SHELF-LIFE EXTENSION AND POSTHARVEST QUALITY IMPROVEMENT OF TOMATO (*Solanum lycopersicum* L.) USING PRE- AND POSTHARVEST TREATMENTS

By

MOHAMMAD NURUN NABI MAZUMDER

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

This thesis is dedicated to my lovely parents my beloved mother and my late father (who died during the period of my study) who always kept praying for me to achieve my goal

To my family members of wife, sons, brothers, and sisters

and

To all of my supervisors, colleagues, and friends who supported me all the time of the study period

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August 2022

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Tomato (*Solanum lycopersicum* L.) is a popularly consumed and mostly cultivated vegetable fruit all over the world. For the fresh market, tomatoes are typically hand-harvested due to their delicate skins and their need to be picked at optimal ripeness. Tomatoes are highly perishable and poor postharvest handling contributes to huge losses of as high as 20%. Therefore, this study was conducted to determine the effects of pre- and postharvest calcium chloride ($CaCl_2$) treatments along with gamma irradiation on the growth, yield, quality, and shelf life of lowland tomato varieties in Malaysia. In the first experiment, four tomato varieties known as MT-1, MT-3, 303, and 105 were selected and applied with foliar $CaCl_2$ (0.0, 1.0, 1.5, and 2.0%, w/v) in the morning after one week of fruit initiation for agronomical traits. Application of 2% $CaCl_2$ was demonstrated as the most effective to control the physiological disorder like blossom end rot of 303 and 105 varieties. The $CaCl_2$ minimized the weight loss (30%) and declined the disease incidence and disease severity by maintaining the firmness of MT-3 tomato fruits. After harvesting, all the fruits were kept at ambient conditions (28 ± 2°C and 75 ± 5% RH) for 20 days. Among all the varieties, MT-3 along with 2% $CaCl_2$ performed better in maintaining the postharvest quality and was able to extend the shelf-life up to 2- 4 days by increasing the fruit firmness, declining the rate of respiration and ethylene production. The different maturity stages of tomato respond differently to $CaCl_2$, the second experiment was conducted to investigate the effects of different maturity stages and postharvest dipping with 0.0, 1.0, 1.5, and 2.0% of $CaCl_2$ (w/v) for 10 minutes on postharvest performance, antioxidant and plant defence enzyme activity stored at ambient conditions (28 ± 2°C and 75 ± 5% RH). Fruits of mature green stage treated with 2% $CaCl_2$ significantly declined ethylene production (15.53%) and delayed colour development by declining the lycopene content (45%) as well as accelerating the defence enzyme activities as compared to control. The final experiment was involved with mature green stage of MT3 tomatoes that had been inoculated with *Fusarium solani* and then exposed to gamma radiations (0.0, 1.0, 2.0, and 3.0 kGy) in order to extend shelf life. The fruits were then stored at ambient conditions (28 ± 2°C and 75 ± 5% RH) for 15

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days. The higher doses of 3 kGy resulted in a significant reduction of ethylene (41.23%), respiration (38.77%), non-marketable fruits (71.23%), and physiological weight loss (28.47%) than the control and lower doses samples.

Additionally, the gamma radiations in the highest doses (3.0 kGy), prolong the shelf-life by up to 2- 4 days than the control and lower doses samples. In storage conditions, the tomato fruits increase the defence enzymes activity of POD (25.67%), PPO (17.33%), and PAL (21.58%) at 3.0 kGy relative to that of control samples. In conclusion, the application of pre-and postharvest $CaCl_2$ on MT-3 (harvested at mature green) could effectively extend the postharvest shelf life for up to 4 days when held at ambient temperature. Besides that, gamma radiation at 3.0 kGy can be successfully used to minimize the losses due to fungal infection, especially *Fusarium solani*, which leads to the extension of the shelf-life of tomato fruits.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMANJANGAN HAYAT DAN PENINGKATAN KUALITI LEPAS TUAI TOMATO (*Solanum lycopersicum* L.) MENGGUNAKAN RAWATAN PRA DAN LEPAS TUAI

Oleh

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Tomato (*Solanum lycopersicum* L.) adalah buah sayuran yang popular dimakan dan kebanyakannya ditanam di seluruh dunia. Untuk pasaran segar, tomato biasanya dituai dengan tangan kerana kulitnya yang halus dan keperluannya untuk dipetik pada tahap kematangan optimum. Tomato sangat mudah rosak dan pengendalian lepas tuai yang lemah menyumbang kepada kerugian besar setinggi 20%. Oleh itu, kajian ini dijalankan untuk menentukan kesan rawatan kalsium klorida ($CaCl_2$) pra dan selepas tuaian berserta penyinaran gamma terhadap pertumbuhan, hasil, kualiti dan jangka hayat varieti tomato tanah pamah di Malaysia. Dalam eksperimen pertama, empat varieti tomato yang dikenali sebagai MT-1, MT-3, 303, dan 105 telah dipilih dan disembur menggunakan $CaCl_2$ (0.0, 1.0, 1.5, dan 2.0%, w/v) pada waktu pagi selepas satu minggu permulaan buah untuk ciri-ciri agronomi. Semburan menggunakan 2% $CaCl_2$ telah adalah yang paling berkesan untuk mengawal gangguan fisiologi seperti reput hujung bunga bagi 303 dan 105 varieti. $CaCl_2$ meminimumkan penurunan berat badan (30%) dan mengurangkan kejadian penyakit dan keterukan penyakit dengan mengekalkan ketegasan buah tomato MT-3. Selepas penuaian, ke semua buah disimpan pada persekitaran ambien (28 ± 2°C dan $75 \pm$ 5% RH) selama 20 hari. Di antara semua varieti, MT-3 bersama 2% $CaCl_2$ menunjukkan prestasi yang lebih baik dalam mengekalkan kualiti lepas tuai dan dapat memanjangkan jangka hayat sehingga 2- 4 hari dengan meningkatkan ketegasan buah, mengurangkan kadar respirasi dan pengeluaran etilena. Peringkat kematangan tomato yang berbeza bertindak balas secara berbeza terhadap $CaCl_2$, eksperimen kedua dijalankan untuk menyiasat kesan peringkat kematangan yang berbeza dan celupan selepas tuai dengan 0.0, 1.0, 1.5, dan 2.0% $CaCl_s$ (w/v) selama 10 minit ke atas prestasi lepas tuai, antioksidan dan aktiviti enzim pertahanan tumbuhan yang disimpan pada keadaan ambien (28 ± 2°C dan 75 ± 5% RH). Buah-buahan peringkat hijau matang yang dirawat dengan 2% $CaCl_2$ telah merosot dengan ketara dari segi pengeluaran etilena (15.53%) dan melambatkan perkembangan warna dengan mengurangkan kandungan likopena (45%) serta mempercepatkan aktiviti enzim pertahanan berbanding dengan kawalan. Sinaran gamma digunakan untuk tujuan kebersihan dan fitosanitari yang boleh

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memanjangkan jangka hayat; percubaan akhir dilakukan dengan peringkat hijau matang tomato MT3 yang disuntik dengan *Fusarium solani* dan kemudian terdedah kepada sinaran gamma (0.0, 1.0, 2.0, dan 3.0 kGy). Buah-buahan kemudiannya disimpan pada keadaan persekitaran ambien (28 ± 2°C dan $75 \pm$ 5% RH) selama 15 hari. Dos 3 kGy yang lebih tinggi menghasilkan pengurangan ketara etilena (41.23%), pernafasan (38.77%), buah-buahan tidak boleh dipasarkan (71.23%), dan penurunan berat badan fisiologi (28.47%) daripada sampel kawalan dan dos yang lebih rendah. Selain itu, sinaran gamma dalam dos tertinggi (3.0 kGy), memanjangkan jangka hayat sehingga 2-4 hari daripada sampel kawalan dan dos yang lebih rendah. Dalam keadaan penyimpanan, buah tomato meningkatkan aktiviti enzim pertahanan POD (25.67%), PPO (17.33%), dan PAL (21.58%) pada 3.0 kGy berbanding sampel kawalan. Kesimpulannya, penggunaan $CaCl_2$ pra-dan selepas tuaian pada MT-3 (dituai pada hijau matang) boleh memanjangkan hayat simpan selepas tuaian secara berkesan sehingga 4 hari apabila disimpan pada suhu ambien. Selain itu, sinaran gamma pada 3.0 kGy boleh berjaya digunakan untuk meminimumkan kerugian akibat jangkitan kulat, terutamanya *Fusarium solani*, bagi melanjutkan jangka hayat buah tomato.

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I certify that the Thesis Examination Committee has met on 08.08.2022 date of viva voce to conduct the final examination of Mohammad Nurun Nabi Mazumder on his thesis entitled "Shelf Life Extension and Postharvest Quality of Tomato Fruit (*Solanum lycopersicum* L.) as Influenced by Pre- and Postharvest Treatments of Calcium Chloride, Harvest Maturity and Gamma Irradiations" in accordance with Universiti Pertanian Malaysia (Higher Degree) act 1980 and Universiti Pertanian Malaysia (Higher Degree) regulations 1981. The committee recommends that the candidate be awarded the relevant degree.

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AA	Ascorbic acid
ACC	1-aminocyclopropane-1-carboxylic acid
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
ATP	Adenosine triphosphate
BER	Blossom end rot
bp	Base pair
BLAST	Basic Local Alignment Search Tool
CA	Citric acid
Ca	Calcium
CAT	Catalase
C_2H_4	Ethylene
$CaCl_2$	Calcium chloride
℃	Degree Celsius
cm	Centimeter
cfu/g	Colony-forming unit per gram
CRD	Completely Randomized Design
CO_2	Carbon dioxide
Cu	Copper
CTAB	Cetyl trimethyl ammonium bromide
DOA	Department of Agriculture

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DAT	Day After Transplant
DI	Disease incidence
º	Degree
DS	Disease severity
df	Degree of freedom
DNA	Deoxyribonucleic acid
DPPH	2,2-Diphenyl-1-picrylhydrazyl
DW	Distilled water
dw	Dry weight
EC	Electric Conductivity
EB	Early blight
EFE	Ethylene Forming Enzyme
etc	Et cetera
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FDA	Food and Drug Administration
Fe	Iron
FID	Flam Ionizing Detector
fw	Fresh weight
g	Gram
GAE	Gallic acid equivalents
GC	Gas Chromatography
ha	Hectare
H_2O	Water
h	Hour

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HCl	Hydrochloric acid
H_2O	Water
HPO_3	Metaphosphoric acid
K	Potassium
kGy	kilo gray
kg	Kilogram
l/L	Liter
LSD	Least Significant Difference
m	Meter
MARDI	Malaysian Agriculture Research and Development Institute
Mg	Magnesium
mg	Milligram
mm	Millimeter
Mn	Manganese
ml	Milliliter
MT	Million Tones
µl	Microliter
µs/cm	Micro siemens per centimetre
mM	Millimolar
MW	Molecular Weight
N	Newton
NCBI	National Center for Biotechnological Information
ns	Non-significant
O_2	Oxygen
P	Phosphorous

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PAL	Phenylalanine ammonia-lyase
PCR	Polymerase chain reaction
PDA	Potato Dextrose Agar
PG	Polygalacturonase
PME	Pectin methylesterase
POD	Peroxidase
ppm	Parts per million
PPO	Polyphenol oxidases
%	Percentage
RH	Relative humidity
ROS	Reactive Oxygen Species
rpm	Rotation per minute
SAS	Statistical Analyses System
SD/ST	Storage Durations / Storage Time
SSC	Soluble Solids content
SSR	Self-Sufficient Ratio
SOD	Superoxide dismutase
t	Ton
TA	Titratable Acidity
TEM	Transmission Electron Microscopy
TFC	Total Flavonoid Content
TPC	Total Phenolic Content
USA	United States of America
USD	United States of Dollar
v/v	Volume per volume

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w/v	Weight per volume
Z	Zinc

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CHAPTER 1

INTRODUCTION

Tomato fruits (*Solanum lycopersicum* L.) are the most commonly cultivated and extensively consumed berry-type horticultural crops belonging to the nightshade family of Solanaceae (Garuba et al., 2018; Macheka et al., 2018). According to the FAOSTAT (2017), tomato production reached approximately 233.47 million tonnes and it ranked second just after potato by weight in total global production out of all horticultural products whereas China ranked first in production all over the world.

According to the research findings, tomato fruits are predominant in vitamins C (Safari et al., 2021; Giuliano, 2017), minerals of Calcium (Ca), Magnesium (Mg), Sodium (Na), Iron (Fe), Phosphorus (P), and Potassium (K) (Safari et al., 2020), carotenoids principally the β-carotene (responsible for fruit's reddish-orange colour) and especially lycopene (predominantly red colour) are available in tomato fruits (Mohammed et al., 2018; Stommel et al., 2005). The phytochemicals present in tomato fruits have antioxidant properties which can reduce the incidence of some heart diseases (Liu et al., 2018; Marti et al., 2017), cardiovascular diseases (Mehta et al., 2018; Paur et al., 2017) and cancer risk (Forni et al., 2019; Cheng et al., 2017).

The maintenance of tomato fruit quality depends on many agronomic practices, pre-and postharvest management practices (Ziv and Fallik, 2021). The postharvest losses in tomato fruits could be as high as approximately 25-42% globally both qualitatively and quantitively (Feizi et al., 2020; Ahmed et al., 2017), resulting in a minimum return to the growers, processors, and traders (Isack and Lyimo, 2015; Snowden, 2010).

The mineral Ca is an important macronutrient, that could be used as an alternative to the fungicides which have influenced plant growth and development, diseases, insect infestation, yield, and postharvest quality attributes of fresh fruits and vegetables (Haleema et al., 2018). Ca is essential to preserve fruit quality by reducing physiological disorders such as blossom end rot symptoms in tomatoes (Hagassou et al., 2019), bitter pit in apples (Falchi et al., 2017), cavity spots in carrots (Klemsdal et al., 2008), and tip burn in cabbage and lettuce (Uno et al, 2016) that increase the fruit firmness by inhibiting the ripening process and extending shelf life (Abbasi et al., 2013).

However, the foliar spray of calcium chloride ($CaCl_2$) in leaves, fruits, or both can decline a wide range of diseases and insect infestation by increasing fruit firmness, declining the levels of ethylene and respiration in tomatoes (Rab and Haq, 2012), papaya (Madani et al., 2014a), apples (Jafarian et al., 2013). The preharvest application of $CaCl_2$ (3% and 5%, w/v) in tomato cultivars 'Rajitha' in Sri Lanka stored at ambient temperature, recorded significantly higher firmness, total Ca content, with a lower level of weight loss, and 2.3 to 3.8 fold extension of shelf life compared to the control treatments (Daundasekera et al., 2015).

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The tomato fruits can be harvested at the different physiological maturity stages of mature green, breaker, half-ripe, and red ripe stages where the postharvest loss differs in different stages (Abebe and Tola, 2017; Moneruzzaman et al., 2009). The mature green stage is recommended for long-distance marketing which is also important for Ca uptake but harvesting at the half-ripen stage to optimize nutritional value is favored for local marketing (Teka, 2013). The major problem with lowland tomato fruits in Malaysia is the postharvest losses due to the high temperature and humidity, also the postharvest management practices.

Ionizing radiation, mainly gamma radiation, X-rays, and Carbon ion beams are generally used for surface sterilization, minimizing the microbial load, inactivation of the storage pest, and delaying ripening that helps to preserve the quality and extended the shelf life of fresh produce (Loro et al., 2018; Duvenhage et al., 2012). Among the different types of ionizing radiations, the application of gamma radiation has already been approved as an important method of the postharvest food storage process (Antonio et al., 2012).

Tomato fruits are irradiated with doses of 1.5 kGy of gamma radiation, resulting in higher firmness, lower respiration, and extended shelf life (Loro et al., 2018). Tomato fruits were exposed to gamma radiation at doses of 0.1, 0.5, and 1 kGy, and the doses of 1.0 kGy resulted in the lowest mean of lycopene content and highest antioxidant activity, suggesting that gamma radiation inhibits the color development during the ripening process (Kumar et al., 2014).

Furthermore, gamma radiation is used all over the world for sanitary and phytosanitary purposes to disinfect agricultural commodities from quarantine pests (Hallman et al., 2016) and it is a cost-effective method for reducing postharvest losses, extending the shelf life of perishable commodities (Fan et al., 2012). Nowadays, producers and traders showing interest to use gamma radiation for sanitary and phytosanitary treatments on tomato fruits instead of using harmful chemicals and fumigations.

The maximum countries of the world such as USA, Brazil, South Africa, member state of Europe and Asian countries perform food irradiation through the application of gamma radiations (Eustice, 2017). As a result, many researchers investigate the effects of different ionizing radiation on the postharvest quality, pathogen infection, and shelf life of tomatoes in storage conditions. The overall research activities' connection between the postharvest loss of tomato fruit's the proposed experiments are represented in the following flow chart (Figure 1.1).

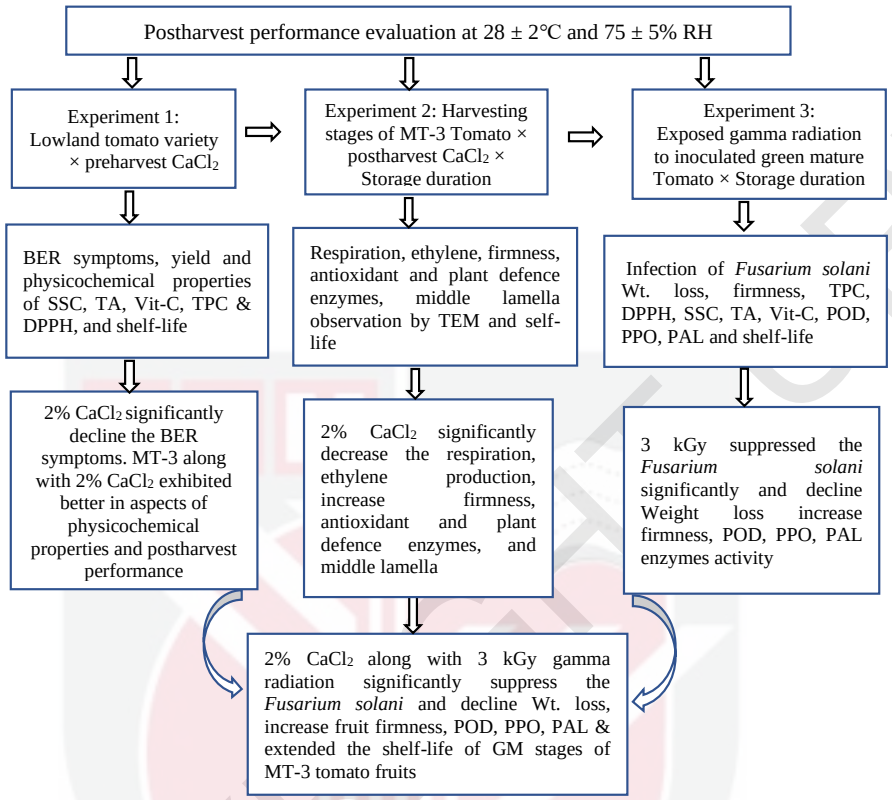

Figure 1.1: Schematic diagram of overall research activities of tomato fruits

The extension of shelf life and maintaining the quality of lowland tomato fruits using pre-and postharvest treatments with $CaCl_2$ along with the suitable harvesting stages might be the new arena of horticultural research in Malaysia. Even though many studies on $CaCl_2$ and gamma radiations on fresh tomato fruits have already been performed around the world individually, there is very little information on the postharvest performance of lowland tomato fruits using the gamma irradiations along with pre and postharvest $CaCl_2$ and this may be a new and exceptional avenue of postharvest research frontier.

General Objective

The study was conducted to determine the effects of pre-and postharvest $CaCl_2$ treatments along with gamma irradiations on growth, yield, postharvest performance, and shelf life of lowland tomato fruits in Malaysia with the following specific objectives:

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Specific Objectives

1. To investigate the effects of preharvest foliar spray of $CaCl_2$ on the growth, yield, quality, and shelf life of lowland tomato varieties.
2. To evaluate the comparative performance of harvesting stages and postharvest $CaCl_2$ dipping on quality, shelf life, enzymatic activity, and histological changes of selected tomato fruits (MT-3).
3. To elucidate the role of gamma radiations on quality, shelf life, relevant enzymes, phytochemicals, and suppression of *Fusarium solani* of lowland tomato fruits.

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