

ENGINEERING FACTORS AFFECTING HANDLING PROCESSES FOR STRAWBERRY FRUITS

By

MUHAMMAD AHMAD MAHMOUD MAYHOUB

B. Sc. Agric. Sc. (Agric. Mechanization), Ain Shams University, 2003

M. Sc. Agric. Sc. (Agric. Mechanization), Ain Shams University, 2009

A Thesis Submitted in Partial Fulfillment

Of

The Requirements for The Degree of

DOCTOR OF PHILOSOPHY

in

Agriculture Science

(Farm Machinery and Power Engineering)

**Department of Agricultural Engineering
Faculty of Agriculture
Ain Shams University**

2016

ENGINEERING FACTORS AFFECTING HANDLING PROCESSES FOR STRAWBERRY FRUITS

By

MUHAMMAD AHMAD MAHMOUD MAYHOUB

B. Sc. Agric. Sc. (Agric. Mechanization), Ain Shams University, 2003

M. Sc. Agric. Sc. (Agric. Mechanization), Ain Shams University, 2009

Under the supervision of:

Dr. Essam Ahmed Soliman El-Sahhar

Prof. of Agricultural Engineering, Department of Agricultural Engineering, Faculty of Agriculture, Ain Shams University (Principal

Dr. Ahmed Abou El-Yazied Abdel-Hafiz

Prof. of Vegetable Crops, Department of Horticulture, Faculty of Agriculture, Ain Shams University

Dr. Mahmoud Zaky El-Attar

Associate Prof. of Agricultural Engineering, Department of Agricultural Engineering, Faculty of Agriculture, Ain Shams University

Approval Sheet

ENGINEERING FACTORS AFFECTING HANDLING PROCESSES FOR STRAWBERRY FRUITS

By

MUHAMMAD AHMAD MAHMOUD MAYHOUB

B. Sc. Agric. Sc. (Agric. Mechanization), Ain Shams University, 2003

M. Sc. Agric. Sc. (Agric. Mechanization), Ain Shams University, 2009

This thesis for Ph.D. degree has been approved by:

Dr. Ayman Hafiz Amer Eissa

Prof. of Agric. Eng., Faculty of Agriculture, Menoufia University.

Dr. Mubarak Mohammed Mostafa

Prof. Emeritus of Agricultural Engineering, Faculty of Agriculture, Ain Shams University.

Dr. Ahmed Abou El-Yazied Abdel-Hafiz

Prof. of Vegetable Crops, Faculty of Agriculture, Ain Shams University.

Dr. Essam Ahmed El-Sahhar

Prof. of Agricultural Engineering, Faculty of Agriculture, Ain Shams University.

Date of Examination: 28 / 5 /2016

ABSTRACT

Muhammad Ahmad Mahmoud Mayhoub: Engineering Factors Affecting Handling Processes for Strawberry Fruits. Unpublished Ph.D. Thesis, Department of Agricultural Engineering, Faculty of Agriculture, Ain Shams University, 2016.

The aim of this study was to find out engineering factors (physical characteristics, and evaluate affecting strawberry fruits quality for appraise the domestic and international marketing demands). The experiment consists of manufacturing and evaluation a vibrational equipment to find energy levels of the transportation process, which was Energy Spectral Density "ESD", levels of fruit crate from the vibrational table, air bubble pad and ultraviolet "UV-C" light dose.

Results revealed, Energy acquired the fruits during transport 1204 J/kg, the modulus of elasticity values were 1.36 and 1.21 N/mm² and firmness were 1.77 and 1.41 N/mm for festival and Fortuna strawberry cultivars resp. The fruit bruising percent was 7 and 7.3% for festival and Fortuna cultivars. the percent of bruising increased by 25%. The use of two-air bubble pads below fruits reduce exposure of the fruits of deterioration by 37.6 to 21.6%. Use dose 3 kJ/m² of UV-C light of good solidarity fruits, which led to increased resistance the fruits.

Keywords: Transportation process, Power spectral density, UV-C light, Firmness, Strawberry, Quality, Postharvest, Damage Vibration, Storability.

ACKNOWLEDGMENT

First of all, thanks to ALLAH for his blessings

The author wishes to express my deep appreciation and gratitude to **Prof. Dr. Essam A. El-Sahhar**, Professor of Agricultural Engineering and Head of Agricultural Engineering Department, Faculty of Agriculture, Ain Shams University, for suggesting the problem of study and for his kindly supervision throughout this work. The author is grateful for his valuable discussions, suggestions and helpful criticism, which helped him to finalize this work.

The author wishes to express his sincere gratitude and appreciation to **Dr. Mahmoud Zaky El-Attar**, Associate Professor of Agricultural Engineering, Agricultural Engineering Department, Faculty of Agriculture, Ain Shams University for his kind supervision, problem suggestion, continuous encouragement and valuable advices throughout this work.

The author also wishes to express his gratitude and appreciation to **Dr. Ahmed A. Abdel-Hafez**, Professor of vegetables, Horticulture Department, Faculty of Agriculture, Ain Shams University, for supervision, kind help and for reviewing the manuscript.

Special thanks to all staff members of the Agricultural Engineering Department, for their valuable help during carried out the experiments of this work.

Finally, deepest appreciations are going towards my family for their understanding, patience and loving encouragement.

CONTENTS

	Page
LIST OF FIGURES	IV
LIST OF TABLES.....	VII
1. INTRODUCTION.....	1
2. REVIEW OF LITERATURE	4
2.1.Strawberry fruit	4
2.2.Strawberry fruit quality	6
2.2.1. Fruit size	8
2.2.2. Strawberry fruit firmness	10
2.2.3.Mechanical injury of strawberry fruits	12
2.2.4. Fruit bruising	14
2.3.Transportation road quality	17
2.4. Machine vibration equipment	19
2.5. Reduce transportation damage to strawberry fruits	20
3. MATERIALS AND METHODS	22
3.1.MATERIALS	22
3.1.1. Strawberry fruits	22
3.1.2. Transportation vehicle	23
3.1.3. Vibration measurement	24
3.1.4.Vibrational equipment	24
3.1.5. Measuring vibration device	25
3.1.6. Bench top Materials Testing Machine	25
3.1.7. Mechanical damage inspector	28
3.1.8.UV lamp	30
3.1.9. Air bubble pad	30
3.2. Methods And Measurements.....	31
3.2.1.Physical and mechanical Properties of fruits	31
3.2.1.1. Fruit size	31
3.2.1.2. Fresh fruit mass (M)	32
3.2.1.3. Fruit volume (V)	32
3.2.1.4. Fruit density (ρ_f)	32
3.2.1.5. Fruit moisture content (M.C)	32
3.2.1.6. Determining the fruit coefficient of friction (μ)	32
3.2.1.7. Determining fruit ripening degree	33
3.2.1.8. Determining the modulus of elasticity of strawberry fruit	34

3.2.1.8.1. Determining compressive stress and instantaneous strain	35
3.2.1.8.2. Determining instantaneous contact area	35
3.2.1.9. Determining the fruit firmness	37
3.2.2. Determining the road transportation quality	39
3.2.3. Determining the energy spectral density “ESD” of the vibrational equipment	43
3.2.4. Determining the fruit bruising	45
3.2.5. Determining the fruit darkness rate	49
3.2.6. Reduce transportation damage to strawberry fruits	49
4. RESULTS AND DISCUSSION.....	51
4.1. Vibration measurements on transporting vehicle-bed for road conditions	51
4.2. Evaluation of the strawberry fruit bruises	54
4.2.1. Effect of vibration energy on bruise percent	54
4.2.2. Effect of strawberry cultivar on bruise percent	54
4.2.3. Effect of fruit ripening degree on bruise percent	54
4.2.4. Effect of storage period on bruise percent	56
4.2.5. Effect of fruit box height on bruise percent	56
4.3. Evaluation of the color change in strawberry fruits	59
4.3.1. Effect of vibration energy on fruit color change	59
4.3.2. Effect of strawberry cultivar on fruit color change	59
4.3.3. Effect of fruit ripening degree on fruit color change	59
4.3.4. Effect of storage period on fruit color change	59
4.3.5. Effect of fruit box height on fruit color change	62
4.4. Evaluation of the strawberry fruit elasticity	62
4.4.1. Effect of vibration energy on fruit elasticity	62
4.4.2. Effect of strawberry cultivar on fruit elasticity	62
4.4.3. Effect of fruit ripening degree on fruit elasticity	65
4.4.4. Effect of storage period on fruit elasticity	65
4.4.5. Effect of fruit box height on fruit elasticity	65
4.5. Fruit firmness	68
4.5.1. Effect of storage period on fruit firmness	68
4.5.2. Effect of fruit box height on fruit firmness	68
4.6. Reduce transportation damage to strawberry fruits	68

4.6.1. Effect of strawberry cultivar on reduce damage	68
4.6.2. Effect of fruit ripening degree on percent of reduce bruise	71
4.6.3. Effect of air bubble pad position on percent of reduce bruise	71
4.6.4. Effect of isolation material on percent of reduce bruise	73
4.6.5. Effect of UV-C treatment on percent of reduce bruise	73
5. SUMMARY AND CONCLUSION.....	75
6. REFERENCES	78
APPENDIX.....	92
ARABIC SUMMARY	

LIST OF FIGURES

No.		Page
1	Orientation of fruit to take dimensions.	10
2	Percent of damage to strawberry fruits during different stages of handling.	14
3	Approximately spherical above and below a contact plane, shown on the bruise shape.	16
4	Transport vibration laboratory simulator.	19
5	Schematic view of experimental vibrational equipment.	20
6	Punnet of strawberry fruit.	22
7	Crate box of strawberry fruit.	22
8	A vehicle used for strawberry transport.	24
9	Vibrational equipment views.	26
10	All parts of mechanism as assembly.	26
11	Crank mechanism details.	27
12	Vibration monitoring android application interface.	27
13	Function generator	27
14	Calibration curve of vibration meter.	27
15	Bench top materials testing machine.	28
16	Mechanical damage inspector.	29
17	Mechanical damage inspector: (a) photographic view, (b): 3D view, and (c): box of Arduino and stepper motor.	29
18	Air bubble pad.	31
19	Three axial dimensions of strawberry fruit.	31
20	The device used to measure the fruit coefficient of friction.	33
21	Percentage of ripening for using fruit in the test.	33
22	Testing machine produce force-deformation curve.	24
23	Stress-strain curves of strawberry fruit.	25
24	Measured contact area steps by ImageJ program.	36
25	Penetration strawberry fruit with prob.	38
26	Penetration force and distance diagram.	38
27	Map indicating vehicle transportation route used in the vibration in measurement study.	38

28	Map indicating vehicle transportation route used in the vibration in measurement study.	39
29	Acceleration of vertical, lateral and longitudinal vibrations for various parts of the transportation road conditions measured in this study.	42
30	Calibration curve for vibrational equipment at 2 mm displacement.	43
31	Effect of displacement on acceleration at different frequencies.	44
32	Effect of frequency on the energy spectral density at different displacements.	44
33	Steps of fruit bruising estimation.	48
34	Effect of type of vibration isolation materials with 31.3 mm thickness on power spectral density.	49
35	Effect of vibration isolation thickness of foam layer on power spectral density.	50
36	PSD of vertical, longitudinal and lateral directions for rough unpaved road.	51
37	PSD of vertical, longitudinal and lateral directions for damage asphalt road.	52
38	PSD of vertical, longitudinal and lateral directions for asphalt road with frequent speed bumps.	52
39	PSD of vertical, longitudinal and lateral directions for older asphalt road.	53
40	Effect of energy spectral density on the fruit bruise at different fruit ripening degrees.	55
41	Effect of storage period after the vibration treatment on the fruit bruise at different energy spectral densities.	57
42	Effect of storage period after the vibration treatment on the fruit bruise at different box positions on vibrational table.	58
43	Effect of accumulated vibrational energy on the fruit color change at different ripening degrees.	60
44	Effect of storage period on fruit color change at different accumulated vibrational energies.	61
45	Effect of storage period after the vibration treatment on the	

	fruit color change at different box positions on vibrational table.	63
46	Effect of Accumulated vibrational energy on the modulus of elasticity of fruit at different ripening degrees.	64
47	Effect of time after treatment on the modulus of elasticity at different Energy spectral density.	66
48	Effect of Storage period on the modulus of elasticity at different levels of the fruit crate from vibrational table.	67
49	Effect of storage period on the fruit firmness at different accumulates vibrational energy.	69
50	Effect of storage period on the fruit firmness at different levels of the fruit crate from vibrational table.	70
51	Effect of accumulated vibrational energy on reduce bruising percent for Festival to Fortuna cultivars at different fruit ripening degrees	71
52	Effect of time after treatment on the fruit bruising percent at different air bubble pads.	72
53	Effect of isolation material on reduce bruising.	73
54	Effect of different doses of UV-C light on Fruit bruise percent, Festival cv.	74

LIST OF TABES

No.		Page
1	Physical and chemical characteristics of strawberry fruit harvested at Floral City.	4
2	Previous studies for some fruits firmness.	11
3	Some physical and mechanical properties for Festival and Fortuna cultivars.	23
4	Technical specifications for bench top materials testing machine.	28
5	Specifications for CCD camera.	30
6	The details of road transportation studied.	40

INTRODUCTION

Strawberry (*Fragaria x ananassa* Duch.) is one of the most important members of the family Rosaceae. It has become one of the economic vegetable crops in Egypt and considered the main cash crop for strawberry growers in Qalyubia, Ismailia, Sharqia and Beheira governorates. It is one of the most favorite and delicious fruits of which the demand has been increased in Egypt for local consumption and for exportation.

According to Food and Agriculture Organization (**FAO, 2015**) of the United Nations, world production of strawberries has exceeded 4.47 million tons since 2000. In 2010, strawberry production in Egypt increased more than 3 times from 70,000 tons to 238,432 tons, becoming the fifth largest strawberry producer in the world (3.6%), behind the China mainland (33.4%), U.S. (19.6%), Turkey (4.5%), and Spain (4.2%). The cultivated area of strawberry during season 2012/2013 was about 15,073 fed., yielded about 254,921 tons. Among them, about 8,571 feddan of frigo plantations (average of 11.46 ton/fed.) cultivated mainly for the local market and about 3,102 feddan of fresh plantations (average 18.5 ton/fed.). The exported amount of strawberry fruits resembled about 50% of the total production of fresh plantations in the aforementioned season, and the remained percentage of fruit production for local market consumption. Egypt strawberry producers exported 301,488 tons in 2012 valued 59 million dollars worth of the fruit. Arabian markets received 86 percent of them, followed by France and Russian markets with 7 percent.

Generally, the main objective of the producers and exporters are to decrease quality losses of fruit and vegetables during handling. Strawberry is a non-climacteric fruit with a limited harvesting period. Because of high susceptibility to mechanical damage, the strawberry has a small post-harvest life. Mechanical injuries are the main reason for considerable decay of fresh fruits. Strawberry production wasted due to

INTRODUCTION

-damage in the chain between the grower and the consumer is estimated at around 20–30%, (**Kader, 1991 and Salami, et al., 2010**). Strawberries are hand harvested directly into the shipping fleet. Therefore, the picker in the field does harvesting, grading and packing. Strawberry handling is a very important step in the system in terms of quality and that losses can best be minimized at this step.

Strawberry fruits during the transportation are affected by vibration due to repetition displacement of fresh fruits, which causes softening and bruising. Abrasion or vibration bruise for fruit occurs against the fruit surface or contact the other product. Mechanical damaged fruit losses moisture quickly, exposes it to attack of the fungus and compromise its quality, aesthetic appeal and reduce its economic value to the grower and exporter. The fruit injury due to the effects of shock and vibration is related to the transportation characteristics of vehicles such as the suspension and the number of axles and the conditions of the roads such as road roughness, distance, travelling speed and load (**Berardinelli et al., 2003**). Vibration injury is defined as damage occurs when fruits are subject to vibratory forces, during transport across a large range of frequencies and with jolts and bumps in the road where fruit will vibrate when the frequency of vibration reaches a certain level. If the resonance frequency of the fruit stack is the same as the excitation frequency of the vehicle or road, the acceleration of the fruit can be considerably increased due to the resonance, and thus severe damage can result. Although, there are various modes of transportation in the growing international trade that requires inter-modal shipments over land, sea and air. However, vehicles are still the most dominant mode in Egypt for used in most cases as the first mode of transportation from the field or packing house to the shipping ports.

The aim of this study is to determine the extent of accumulated vibrational energy to strawberry fruit quality during the road transportation—in Egypt, to study some factors affecting the quality losses