	2	10	5	85	No/Yes
Test 3	1	3	3	3	10	10	95	Yes
Test 4	2	1	2	3	20	1	85	Yes
Test 5	2	2	3	1	20	5	95	No
Test 6	2	3	1	2	20	10	75	No/Yes
Test 7	3	1	3	2	30	1	95	No/Yes
Test 8	3	2	1	3	30	5	75	Yes
Test 9	3	3	2	1	30	10	85	No

An analysis of signal-to-noise ratio was carried out to evaluate the results. For eggplant, quality attributes such as weight loss and total color difference have "smaller the better" quality characteristics since the reduction of postharvest loss is greater when the produce still maintains its fresh color, and loses less moisture during handling. However, quality parameters like firmness and quality index were best desired to have "larger the better" type of measurement because the consumer will always prefer to purchase a firmer and higher quality eggplant. Subsequently, the signal-to-noise ratio was computed based on the following formulas (Ross, 1996; Roy, 2001):

$$\frac{S}{N} = -10Log_{10}\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \text{ for larger the better} \tag{1}$$

$$\frac{S}{N} = -10Log_{10}\left(\frac{1}{n}\sum y_i^2\right) \text{ for smaller the better} \tag{2}$$

where "n" is the number of observations or replicates of the particular commodity under the same experimental conditions, and y represents the respective values. Here "y" is the measured quality attribute for each experimental test. To determine the optimal conditions for minimizing quality loss, the mean S/N ratio of each factor (A, B, C, D) in each level (1, 2, 3) was computed using equation 3 (Sadeghi et al., 2012) and the maximum value of the mean S/N ratio of a certain factor among three levels indicated the optimum conditions.

$$(M)_{Factor=I}^{Level=i} = \frac{1}{n_{Ii}}\sum_{j=1}^{n_{Ii}}\left[\left(\frac{S}{N}\right)_{Factor=I}^{Level=i}\right]_j \tag{3}$$

For each quality attribute, an analysis of variance (ANOVA) was conducted to statistically evaluate the effect of different levels of environmental factors on postharvest quality of the produce. Verification and validation experiments were then conducted using optimum conditions.

7.4.3 Quality evaluation

Both initial (used as control) and final qualities after each storage combination were evaluated. The quality index (QI) was assessed for individual produce using a nine point hedonic scale for the subsequent parameters: symptoms of deterioration and limits of marketability. A quality index (Table 7.3) for eggplant summarizing all these parameters was determined and the total score for each parameter was calculated.

Table 7.3 Full description of quality index scales of eggplant.

Quality Index	Quality	Description
9	Excellent	Calyx of freshly dark green color, turgid appearance. Glossy skin and dark black in color. Firm in texture. Absence of major handling defects. Absence of decay.
7	Good	Green calyx, slightly wilting appearance. Skin reasonably glossy and black in color. Slight loss of firmness. Presence of minor handling defects. Absence of decay.
5	Average	Pale green calyx, wilted or slightly dry and brownish in color at its end. Dull skin and lightly browning. Slight softness in texture. Presence of decay and major handling defects.
3	Poor	Very pale calyx and brown in color, severe wilting or partly drying. Major browning in skin. Soft in texture. Presence of remarkable decay and major handling defects.
1	Unmarketable	Brown calyx, complete wilting or drying. Skin very brown in color. Very soft in texture. Presence of complete decay and severe handling defects.

Color of studied samples was expressed in CIELAB color space using a Minolta Spectrophotometer (CM-3500d, Japan) where L* defines lightness, a* describes the red/green coordinate and b* the yellow/blue value. The equipment was calibrated against standard ceramic white and black tiles. The total color difference (ΔE) was stated as a single value using the following equation:

$$\Delta E = \sqrt{\left(\Delta L^2\right) + \left(\Delta a^2\right) + \left(\Delta b^2\right)} \tag{4}$$

where $\Delta L = L^* - L^*_o$; $\Delta a = a^* - a^*_o$; $\Delta b = b^* - b^*_o$; and the $L^*_o a^*_o b^*_o$ values were defined as the initial color values of the freshly harvested produce. Triplicate readings were taken for each of the individual samples to obtain a better representation of its color.

Another important quality attribute such as weight loss (WL) was quantified using the formula:

$$WL = 100 * \left(W_i - W_f\right) / W_i \tag{5}$$

where W_i and W_f were the initial and the final weight of the produce calculated before and after treatment.

Firmness or texture evaluation was measured using the Instron Universal Testing Machine (Model 4502, Instron, Canton, MA, USA). A compression test was carried out with 5 mm diameter probe, a crosshead speed of 5 mm/min and a maximum load cell of 50 N. For the purpose of this study, the firmness was defined in terms of applied force (F) or load on the surface of the commodity and was expressed in Newton (N). For each replicate of the experiment, a total of three readings were acquired for every sample and an average firmness was registered.

7.5 RESULTS AND DISCUSSION

7.5.1 Signal-to-Noise ratio

Table 7.4 showed the highest and lowest S/N ratios (boldfaced) for each quality attribute among all different combinations used in the Taguchi design. For eggplant, test 1 resulted in higher S/N ratio for all quality parameters. Similarly, storing the eggplant for one day at elevated daytime temperatures and full light was also shown to maintain its color, weight, firmness and overall quality index. The results also revealed that the produce continued to maintain its fresh color (S/N = 2.95) after 5 days of storage at $10^{o}C$ and 85% RH under 12 hours of daily light. However, storage for longer period (10 days) at $20^{o}C$ caused a significant ($P < 0.05$) color loss (S/N = -15.61) when the eggplant was exposed to the same amount of light daily. From Table 7.4, a longer and continuous exposure to light dramatically reduced the S/N ratio as shown at $10^{o}C$ and $30^{o}C$ (tests 3 and 8). In terms of weight reduction during handling, factors such as high temperature, longer storage duration, low relative humidity in the surrounding environment and permanent light exposure were responsible for increased weight loss of eggplant (S/N = -27.15). Firmness response was decreased under $30^{o}C$ after 10 days (S/N = 2.59) and was not affected by the light factor. Similar to weight loss, the general quality index of the eggplant was affected by all noise factors as demonstrated in test 8 (S/N = 2.01).

Table 7.4 Results of signal-to-noise ratios for all test combinations.

Test	Factors				S/N *for*			
	Temperature (^{o}C)	Time (days)	Relative Humidity (%)	Light	Total Color Difference	Weight Loss	Firmness	Quality Index
Test 1	10	1	75	No	**4.49***	**25.31***	**16.05***	**19.08***
Test 2	10	5	85	No/Yes	2.95	-16.90	8.64	13.86
Test 3	10	10	95	Yes	-14.09	-14.54	4.42	13.98
Test 4	20	1	85	Yes	1.35	3.90	15.07	16.84
Test 5	20	5	95	No	-10.73	-12.87	6.75	14.31
Test 6	20	10	75	No/Yes	**-15.62****	-13.58	3.11	11.21
Test 7	30	1	95	No/Yes	3.76	11.50	14.45	16.31
Test 8	30	5	75	Yes	-14.99	**-27.16****	2.68	**2.01****
Test 9	30	10	85	No	-37.70	-20.03	**2.60****	9.20

* The highest S/N ratio
** The lowest S/N ratio

7.5.2 Optimum conditions

In this study, the optimization of the postharvest handling process seeks to reduce variability caused by environmental or noise factors in order to reduce quality loss of fresh commodity. By substituting S/N ratios from equations 1 and 2 into equation 3, the mean ratios for each factor in their different levels was obtained as illustrated in Figure 7.1. The results revealed that continuous exposure of direct light has significantly ($P < 0.05$) decreased the quality of the produce during storage. Similar effect to light, storing the eggplant at 75% RH showed a significant ($P < 0.05$) quality loss in terms of color change, firmness and general quality index. Therefore, low environmental humidity during postharvest handling is not suitable to maintain fresh quality of eggplant. Similar results were stated by Zaro et al. (2014b). Significant ($P < 0.05$) difference was also noticed between the three temperatures; storing the eggplant at elevated temperature (30^{o}C) caused major weight loss as well as losses in firmness and quality index compare to lower temperature (10^{o}C) with the exception of color where major loss happened at 20^{o}C. In addition to all the above, the factor time has demonstrated to be a major driver for quality degradation during postharvest process. Significant ($P < 0.05$) increase in loss occurred after 5 days of harvesting and continued to increase for longer storage period. However, a different scenario was observed in the case of weight loss, where, the eggplant has shown a higher reduction in its weight after only 5 days of storage.

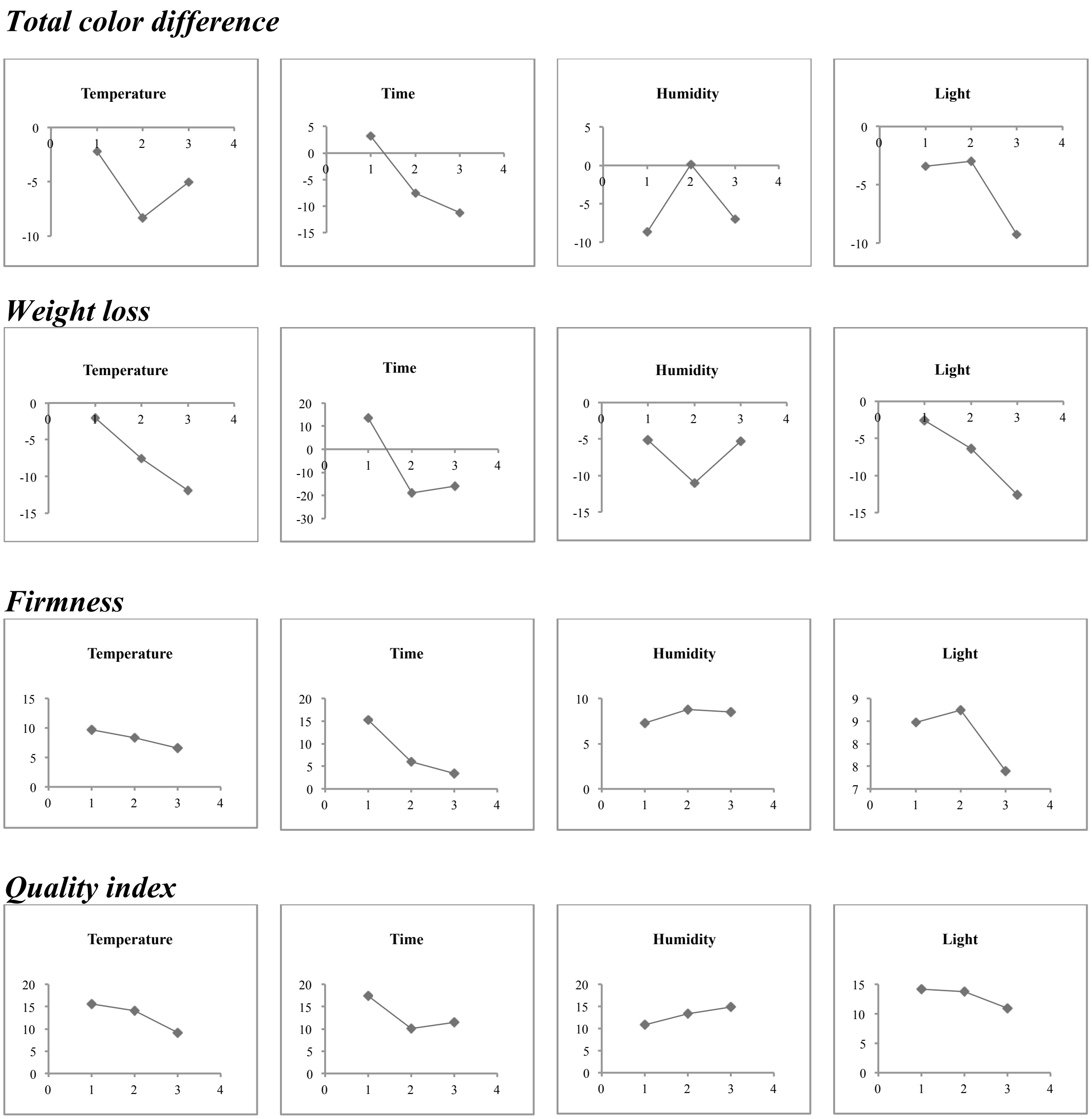

Figure 7.1 Graphical representation of means S/N ratios for all factors at different levels.

Then by selecting the highest mean ratios (peak values) for the same factor among its 3 levels (Figure 7.1), this allowed for the determination of the optimum conditions for handling of eggplant that best retain their quality. Therefore, the optimal environmental settings to minimize color loss for the study crop were at 10^{o}C and 85% RH for 1 day under an interval of 12 hours of lightness/darkness daily. In terms of weight loss, higher S/N ratios for eggplant resulted from combining A/1-B/1-C/3-D/1 together. From the results obtained, the optimum conditions to provide firmer produce during postharvest handling process were achieved through storing the produce for 1 day at 10^{o}C and 85% RH with 12 hours daily light. Similar to optimal conditions of commercial storage for fresh eggplant (Gross et al., 2014), the Taguchi design recommended storing the produce for 1 day at 10^{o}C and 95% RH with no light exposure in order to obtain the best quality index of this crop during handling. It was also important to mention that the second best storage conditions to curtail postharvest quality loss and to maintain high quality index were found under storage for 10 days at 20^{o}C and 85% RH with a rotation of 12 hours daily light (A/2-B/3-C/2-D/2).

7.5.3 Verification experiment

A verification or validation experiment is usually the final step in any DOE. Therefore, in this study, a test including all combinations at optimum conditions of noise factors and their levels in response to different signals of quality loss was conducted in order to validate the Taguchi approach during the postharvest handling process. Confirmation experiments were carried out in triplicates for each quality attribute. As shown in Table 7.5, all S/N ratios obtained when storing the eggplant under optimum conditions not used previously in this Taguchi design were higher compared to the best test combinations used in L-9 orthogonal arrays. Storing the eggplant for 1 day after harvesting at a combination of 10^{0}C, 85% RH and 12 hours of light interval was shown to be a better strategy (S/N = 4.90) compared to 75% RH and absence of light (S/N = 4.48) for retaining less color difference and higher firmness of the produce. Likewise, maintaining the highest quality index and lowest weight loss for eggplant was found at A1/B/1/C2/D1 rather than A1/B/1/C1/D1 combinations.

Those results confirmed that the Taguchi technique was valid and excellent tool that allowed the researchers to gain more knowledge on better or alternative environmental handling conditions for fresh eggplant aiming to reduce its quality loss after harvest.

Table 7.5 Response of S/N ratios of best combination used in Taguchi experiments and optimum condition recommended by Taguchi design.

	Factor				*S/N*
	Temperature (^{o}C)	**Time (days)**	**Relative Humidity (%)**	**Light**	
Total Color Difference					
Test 1	10	1	75	No	4.48
Optimum Conditions	10	1	85	No/Yes	4.90
Weight Loss					
Test 1	10	1	75	No	25.30
Optimum Conditions	10	1	95	No	26.13
Firmness					
Test 1	10	1	75	No	16.04
Optimum Conditions	10	1	85	No/Yes	16.60
Quality Index					
Test 1	10	1	75	No	19.08
Optimum Conditions	10	1	95	No	19.08

7.6 CONCLUSIONS

For the first time, the Taguchi approach was used as a new technique to optimize the postharvest handling process and to minimize quality loss of fresh eggplant. This approach enabled the researchers to quantify the quality for all combinations used in this experiment and was expressed in terms of S/N ratios. The eggplant continued to maintain its fresh color (S/N = 2.95) after 5 days of storage at $10^{o}C$ and 85% RH under 12 hours of daily light. However, storage for longer period (10 days) at $20^{o}C$ caused a significant color loss (S/N = -15.61). Factors such as high temperature, longer storage duration, low relative humidity and permanent light exposure were responsible for increased weight loss of eggplant (S/N = -27.15). Firmness response was decreased under $30^{o}C$ after 10 days (S/N = 2.59) and was not affected by the light factor. Similar to weight loss, the quality index of the eggplant was affected by all noise factors (S/N = 2.01). The Taguchi method was proven to be able to identify optimum conditions of environmental or uncontrollable factors throughout the handling process of eggplant. Postharvest quality management is very complex, however, the Taguchi approach was an excellent statistical tool to manage the supply chain settings in a holistic manner rather than segregating it into independent segments. Consequently, this technique can enhance postharvest quality management from field to fork and alleviate quality loss of fresh fruits and vegetables. Finally, the Taguchi method could be recommended as a robust design of quality in postharvest technology and could be applied to many other crops exposed to various environmental conditions not studied in this work.

CHAPTER 8. GENERAL SUMMARY AND CONCLUSIONS

A fundamental problem that underlies food availability in many countries is the inefficient postharvest handling of fresh fruits and vegetables. This results in a high level of crop losses and major issues of food quality. Fresh fruits and vegetables are highly perishable plant produce and can undergo varying degrees of stress during postharvest handling process if exposed to undesirable environmental conditions, resulting in major qualitative and quantitative losses. Quality is a complex multidimensional parameter; therefore, quality loss is typically more difficult to reduce than quantitative. Effective postharvest quality management of food crops has definitely lead to increase food availability and therefore, alleviating food insecurity around the world. Increasing food availability through loss reduction is easier and less expensive than through increasing food production. This is especially true for some developing countries with limited agricultural land and water resources, and soil problems, among other limitations. This research study attempted to enhance postharvest management of fresh cucumber and eggplant through the application of reliable methodologies to effectively quantify postharvest quality losses.

Produce quality can be irreversibly damaged by exposing it to fluctuated temperature and light when moving along various segments in the supply chain. Results from PHS baseline surveys and MCW method revealed that high percentage of the crops harvested in St. Kitts-Nevis and Guyana is lost due to on-farm spoilage, sunlight, high temperatures and inappropriate handling at the retail level. There is a serious problem with regard to market access for small farmers, which compounds the problem of postharvest losses arising from limitations in postharvest technology. As the produce travelled throughout the supply chain, it started to lose significantly ($P < 0.05$) its freshness and its marketable value as well. These losses were due to inappropriate handling and exposure to undesirable environmental conditions.

Simulating experiments in laboratory showed that postharvest losses of quality attributes in dark purple eggplant were affected by constant and fluctuating storage temperature and light. Higher losses occurred at 30^{o}C under light exposure during a 10-day period. Storage at higher temperature decreased further the quality in fresh vegetables. The lower storage temperature (10^{o}C) delayed the quality changes over time. Similarly, light has a great influence on degrading quality same as high temperature under complete darkness. The utilization of wrapping material extended significantly ($P < 0.05$) the shelf life and maintained the quality of studied samples during the entire storage duration. Phytochemicals in plants are known for their potential health benefits, provide consumers with valuable antioxidant, anti-inflammatory, and anti-cancer benefits. Exposure to light showed also a similar influence on retention and/or degradation of phytochemical contents same as at higher temperatures. Fluctuating conditions right after harvesting and during the handling process caused greater phytonutrient losses than constant storage at $30^{o}C$ in the presence of light. Therefore, enhancing postharvest quality management from farm to fork through maintaining low temperature of $10^{0}C$ with complete darkness has proven to significantly ($P < 0.05$) reduce postharvest phytonutrient quality loss. Kinetic models were quite useful in predicting the changes of various quality attributes such as firmness, weight loss, quality index, color and phenolic content of fresh cucumber and eggplant during constant and fluctuating storage and therefore allowed for a better assessment of quality at each step along the supply chain.

For the first time, the Taguchi approach was used as a new technique to quantify postharvest quality loss of fresh crops during the handling process. The experimental design included the 4 three-level factors and an L-9 orthogonal array. The Taguchi loss function was used to quantify quality loss of fresh cucumber after each storage combination. The results revealed that fresh cucumber lost some of its quality attributes immediately after harvest. At firmness of 15.68 N, the loss was equivalent to 13.68 units. However, at 7.68 N firmness, the loss value was increased by almost 4 times (56.98 units). In terms of quality index, it was noticed that even when the score was high (QI = 9 points), the produce had lost 8.74 units of its quality. In theory, the only time when the loss is equal to zero is when the cucumber fruit is still attached to its mother plant. When the quality index dropped to 1.67 points, the loss was increased by almost 30 times more (loss = 254.91 units). The results showed how large the extent of loss could be when fresh cucumber is stored under undesirable conditions. The percent influence of studied factors on each quality attribute was also determined. For the overall quality, 46.5% of loss was due to time, followed by 18% due to temperature and 11.5% due equally to light and humidity. Results also confirmed the ability of the Taguchi technique to predict postharvest quality loss of fresh produce in response to different combinations of factors and their levels.

In addition, Taguchi's approach was proven to be able to identify the optimum conditions of environmental or uncontrollable factors throughout the handling process of eggplant. For each quality attribute, the highest S/N ratio was determined which corresponded to the least variability of the noise factors around the desired target of this attribute. Postharvest quality management is very complex, however, the Taguchi's approach was an excellent statistical tool to manage the supply chain settings in a holistic manner rather than segregating it into independent segments. Consequently, this technique can enhance postharvest quality management from field to fork and alleviate quality loss of fresh fruits and vegetables.

CHAPTER 9. CONTRIBUTION TO KNOWLEDGE

This thesis was designed to contribute to the scientific knowledge by enhancing postharvest quality management of fresh cucumber and eggplant, and following are few of several contributions of this research:

1. This work has provided an effective tool that allows for the closing of major gaps in the knowledge of quantifying postharvest quality changes of fresh produce as affected by temperature and light fluctuations during handling practices and the prediction of the outcome of different storage and distribution conditions, aiming to increase fresh-market food availability and to recommend best strategies to reduce postharvest losses of fruits and vegetables.

2. For the first time, the Taguchi approach was used as a new technique to quantify postharvest quality loss during the handling process. This approach was proved to be able to identify the optimum conditions of environmental or uncontrollable factors and to predict postharvest quality loss of fresh produce in response to different combinations of factors and their levels. Therefore, this technique could be recommended as a robust design of quality in postharvest technology and could be applied to many other crops exposed to various environmental conditions.

3. Reliable data on postharvest loss of some key horticultural crops along all segments of the supply chain were generated for the Caribbean regions using producer household surveys and modified count and weight method. These data will provide useful information for analyses and policy making on food availability in these regions.

4. A field-work protocol on postharvest quality loss was generated for the first time for Guyana and St. Kitts-Nevis. The developed document can be used for other crops and other countries in the region.

5. The utilization of food grade polyethylene wrapping film extended significantly ($P < 0.05$) the shelf life of cucumber and eggplant and maintained their quality during storage.

This technique can be recommended as an efficient and low-cost intervention to reduce postharvest loss of fresh produce especially in developing countries where cold storage is not practiced.

CHAPTER 10. RECOMMENDATIONS FOR FUTURE STUDIES

Starting from the famous quote for Edward Deming "*You can't manage what you don't measure*", this research investigated promising approaches to measure postharvest loss of fresh cucumber and eggplant to further enhance quality loss management during handling. Postharvest loss concept is extremely complex due to measurement problems and qualitative loss being more difficult to measure than quantitative, therefore, there is still a need for supplementary studies and understanding in this field. Following are some recommendations for future investigations:

1. Quality loss is a multidimensional concept and can be seen differently by different people. It is therefore recommended that this complex concept be more explored and defined.

2. Quantifying postharvest quality loss is extremely difficult due to the various factors affecting the quality after harvesting. Further research on effective and consistent methods to quantify postharvest loss and to generate reliable data is highly recommended.

3. For the first time, Taguchi's approach was successfully applied in postharvest management as a new technique to quantify quality loss and optimize handling process of fresh cucumber and eggplant as affected by environmental factors. Additional studies are necessary to apply Taguchi's approach to measure postharvest losses of other fresh horticultural crops. Furthermore, this method is strongly recommended to optimize postharvest handling practices as affected by other factors and levels such as: farm and farmer related factors, level of mechanization, distance to storage, quality of storage, processing plant related factors, quality of supply chain, use of standards and grading, firm and operator related factors, quality of packaging, transportation, retail outlet and manager related factors, quality of logistics and inventory control, and biological factors (respiration, transpiration, ethylene).

4. The optimization engineering that can be accomplished with the Taguchi method should be further investigated and compared with other optimization statistical method such as the Response Surface method for their efficiency, reliability, and accuracy.

5. Food grade polyethylene wrapping film has significantly reduced postharvest quality loss of fresh cucumber and eggplant stored under specific conditions of temperature, light and relative humidity. Other studies using various types and permeability of wrapping films are highly recommended under different storage conditions using different commodities.

REFERENCES

Ayala, F., Echavarri, J. F., Olarte, C., & Sanz, S. (2009). Quality characteristics of minimally processed leek packaged using different films and stored in lighting conditions. International Journal of Food Science and Technology, 44(7), 1333-1343.

Affognon, H., Mutlingi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis. World Development, 66, 49-68.

Agarwal, M., Kumar, A., Gupta, R., & Upadhyaya, S. (2012). Extraction of Polyphenol, Flavonoid from Emblica officinalis, Citrus limon, Cucumis sativus and Evaluation of their Antioxidant Activity. Oriental Journal of Chemistry, 28(2), 993-998.

Ainsworth, E. A., & Gillespie, K. M. (2007). Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin-Ciocalteu reagent. Nature Protocols, 2(4), 875-877.

Alarcón-Flores, M. I., Romero-González, R., Martínez Vidal, J. L., Egea González, F. J., & Garrido Frenich, A. (2014). Monitoring of phytochemicals in fresh and fresh-cut vegetables: A comparison. Food Chemistry, 142(0), 392-399.

Alcock, C. M., & Bertling, I. (2013). Effect of Light and Fruit Maturity on Postharvest Colour Change in Green 'Sondela' Peppers (Capsicum annuum L.). Ii All Africa Horticulture Congress, 1007, 171-177.

Aulakh, J., & Regmi, A. (2013). Postharvest food losses estimation: development of consistent methodology. Food and Agriculture Organization of the United Nations. 34 p.

Barker, T. B. (1990). Engineering quality by design : interpreting the Taguchi approach (Vol. 113). New York: M. Dekker. 250 p.

Batt, J. P. (2006). Quality Management: Food and Agriculture Organization of the United Nations. 166 p.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., & Giller, K. E. (2012). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Research, 132(0), 117-128.

Becker, B. R., & Fricke, B. A. (1996). Transpiration and respiration of fruits and vegetables. New Developments in Refrigeration for Food Safety and Quality, 110-121.

Bendell, A., Disney, J., & Pridmore, W. A. (1989). Taguchi methods : applications in world industry: IFS series in industrial management. 399 p.

Besterfield, D. H., Besterfield-Michna, C., Besterfield, G. H., & Besterfield-Sacre, M. (1995). Total Quality Management. New Jersey: A Simon & Schuster Company. 445 p.

Bhande, S. D., Ravindra, M. R., & Goswami, T. K. (2008). Respiration rate of banana fruit under aerobic conditions at different storage temperatures. Journal of Food Engineering, 87(1), 116-123.

Boivin, D., Lamy, S., Lord-Dufour, S., Jackson, J., Beaulieu, E., Cote, M., & Beliveau, R. (2009). Antiproliferative and antioxidant activities of common vegetables: A comparative study. Food Chemistry, 112(2), 374-380.

Boulekbache-Makhlouf, L., Medouni, L., Medouni-Adrar, S., Arkoub, L., & Madani, K. (2013). Effect of solvents extraction on phenolic content and antioxidant activity of the byproduct of eggplant. Industrial Crops and Products, 49, 668-674.

Bouzo, C. A., Travadelo, M., & Gariglio, N. F. (2012). Effect of Different Packaging Materials on Postharvest Quality of Fresh Fig Fruit. International Journal of Agriculture and Biology, 14(5), 821-825.

Box, G. (1988). Signal-to-Noise Ratios, Performance Criteria, and Transformations. Technometrics, 30(1), 1-17.

Braidot, E., Petrussa, E., Peresson, C., Patui, S., Bertolini, A., Tubaro, F., Zancani, M. (2014). Low-intensity light cycles improve the quality of lamb's lettuce (Valerianella olitoria [L.] Pollich) during storage at low temperature. Postharvest Biology and Technology, 90, 15-23.

Brocka, B., & Brocka, S. (1992). Quality management : implementing the best ideas of the masters.

Burden, J., & Wills, R. B. H. (Eds.). (1989). Prevention of post-harvest food losses fruits, vegetables and root crops Rome, Italy: Food and Agriculture Organization of the United Nations.

Burton, M., Subic, A., Mazur, M., & Leary, M. (2010). Systematic Design Customization of Sport Wheelchairs using the Taguchi Method. Engineering of Sport 8: Engineering Emotion - 8th Conference of the International Sports Engineering Association (Isea), 2(2), 2659-2665.

Buzby, C. J., Wells, F. H., Axtman, B., & Mickey, J. (2009). Supermarket Loss Estimates for Fresh Fruit, Vegetables, Meat, Poultry, and Seafood and Their Use in the ERS Loss-Adjusted Food Availability Data. Economic Information Bulletin (Vol. 44): United States Department of Agriculture. 26 p.

CARICOM Secretariat. (2011). Food security in CARICOM. CARICOM View Magazine. 37 p.

Cervera, S. S., Olarte, C., Echavarri, J., & Ayala, F. (2007). Influence of exposure to light on the sensorial quality of minimally processed cauliflower. Journal of Food Science, 72(1), S12-S18.

Compton, J. A. F., Floyd, S., Ofosu, A., & Agbo, B. (1998). The modified count and weigh method: An improved procedure for assessing weight loss in stored maize cobs. Journal of Stored Products Research, 34(4), 277-285.

Compton, J. A. F., & Sherington, J. (1999). Rapid assessment methods for stored maize cobs: Weight losses due to insect pests. Journal of Stored Products Research, *35*(1), 11.

Concellón, A., Anon, M. C., & Chaves, A. R. (2007). Effect of low temperature storage on physical and physiological characteristics of eggplant fruit (Solanum melongena L.). Lwt-Food Science and Technology, 40(3), 389-396.

Concellón, A., Zaro, M. J., Chaves, A. R., & 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(0), 35-41.

Conviron. (2014). http://www.conviron.com.

Cortbaoui, P. (2005). Assessment of precooling technologies for sweet corn. (M.Sc.), McGill University, Montreal, Canada. 106 p.

Cortbaoui, P., Goyette, B., Gariepy, Y., Charles, M. T., Raghavan, V. G. S., & Vigneault, C. (2005). Forced air cooling system for Zea mays. International Journal of Food, Agriculture & Environment, 4(1), 100-104.

Cruz, R. M. S., Vieira, M. C., & Silva, C. L. M. (2009). Effect of cold chain temperature abuses on the quality of frozen watercress (Nasturtium officinale R. Br.). Journal of Food Engineering, 94(1), 90-97.

Da Silva, C. A., Baker, D., Sheperd, A. W., Jenane, C., & Miranda-da-Cruz, S. (2009). Agro-industries for development. The Food and Agriculture Organization of the United Nations.

Dhall, R. K., Sharma, S. R., & Mahajan, B. V. C. (2012). Effect of shrink wrap packaging for maintaining quality of cucumber during storage. Journal of Food Science and Technology-Mysore, 49(4), 495-499.

Dingal, S., Pradhan, T. R., Sundar, J. K. S., Choudhury, A. R., & Roy, S. K. (2008). The application of Taguchi's method in the experimental investigation of the laser sintering process. International Journal of Advanced Manufacturing Technology, 38(9-10), 904-914.

Dixon, J., Gulliver, A., & Gibbon, D. (2001). Farming Systems and Poverty: improving farmers' livelihoods in a changing world. FAO and World Bank.

Dora, M., Kumar, M., Van Goubergen, D., Molnar, A., & Gellynck, X. (2013). Food quality management system: Reviewing assessment strategies and a feasibility study for European food small and medium-sized enterprises. Food Control, 31(2), 607-616.

Ella, L., Zion, A., Nehemia, A., & Ammon, L. (2003). Effect of the ethylene action inhibitor 1-methylcyclopropene on parsley leaf senescence and ethylene biosynthesis. Postharvest Biology and Technology, 30, 8.

Emadi, B., Abbaspour-Fard, M. H., & Yarlagadda, P. K. D. V. (2008). Mechanical peeling of pumpkins. Part 1: Using an abrasive-cutter brush. Journal of Food Engineering, 89(4), 448-452.

Evans, J. R. and Lindsay, W. M. (2005). The management and control of quality. 6th edition. Thomson Corporation, South Western, Ohio, USA. 848 pp.

FAO-World Bank. (2010). Reducing post-harvest losses in grain supply chains in Africa. Report of FAO-World Bank workshop held from18-19th March.

FAO. (2002). Fruits and vegetables: an overview on socio-economical and technical issues. Agriculture and consumer Protection.

FAO. (2007). Safety and quality of fresh fruit and vegetables: a training manual for trainers. New York and Geneva: UNITED NATIONS.

FAO. (2011). Food loss reduction strategy: Rural infrastructure and agro-industries division. 8 p.

FAO. (2013). FAO Statistical Yearbook: World Food and Agriculture (S. division, Trans.). Rome: Food and Agriculture Organization of the United Nations.

FAO. (2014). Save Food: Global initiative on food losses and waste reduction. from http://www.fao.org/save-food

FAO/WHO. (2010). Assuring food safety and quality: guidelines for strengthening national food control systems. Food and Agriculture Organization of the United Nations. 76 p.

FAOSTAT. (2013). from http://faostat3.fao.org

Fennema, O. R., & Tannenbaum, S. R. (1996). Introduction to food chemistry. New York: Marcel Dekker, Inc. 16 p.

Florkowski, W. J., Shewfelt, R. L., Brueckner, B., & Prussia, S. E. (2014). Postharvest Handling: A Systems Approach (Third ed.): Elsevier Science Publishing Co Inc. 592 p.

Fonseca, S. C., Oliveira, F. A. R., & Brecht, J. K. (2002). Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. Journal of Food Engineering, 52(2), 99-119.

Ford, J. R. D. (1992). Guyana's food performance in a Caribbean context: Lessons for food security policy. Food Policy, 17(5), 326-336.

Gajewski, M., Katarzyna, K., & Bajer, M. (2009). The Influence of Postharvest Storage on Quality Characteristics of Fruit of Eggplant Cultivars. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 37(2), 200-205.

Garvin, D. A. (1984). What does product quality really mean? Sloan Management Review, 26, 25-43.

Ghidelli, C., Mateos, M., Rojas-Argudo, C., & Pérez-Gago, M. B. (2014). Extending the shelf life of fresh-cut eggplant with a soy protein–cysteine based edible coating and modified atmosphere packaging. Postharvest Biology and Technology, 95(0), 81-87.

Giannakourou, M. C., & Taoukis, P. S. (2003). Kinetic modelling of vitamin C loss in frozen green vegetables under variable storage conditions. Food Chemistry, 83(1), 33-41.

Golob, P., Farell, G., & Orchard, J. E. (2002). Postharvest science and technology, principles and practices: Blackwell Sciences.

Grolleaud, M. (2002). Post-harvest losses: Discovering the full story. From http://www.fao.org/docrep/004/AC301E/AC301E00.HTM

Gross, K. C., Yi Wang, C., & Saltveit, M. (2014). The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks: USDA, Agriculture Handbook Number 66.

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R., & Meybeck, A. (2011). Global Food Losses and Food Waste. Food and agriculture organization of the UNITED NATIONS.

Hanson, P. M., Yang, R. Y., Tsou, S. C. S., Ledesma, D., Engle, L., & Lee, T. C. (2006). Diversity in eggplant (Solanum melongena) for superoxide scavenging activity, total phenolics, and ascorbic acid. Journal of Food Composition and Analysis, 19(6-7), 594-600.

Hassan, F. A. S., & Mahfouz, S. A. (2010). Effect of 1-methylcyclopropene (1-MCP) treatment on sweet basil leaf senescence and ethylene production during shelf-life. Postharvest Biol. Technol., 55, 5.

Heldman, R. D. (2011). Food preservation process design: Elsevier Inc.

Hodges, R. J., Buzby, J. C., & Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. Journal of Agricultural Science, 149, 37-45.

Hoogerwerf, A., Simons, A. E., & Reinders, M. P. (1994). A systems view on horticultural distribution applied to the postharvest chain of cut flowers. Agricultural Systems, 44(2), 163-180.

Humphrey, J., & Memedovic, O. (2006). Global value chains in the agrifood sector. Vienna: United Nations Industrial Development Organization.

Hung, D. V., Tong, S., Tanaka, F., Yasunaga, E., Hamanaka, D., Hiruma, N., & Uchino, T. (2011). Controlling the weight loss of fresh produce during postharvest storage under a nano-size mist environment. Journal of Food Engineering, 106(4), 325-330.

IICA Secretariat. (2013). Post-harvest Losses in Latin America and the Caribbean: Challenges and Opportunities for Collaboration: Inter-American Institute for Cooperation on Agriculture.

Ismail, H. I., Chan, K. W., Mariod, A. A., & Ismail, M. (2010). Phenolic content and antioxidant activity of cantaloupe (cucumis melo) methanolic extracts. Food Chemistry, 119(2), 643-647.

ISO. (2014). International Standard Organization. From http://www.iso.org

Janave, M. T., & Sharma, A. (2005). Extended storage of gamma-irradiated mango at tropical ambient temperature by film wrap packaging. Journal of Food Science and Technology-Mysore, 42(3), 230-233.

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

Kader, A. A. (2005). Increasing food availability by reducing postharvest losses of fresh produce. Proceedings of the 5th International Postharvest Symposium, Vols 1-3(682), 2169-2175.

Kader, A. A. (2002). Postharvest Technology of Horticutlural Crops.

Kader, A. A. (2003). A perspective on postharvest horticulture (1978-2003). Hortscience, 38(5), 1004-1008.

Kader, A. A. (2004). Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce Paper presented at the 5th International Postharvest Symposium, Verona, Italy.

Kader, A. A., & Cantwell, M. (2010). Produce quality: rating scales and color charts Postharvest Horticulture Series No. 23: University of California, Davis.

Kader, A. A., & Rolle, S. R. (2004). The role of post-harvest management in assuring the quality and safety of horticultural produce (Vol. 152). Rome: Food and Agriculture Organization of the United Nations.

Kaur, C., Nagal, S., Nishad, J., Kumar, R., & Sarika. (2014). Evaluating eggplant (Solanum melongena L) genotypes for bioactive properties: A chemometric approach. Food Research International, 60(0), 205-211.

Kendall, P., & Petracco, M. (2009). The Current State and Future of Caribbean Agriculture. Journal of Sustainable Agriculture, 33(7), 780-797.

Kirca, A., & Cemeroglu, B. (2003). Degradation kinetics of anthocyanins in blood orange juice and concentrate. Food Chemistry, 81(4), 583-587.

Kitinoja, L., & AlHassan, H. Y. (2012). Identification of Appropriate Postharvest Technologies for Small Scale Horticultural Farmers and Marketers in Sub-Saharan Africa and South Asia - Part 1. Postharvest Losses and Quality Assessments. Xxviii International Horticultural Congress on Science and Horticulture for People (Ihc2010): International Symposium on Postharvest Technology in the Global Market, 934, 31-40.

Kitinoja, L., & Kader, A. A. (Eds.). (2002). Small-Scale Postharvest Handling Practices: A manual for Hoticultural Crops (4th ed. Vol. 8E). California, USA: University of California, Davis.

Knight, A., & Davis, C. (2007). What a waste! Surplus fresh foods research project, Retrieved from http://www.veoliatrust.org/docs/Surplus_Food_Research.pdf

Koester, U. (2013). Total and per capita value of food loss in the United States - Comments. Food Policy, 41, 63-64.

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., & Ward, P. J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Science of The Total Environment, 438(0), 477-489.

Kushwaha, S. G. (2010). Sustainable development through strategic green supply chain management. International Journal of Engineering and Management Sciences, 1(1), 7-11.

Lana, M. M., Tijskens, L. M. M., & van Kooten, O. (2005). Effects of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biology and Technology, 35(1), 87-95.

Lange, D. D., & Cameron, A. C. (1994). Postharvest Shelf Life of Sweet Basil (Ocimum basilicum). HortScience, 29, 2.

Laurin, E., Nunes, M. C. N., Brecht, J. K., & Emond, J. P. (2005). Vapor pressure deficit and water loss patterns during simulated air shipment and storage of Beit Alpha cucumbers. Proceedings of the 5th International Postharvest Symposium, Vols 1-3(682), 1697-1703.

Lin, C. H., & Chen, B. H. (2005). Stability of carotenoids in tomato juice during storage. Food Chemistry, 90(4), 837-846.

Liu, C. H., & Liu, Y. (2014). Effects of Elevated Temperature Postharvest on Color Aspect, Physiochemical Characteristics, and Aroma Components of Pineapple Fruits. Journal of Food Science, 79(12), C2409-C2414.

Loose, L. H., Maldaner, I. C., Heldwein, A. B., Lucas, D. D. P., & Righi, E. Z. (2014). Maximum evapotranspiration and crop coefficient of eggplant cultivated in plastic greenhouse. Revista Brasileira De Engenharia Agricola E Ambiental, 18(3), 250-257.

Lopez, J., Uribe, E., Vega-Galvez, A., Miranda, M., Vergara, J., Gonzalez, E., & Di Scala, K. (2010). Effect of Air Temperature on Drying Kinetics, Vitamin C, Antioxidant Activity, Total Phenolic Content, Non-enzymatic Browning and Firmness of Blueberries Variety OA ' Neil. Food and Bioprocess Technology, 3(5), 772-777.

Lundqvist, J., de Fraiture, C., & Molden, D. (2008). Saving water: from field to fork - Curbing losses and wastage in the food chain. SIWI policy brief.

Luning, A. P., & Marcelis, J. W. (2009). Food quality management: Technicological and managerial principles and practices: Wageningen Academic Publishers.

Maftoonazad, N., & Ramaswamy, H. S. (2008). Effect of pectin-based coating on the kinetics of quality change associated with stored avocados. Journal of Food Processing and Preservation, 32(4), 621-643.

Maghsoodloo, S., Ozdemir, G., Jordan, V., & Huang, C.-H. (2004). Strengths and limitations of taguchi's contributions to quality, manufacturing, and process engineering. Journal of Manufacturing Systems, 23(2), 73-126.

Manjunatha, M., & Anurag, R. K. (2014). Effect of modified atmosphere packaging and storage conditions on quality characteristics of cucumber. Journal of Food Science and Technology-Mysore, 51(11), 3470-3475.

Martinez-Sanchez, A., Tudela, J. A., Luna, C., Allende, A., & Gil, M. I. (2011). Low oxygen levels and light exposure affect quality of fresh-cut Romaine lettuce. Postharvest Biology and Technology, 59(1), 34-42.

Massa, G. D., Kim, H. H., Wheeler, R. M., & Mitchell, C. A. (2008). Plant productivity in response to LED lighting. Hort Science, 43, 5.

Matsubara, K., Kaneyuki, T., Miyake, T., & Mori, M. (2005). Antiangiogenic activity of nasunin, an antioxidant anthocyanin, in eggplant peels. Journal of Agricultural and Food Chemistry, 53(16), 6272-6275.

Memedovic, O., & Shepherd, A. (2009). Agri-food value chains and poverty reduction: overview of main issues, trends and experiences. United Nations Industrial Development Organization.

Mishra, B. B., Gautam, S., & Sharma, A. (2012). Browning of fresh-cut eggplant: Impact of cutting and storage. Postharvest Biology and Technology, 67(0), 44-51.

Moretti, C. L., Mattos, L. M., Calbo, A. G., & Sargent, S. A. (2010). Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review. Food Research International, 43(7), 1824-1832.

Mukherjee, P. K., Nema, N. K., Maity, N., & Sarkar, B. K. (2013). Phytochemical and therapeutic potential of cucumber. Fitoterapia, 84, 227-236.

Nachtigall, A. M., Da Silva, A. G., Stringheta, P. C., Silva, P. I., & Bertoldi, M. C. (2009). Correlation between spectrophotometric and colorimetric methods for the determination of photosensitivity and thermosensitivity of tomato carotenoids. Boletim do Centro de Pesquisa e Processamento de Alimentos, 27, 11-18.

Nair, V. N., Abraham, B., Mackay, J., Box, G., Kacker, R. N., Lorenzen, T. J., Wu, C. F. J. (1992). Taguchi Parameter Design - a Panel Discussion. Technometrics, 34(2), 127-161.

Namitha, K. K., & Negi, P. S. (2010). Chemistry and Biotechnology of Carotenoids. Critical Reviews in Food Science and Nutrition, 50(8), 728-760.

Nath, A., Bagchi, B., Misra, L. K., & C. Deka, B. (2011). Changes in post-harvest phytochemical qualities of broccoli florets during ambient and refrigerated storage. Food Chemistry, 127(4), 1510-1514.

Nourian, F., Ramaswamy, H. S., & Kushalappa, A. C. (2003). Kinetics of quality change associated with potatoes stored at different temperatures. Lebensmittel-Wissenschaft Und-Technologie-Food Science and Technology, 36(1), 49-65.

Okmen, B., Sigva, H. O., Mutlu, S., Doganlar, S., Yemenicioglu, A., & Frary, A. (2009). Total Antioxidant Activity and Total Phenolic Contents in Different Turkish Eggplant (Solanum Melongena L.) Cultivars. International Journal of Food Properties, 12(3), 616-624.

Olarte, C., Sanz, S., Echavarri, J. F., & Ayala, F. (2009). Effect of plastic permeability and exposure to light during storage on the quality of minimally processed broccoli and cauliflower. Lwt-Food Science and Technology, 42(1), 402-411.

Oztop, M. H., Sahin, S., & Sumnu, G. (2007). Optimization of microwave frying of potato slices by using Taguchi technique. Journal of Food Engineering, 79(1), 83-91.

Padda, M. S., & Picha, D. H. (2008). Effect of low temperature storage on phenolic composition and antioxidant activity of sweetpotatoes. Postharvest Biology and Technology, 47(2), 176-180.

Paull, R. (1999). Effect of temperature and relative humidity on fresh commodity quality. Postharvest Biology and Technology, 15(3), 263-277.

Pinheiro, J., Alegria, C., Abreu, M., Gonçalves, E. M., & Silva, C. L. M. (2013). Kinetics of changes in the physical quality parameters of fresh tomato fruits (Solanum lycopersicum, cv. 'Zinac') during storage. Journal of Food Engineering, 114(3), 338-345.

PMBOK. (2013). A Guide to the Project Management Body of Knowledge (Vol. Fifth edition): Project Management Institute.

Pyrotis, S., Abayomi, L., Rees, D., & Orchard, J. (2011). Effect of Temperature and Humidity on Strawberry Firmness at Two Different Sites in the Huelva Region of Spain. Xxviii International Horticultural Congress on Science and Horticulture for People (Ihc2010): International Symposium on Berries: From Genomics to Sustainable Production, Quality and Health, 926, 567-570.

Reardon, T., Barrett, C. B., Berdegué, J. A., & Swinnen, J. F. M. (2009). Agrifood Industry Transformation and Small Farmers in Developing Countries. World Development, 37(11), 1717-1727.

Ross, J. P. (1996). Taguchi techniques for quality engineering (2nd ed.).

Roy, K. R. (2001). Design of experiments using the Taguchi approach: 16 steps to product and process improvement. Canada: John Wiley & Sons.

Sadeghi, S. H., Moosavi, V., Karami, A., & Behnia, N. (2012). Soil erosion assessment and prioritization of affecting factors at plot scale using the Taguchi method. Journal of Hydrology, 448–449(0), 174-180.

Samtha, T., Shyamsundarachary, R., Sprinivas, P., & Ramaswamy, N. (2012). Quantification of total phenolic and total flavonoid contents in extracts of oroxylum indicum l.kurz. Asian Journal of Pharmaceutical and Clinical Research, 5(4).

Samuoliene, G., Sirtautas, R., Brazaityte, A., & Duchovskis, P. (2012). LED lighting and seasonality effects antioxidant properties of baby leaf lettuce. Food Chemistry, 134, 5.

Sanchez-Rangel, J. C., Benavides, J., Heredia, J. B., Cisneros-Zevallos, L., & Jacobo-Velázquez, D. A. (2013). The Folin–Ciocalteu assay revisited: improvement of its specificity for total phenolic content determination. Analytical Methods, 5, 5990-5999.

Sanz, S., Olarte, C., Ayala, F., & Echavarri, J. F. (2009). Evolution of Quality Characteristics of Minimally Processed Asparagus During Storage in Different Lighting Conditions. Journal of Food Science, 74(6), S296-S302.

Sharkey, P. J., & Peggie, I. D. (1984). Effects of high-humidity storage on quality, decay and storage life of cherry, lemon and peach fruits. Sci. Hortic., 23, 10.

Shewfelt, R. L. (1999). What is quality? Postharvest Biology and Technology, 15(3), 197-200.

Shin, Y., Liu, R. H., Nock, J. F., Holliday, D., & Watkins, C. B. (2007). Temperature and relative humidity effects on quality, total ascorbic acid, phenolics and flavonoid concentrations, and antioxidant activity of strawberry. Postharvest Biology and Technology, 45(3), 349-357.

Singaravelu, J., Jeyakumar, D., & Rao, B. N. (2009). Taguchi's approach for reliability and safety assessments in the stage separation process of a multistage launch vehicle. Reliability Engineering & System Safety, 94(10), 1526-1541.

Singleton, V. L., & Rossi Jr, J. A. (1965). Colorimetry of total phenolics with phosphomolybidic–phosphotungstic acid reagents. American Journal of Enology and Viticulture, 16, 144-158.

Sivakumar, D., Jiang, Y., & Yahia, E. M. (2011). Maintaining mango (Mangifera indica L.) fruit quality during the export chain. Food Research International, 44(5), 1254-1263.

Smith, L. C., El Obeid, A. E., & Jensen, H. H. (2000). The geography and causes of food insecurity in developing countries. Agricultural Economics, 22(2), 199-215.

Somner, N. F., Mitchell, F. G., Guillou, R., & Luvisi, D. A. (1960). Fresh fruit and transit injury. Am. Soc. Hortic. Sci., 76, 156±162.

Statistic Canada. (2015). The changing face of the Canadian fruit and vegetable sector: 1941 to 2011. from http://www.statcan.gc.ca

Sun, W. Q., Wang, D. B., Wu, Z. Z., & Zhi, J. R. (1990). Seasonal Change of Fruit Setting in Eggplants (Solanum-Melongena L) Caused by Different Climatic Conditions. Scientia Horticulturae, 44(1-2), 55-59.

Taguchi, G. (1993). Taguchi on Robust Technology Development: Bringing Quality Engineering Upstream.

Taguchi, G., Chowdhury, S., & Wu, Y. (2005a). Taguchi's Quality Engineering Handbook. Canada: John Wiley & Sons, Inc.

Taguchi, G., Chowdhury, S., & Wu, Y. (2005b). Introduction to the Quality Loss Function Taguchi's Quality Engineering Handbook (pp. 169-179): John Wiley & Sons, Inc.

Taguchi, G., Chowdhury, S., & Wu, Y. (2005c). Introduction to the Signal-to-Noise Ratio Taguchi's Quality Engineering Handbook (pp. 221-238): John Wiley & Sons, Inc.

Thompson-Colón, Theresa and Sonia Laszlo. 2013. Producer Household Survey: Methodology Report for the Baseline Survey Data Collection in Guyana, St. Lucia, Trinidad-Tobago, and St. Kitts-Nevis. CIFSRF CARICOM Project (Technical Report), McGill University, Quebec, Canada.

Thompson, A. K. (2003). Fruit and vegetables: harvesting, handling and storage (2nd ed.): Blackwell Publishing Ltd.

Tiwari, B. K., Brunton, N. P., & Brennan, C. S. (2013). Handbook of plant food phytochemicals: sources, stability and extraction. Oxford, UK: Wiley-Blackwell.

Trabelsi, K., Rourou, S., Loukil, H., Majoul, S., & Kallel, H. (2006). Optimization of virus yield as a strategy to improve rabies vaccine production by Vero cells in a bioreactor. Journal of Biotechnology, 121(2), 261-271.

Trotman, A., Gordon, R. M., Hutchinson, S. D., Singh, R., & McRae-Smith, D. (2009). Policy responses to GEC impacts on food availability and affordability in the Caribbean community. Environmental Science & Policy, 12(4), 529-541.

Tukmen, I., Gul, R., & Celik, C. (2008). A Taguchi approach for investigation of some physical properties of concrete produced from mineral admixtures. Building and Environment, 43(6), 1127-1137.

Uchino, T., Nei, D., Hu, W. Z., & Sorour, H. (2004). Development of a mathematical model for dependence of respiration rate of fresh produce on temperature and time. Postharvest Biology and Technology, 34(3), 285-293.

United Nations. (2004). World population to 2300 Economic and social affairs: United Nations.

United Nations. (2013). From http://www.un.org

United, Nations. (2005). Household Sample Surveys in Developing and Transition Countries. New York: Department of Economic and Social Affairs.

Van Dijk, M. P., & Trienekens, J. (2012). Global value chains: Linking local producers from developing countries to international markets. Amsterdam: European Association of Development Research and Training Institutes.

Vigneault, C., Goyette, B., Gariepy, Y., Cortbaoui, P., Charles, M. T., & Raghavan, V. G. S. (2007). Effect of ear orientations on hydrocooling performance and quality of sweet corn. Postharvest Biology and Technology, 43(3), 351-357.

Wang, J.-M., Yan, H.-J., Zhou, J.-M., Li, S.-X., & Gui, G.-C. (2012). Optimization of parameters for an aluminum melting furnace using the Taguchi approach. Applied Thermal Engineering, 33–34(0), 33-43.

Watkins, C. B. (2003). Crop Management and Postharvest Handling of Horticultural Products. Postharvest Biology and Technology, 29(3), 353.

WFS. (1996). Rome Declaration on World Food Security.: World Food Summit.

WHO. (2012). World population growth: from 2008 to 2050.

World Bank. (2011). Missing food: The case of postharvest grain losses in Sub-Saharan Africa (pp. 116). Washington, DC: The World Bank.

Xiao, Z. L., Lester, G. E., Luo, Y. G., Xie, Z. H., Yu, L. L., & Wang, Q. (2014a). Effect of light exposure on sensorial quality, concentrations of bioactive compounds and antioxidant capacity of radish microgreens during low temperature storage. Food Chemistry, 151, 472-479.

Xiao, Z. L., Luo, Y. G., Lester, G. E., Kou, L. P., Yang, T. B., & Wang, Q. (2014b). Postharvest quality and shelf life of radish microgreens as impacted by storage temperature, packaging film, and chlorine wash treatment. Lwt-Food Science and Technology, 55(2), 551-558.

Xu, X. Y., Li, W. D., Lu, Z. H., Beta, T., & Hydamaka, A. W. (2009). Phenolic Content, Composition, Antioxidant Activity, and Their Changes during Domestic Cooking of Potatoes. Journal of Agricultural and Food Chemistry, 57(21), 10231-10238.

Yahia, E. (2005). Postharvest technology of food crops in the near east and north africa (nena) region. Crops: Growth, Quality and Biotechnology.

Zaro, M. J., Chaves, A. R., Vicente, A. R., & Concellón, A. (2014a). Distribution, stability and fate of phenolic compounds in white and purple eggplants (Solanum melongena L.). Postharvest Biology and Technology, 92, 70-78.

Zaro, M. J., Keunchkarian, S., Chaves, A. R., Vicente, A. R., & Concellón, A. (2014b). Changes in bioactive compounds and response to postharvest storage conditions in purple eggplants as affected by fruit developmental stage. Postharvest Biology and Technology, 96(0), 110-117.

Zeng, M., Tang, L. H., Lin, M., & Wang, Q. W. (2010). Optimization of heat exchangers with vortex-generator fin by Taguchi method. Applied Thermal Engineering, 30(13), 1775-1783.

Zhang, Y. Z., Zhang, M. L., & Yang, H. Q. (2015). Postharvest chitosan-g-salicylic acid application alleviates chilling injury and preserves cucumber fruit quality during cold storage. Food Chemistry, 174, 558-563.

APPENDICES

Appendix 1. Producer household survey questionnaire

B4. What is [HOUSEHOLD HEAD]'s age?
B5. Is [HOUSEHOLD HEAD] male or female?
B6. What is [HOUSEHOLD HEAD]'s marital status?
B7. Is [HOUSEHOLD HEAD] currently in school?
B8. In what level of education is [HOUSEHOLD HEAD] enrolled?
B9. What is [HOUSEHOLD HEAD]'s highest level of education achieved?
B10. What ethnic group do you think best classifies [HOUSEHOLD HEAD]?
C1. How would you best describe this dwelling?
C2. What is the main material used for outer walls?
C3. How many rooms are occupied by this household, exclude verandas, kitchens, and bathrooms?
C4. What type of toilet facilities are used by your household?
C5. Does this household rent, own, or lease this dwelling?
C6. Does this household rent, own, or lease the land on which this dwelling is located?
C7. What is the main source of drinking water for your household?
C8_1. Does your household have access to [1] TELEPHONE, USING LAND LINE?
C8_2. Does your household have access to [2] MOBILE OR CELLULAR TELEPHONE?
C8_3. Does your household have access to [3] INTERNET?
I1_1. How many acres of land do you operate for [1] crops in open field?
I1_2. How many acres of land do you operate for [2] crops in greenhouse(s)?
I1_3. How many acres of land do you operate for [3] livestocks?
I2_1. How many years have you been [1] farming in open fields?
I2_2. How many years have you been [2] farming in greenhouse(s)?
I2_3. How many years have you been [3] raising livestocks?
I3. Temporary food crops harvested in the past 12 months [Recoded using FAO categories]
I3_1. Temporary food crops- total months harvested
I4. Forage crops harvested in the past 12 months [Recoded using FAO categories]
I4_1. Forage crop total months harvested
I5. Permanent crop harvested in the past 12 months [Recoded using FAO categories]
I5_1. Permanent crop total months harvested
I6. Do you operate any land previously used for permanent crops such as banana, sugar cane, others?
I7. How many years ago did you stop producing permanent crops?
I8_1. Would you say that Lack of Finance is a major constraint for your successful production?
I8_2. Would you say that Lack of Information is a major constraint for your successful production?
I8_3. Would you say that Lack of Technical Assistance is a major constraint for your successful production?
I8_4. Would you say that Weeds, Pests, Diseases are a major constraint for your successful production?
I8_5. Would you say that Humidity, Heat is a major constraint for your successful production?
I8_6. Would you say that Flooding is a major constraint for your successful production?
I8_7. Would you say that Drought is a major constraint for your successful production?

I8_8. Would you say that Larceny is a major constraint for your successful production?
I8_9. Would you say that Animal Attacks are a major constraint for your successful production?
I8_10. Would you say that Government Agricultural Policy is a major constraint for your successful production?
I8_11. Would you say that Timely Availability of Inputs is a major constraint for your successful production?
I8_12. Would you say that Marketing is a major constraint for your successful production?
I8_13. Would you say that Farm Accessibility is a major constraint for your successful production?
I9. In the past 12 months, what type of record keeping system did you keep?
K3. Ownership of this plot of land… ?
K4. Is the co-owner a HH member?
K5. Which HH member manages this plot?
K6. Which HH member has cultivation right on this plot?
K7. What is the area of the plot (in acres)?
K8. What type of business in this?
K9. Is this plot for…?
K10. Is most of the plot watered?
K11. How many crops do you grow on this plot?
K12. List up to four crops grown in this plot, starting with the main crop.
K17. Describe the topography of this land.
L2. In the past 12 months, what crops did you harvest?
L3. How long (Years) have you been planting CROP?
L4. Was CROP produced in?
L8. In the past 12 months, did you keep some of the harvest for planting material?
L10. Of the crops harvested in the past 12 months, did you give some away?
L12. In the past 12 months, did you keep some of the harvest of CROP for consumption in your household?
L13. Did you use some of the harvest of CROP to pay in kind?
L16_1. Do you store your CROP after harvest?
L16_2. Do you store your CROP after harvest? - WHERE
T2a_1. Where is the most likely location you sell VEGETABLES?
T2b_1. Where is the second most likely location you sell VEGETABLES?
T2a_2. Where is the most likely location you sell FRUIT?
T2b_2. Where is the second most likely location you sell FRUIT?
T2a_3. Where is the most likely location you sell VEGETABLE BY-PODUCTS OR FRUIT BY-PRODUCTS?
T2b_3. Where is the second most likely location you sell VEGETABLE BY-PODUCTS OR FRUIT BYPRODUCTS?
T3. In general, who does most of the marketing?
T4. In general, who goes to the market?
T5_1. At harvest, do you usually use [1] BAGS?
T5_2. At harvest, do you usually use [2] CARTS?
T5_3. At harvest, do you usually use [3] CRATES?
T5_4. At harvest, do you usually use [4] TRAILERS?
T5_5. At harvest, do you usually use [5] BOXES?

T5_6. At harvest, do you usually use [6] OTHER?
T6. At harvest, is it new?
T7. At harvest, is it cleaned before using?
T8. For selling, do you usually use INPUT?
T9. For selling, is it new?
T10. For selling, is it cleaned before using?
T11. In general, who does most of the marketing?
T12_1. In general, what mode of transportation do you use to sell your product? [1] ON FOOT
T12_2. In general, what mode of transportation do you use to sell your product? [2] BICYCLE OR CART
T12_3. In general, what mode of transportation do you use to sell your product? [3] CAR/TRUCK/BUS
T12_4. In general, what mode of transportation do you use to sell your product? [4] BUYER PICK-UP
T13. Do you currently have contracts with your buyers?
T14_1. In the past 12 months, which crop was your highest income earner?
T14_2. In the past 12 months, which crop was your second highest income earner?
T14_3. In the past 12 months, which crop was your third highest income earner?
T15_1. In general, who in your household keeps and decides what to do with the sales earnings first?
T15_2. In general, who in your household keeps and decides what to do with the sales earnings second?

Appendix 2. Controlled chambers at McGill University

Appendix 3. Fresh crops inside the controlled chamber

Appendix 4. Instron universal testing machine

Appendix 5. UV –VIS spectrophotometer

Appendix 6. Freeze dryer