

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

PERFORMANCE OF RECYCLED PAPER PULP TRAYS IN RELATION TO IMPACT DAMAGE IN APPLE CARTONS

A thesis presented in partial fulfillment

of the requirements for the degree of

Master of Horticultural Science

in Agricultural Engineering at

Massey University, Palmerston North,

New Zealand

Rebecca Alison Heap

April 1994

ABSTRACT

Excessive bruising during transit of Count 88 apples packed in cartons using paper pulp (Friday) trays is of major concern to the apple industry. The literature shows that this has been observed since at least 1962. Many experiments have been conducted but these have generally involved small quantities of fruit and been directed to specific issues. The object of this project was to review the literature and to examine the performance of Friday Trays directly by the study of their physical properties and indirectly through the experimental bruising of a significant amount of fruit under carefully defined conditions.

The carton configurations of Count 88 and Count 100 apples were assessed through visual observation and by computed tomography to determine the spatial relationships of fruit within the packs. Count 88 cartons had fruit in a 2x2 configuration and the apples were tightly packed. The fruit were close proximity with two contact points above and below for central fruit and one for those on the ends of the pack. Count 100 cartons had fruit in a 3x2 configuration. The apples were more widely spaced on the trays, with the fruit being, to some degree, 'hammocked' by the Friday Tray with less direct pressure on adjacent fruit in the static state. However, under dynamic loading it was shown that force was transmitted between fruit at four contact points above and below for central fruit and at a lesser number for those on the periphery of the pack.

Cartons of Count 88 and Count 100 apples were dropped under standardised conditions from a height of 600mm and the amount and distribution of bruising recorded. Prior experimental work defined the relationship between energy absorbed and bruise production so that it was possible to calculate the energy absorbed by the fruit and other mechanisms in both configurations. With Count 88 cartons the packaging material and other mechanisms absorbed 87% of the energy whilst in Count 100 cartons 97.5% was absorbed

The tensile strength of samples of Friday trays were measured at two moisture contents (MC), based on the MC when trays are first placed in the cartons (8 % MC) and after a minimum of 24 hours in coolstorage (15 % MC). Samples were 16% stronger at 8% MC than 15% MC.

The distribution of energy absorption was assessed using trays at 8% and 15% MC. Whilst tray splitting was more common with trays at 8% MC, the total energy absorbed was not altered and variation in another physical property, such as the ability to stretch, must have been responsible for this.

The study suggests that there is a relationship between excessive bruising and carton configuration. The previously described 'hammock effect' appears to be a protective mechanism in Count 100 packs but the closer spacing of Count 88 packs precludes this. Bruising in the Count 88 configuration may be reduced if a five layer pack similar to Count 100 were adopted or more energy absorptive trays used that would reduce the force transmitted between adjacent fruit. Such changes could have adverse effects in terms of carton overfill and would need further investigation.

ACKNOWLEDGEMENTS

I would like to thank:

My supervisors, Dr Cliff Studman and Prof Gavin Wall of the Department of Agricultural Engineering

Les Boyd for practical assistance with the experiments

Stella McLeod and Tony Lorkin of the New Zealand Apple and Pear Marketing Board for providing technical information and access to files.

The Department of Production Technology for use of facilities and in particular Dr Ted Smith

Dr Paul Merrick for assistance with statistical analysis

The Department of Radiology, School of Medicine, University of Auckland

Mercy Radiology, Auckland

New Zealand Apple and Pear Marketing Board for supplying the research grant, fruit, apple cartons and Friday Trays

TABLE OF CONTENTS

Abstract	iii
Acknowledgments	v
Table of Contents	vii
Table of Figures	xiii
Chapter 1 - INTRODUCTION	1
1.1 BACKGROUND DETAILS	1
1.2 PRODUCTION INFORMATION	2
1.3 PRODUCT HANDLING	3
1.4 PREVIOUS RESEARCH	4
Chapter 2 - LITERATURE REVIEW	5
2.1 INTRODUCTION	5
2.2 FRIDAY TRAYS	5
2.2.1 Carton Configurations	6
2.3 PROTECTIVE MECHANISMS OF TRAY PACKS	8
2.4 THE EFFECTS OF STATIC AND DYNAMIC LOADS	10
2.4.1 Static vs Dynamic Loads on Apple Cartons	10
2.4.2 Dynamic Behaviour of Apple Columns and Cartons	11
2.5 DROP HEIGHT EFFECTS AND POSITION OF BRUISED FRUIT	12
2.5.1 Effect of Drop Heights	12
2.5.2 Position of Bruised Fruit	13
2.6 CARTON CONFIGURATION AND PACKING	14
2.6.1 Packing Configurations and Packing Densities	14
2.6.2 Apple Packing Configuration	15
2.6.3 Bruising in Relation to Carton Configuration	16
2.6.4 Underfill and Overfill Cartons	18
2.6.5 Bruising in Count 88 Packs	20
2.7 RECYCLED PAPER PULP TRAYS	21
2.7.1 Pulp Tray Performance	21
2.7.2 Effects of Tray Design on Bruising	22
2.7.3 Tray Weights	23
2.7.4 Moisture Content	25
2.7.5 Damaged Friday Trays	25

2.8 ALTERNATIVE TRAYS AND TRAY COMBINATIONS	25
2.8.1 Double Trays	26
2.8.2 Polystyrene Trays	26
2.8.3 Polyurethane Foam Pads	26
2.8.4 Polystyrene Foam Pads	27
2.8.5 Pressed Foam	28
2.8.6 Foam Netting	28
2.8.7 Polybubble Sheets	28
2.8.8 Effect Heavy Duty vs Standard Cartons	28
2.8.9 Impacts onto Polybubble Mats	29
2.9 SHIPPING METHODS AND STACKING PATTERNS	29
2.9.1 Shipping Method	29
2.9.2 Stacking Patterns	29
2.10 SUMMARY AND CONCLUSIONS	30
2.10.1 Bruising	30
2.10.2 Carton Configurations in Relation to Bruising	30
2.10.3 Bruise Patterns and Damage Trends	31
2.10.4 Underfill and Overfill	32
2.10.5 Moisture Content	32
2.10.6 Pulp Trays and Other Materials	32
Chapter 3 - OBJECTIVES	35
Chapter 4 - ANALYSIS OF CARTON CONFIGURATIONS	37
4.1 INTRODUCTION	37
4.2 VISUAL ANALYSIS OF CARTONS	41
4.3 ANALYSIS OF CARTONS BY COMPUTED TOMOGRAPHY	47
4.3.1 Computed Tomography Background Details	48
4.3.2 Computed Tomography Scans	48
4.3 DISCUSSION	61
Chapter 5 - TENSILE STRENGTH TESTS	63
5.1 INTRODUCTION	63
5.2 EXPERIMENTAL DETAILS AND PROCEDURE	64
5.2.1 Experimental Design	64
5.2.2 Conditioning of Samples	65
5.2.3 Moisture Content Analysis	65
5.2.4 Sample Dimensions	65
5.2.5 Testing Procedure	66

5.3 RESULTS	67
5.4 DATA ANALYSIS	68
5.4.1 t-Tests	68
5.4.2 Thickness of Trays and Sample Pieces	68
5.4.3 Stress Required to Break Samples at Different Moisture Contents	68
5.4.4 Stress Required to Break the 18 Sample Pieces from each Tray	69
5.4.5 Stress Required to Break the 6 Sample Pieces from the same Position on Each Tray	69
5.5 INTERPRETATION OF RESULTS	69
Chapter 6 - DROP TESTS	
EXPERIMENTAL DETAILS AND RESULTS	71
6.1 INTRODUCTION	71
6.2 EXPERIMENTAL DESIGN	72
6.3 EXPERIMENTAL DETAILS	73
6.3.1 Fruit Details	73
6.3.2 Tray and Carton Details	79
6.4 EXPERIMENTAL PROCEDURE	79
6.4.1 Calculation of Bruise Resistance	79
6.4.2 Drop Testing and Fruit Analysis	80
6.4.3 Documentation of Data	81
6.5 RESULTS AND ANALYSIS OF DROP TEST EXPERIMENTS	82
6.5.1 Bruise Resistance Coefficient	82
6.5.2 Data Variability	82
6.5.3 Energy Absorbed in Creating Bruises	83
6.5.4 Bruising Patterns within Each Carton	83
6.5.5 Bruising Patterns at Each Layer	90
6.5.6 Bruise Location	92
6.5.7 Bruising Patterns on Individual Apples	93
6.5.8 Fruit Diameter and Weight	105
6.5.9 Tray Splits per Carton	106
6.5.10 Energy Absorbed in Bruising and Tray Splits	107
6.5.11 Carton Movement on Impact	107
6.5.12 One Off Tests	113

Chapter 7 - ANALYSIS OF RESULTS	119
7.1 BRUISING OF THE FRUIT	119
7.2 ENERGY BALANCE WITHIN THE CARTON AT IMPACT	119
7.3 EFFECT OF MOISTURE CONTENT IN TERMS OF TRAY STRENGTH AND FRUIT DAMAGE	121
7.4 FRUIT DIAMETER AND WEIGHT	122
7.5 RELATIONSHIP BETWEEN BRUISES, SPLITS, WEIGHT AND HEIGHT	122
7.5.1 Chi Squared Tests of Parameters	123
i Tray Splitting and Bruised Fruit	123
ii Tray Splitting and Fruit Weight	123
iii Bruising and Fruit Weight	123
iv Bruising and Fruit Height	123
7.5.2 Tray Splitting and Fruit Height	124
7.5.3 Conclusions	125
7.6 CARTON CONFIGURATIONS AND TRAY MATERIAL	125
Chapter 8 - DISCUSSION AND CONCLUSIONS	127
8.1 DISCUSSION	127
8.2 CONCLUSIONS	129
Chapter 9 - RECOMMENDATIONS FOR FURTHER RESEARCH	131
References	133
APPENDICES	
Appendix 1 - THE THEORY OF BRUISING IN APPLES	139
1.1 MECHANISMS OF BRUISING IN APPLES	139
1.2 BRUISE VOLUMES, ENERGY CALCULATIONS AND BRUISE RESISTANCE	140
1.2.1 Bruise Volume	141
1.2.2 Energy Absorbed	142
1.2.3 Bruise Resistance Coefficient C	143
Appendix 2 - THE PROPERTIES AND STRENGTH OF PAPER AND PAPER PRODUCTS	145
2.1 PROPERTIES OF PAPER	145
2.2 FACTORS AFFECTING TENSILE STRENGTH	145

Appendix 3 - MANUFACTURE OF PULP TRAYS	147
3.1 INTRODUCTION	147
3.2 RAW PRODUCT	147
3.3 MANUFACTURING PROCESS	148
3.4 QUALITY CONTROL	148
Appendix 4 - NZAPMB TRAY MANUFACTURING SPECIFICATIONS	149
Appendix 5 -BRUISING COEFFICIENT TEST DATA	153
Appendix 6 - DROP TEST DATA	157
Appendix 7 - SUMMARIES OF DROP TEST DATA	309
Appendix 8 - SUMMARY OF COUNT 100 DROP TEST DATA INCLUDING CARTON 2	327
Appendix 9 - SPLIT SITES AND SPLIT DATA	333
Appendix 10 -TENSILE STRENGTH DATA	341
Appendix 11 -CHI SQUARED TESTS	347
Appendix 12 - RECOMMENDATIONS ON SIZE OF FUTURE TRIALS	349
12.1 Graphs of Coefficient of Variation Data against Summed Cartons	349
12.2 Interpretation of Graphs	351
Appendix 13 - TECHNICAL PRODUCTION DETAILS	353

LIST OF FIGURES AND TABLES

Chapter 1 - INTRODUCTION	1
Figure 1.1 Percentage Distribution of Count Sizes from the Total 1993 Crop. (Adapted from NZAPMB 1993c)	2
Figure 1.2 1992 Average Grower Payout per Carton of Export Fruit (Adapted from NZAPMB 1992)	3
Chapter 2 - LITERATURE REVIEW	5
Figure 2.1 Arrangement of Spheres to Demonstrate Carton endview of 2x2 Packing Configuration	6
Figure 2.2 Arrangement of Spheres to Demonstrate Carton endview of 3x2 Packing Configuration	7
Table 2.1 Count size specifications as for the 1993 season (From NZAPMB 1992)	8
Figure 2.3 Typical Peg Type Trays (from Peleg (1985))	9
Figure 2.4 Friday Trays (courtesy Keyes Fibre Co, from Peleg (1985)).	10
Figure 2.5 Plan view of Apple Arrangements from Holt and School (1982)	15
Table 2.2 Percentage bruising on Out-turn in Europe NZAPMB 1992	18
Figure 2.6 A and B Style Friday Trays used in 5 Layer Count 88 Packs (from Fountain 1962)	20
Figure 2.7 Mean bruise volumes against tray position at different tray weights adapted from Byrom (1989)	24
Chapter 4 - ANALYSIS OF CARTON CONFIGURATIONS	37
Figure 4.1 Hexagonal Closest Packing of Spheres	37
Figure 4.2 Face Centred Cube (fcc) Packing of Spheres	38
Figure 4.3 Arrangement of Spheres in the Configuration of Count 88 Fruit.	39
Figure 4.4 Arrangement of Spheres in the Configuration of Count 100 Fruit.	39
Figure 4.5 Dimensions of Actual Fruit Placement 2x2	40
Figure 4.6 Dimensions of Actual Fruit Placement 3x2	40

Figure 4.7 Side Views of Cartons of Fruit	43
Photograph 1 Count 88 Carton	43
Photograph 2 Count 100 Carton	43
Figure 4.8 Plan View of Trays of Fruit	45
Photograph 1 Tray of Count 88 Apples	45
Photograph 2 Tray of Count 100 Apples	45
Figure 4.9 Support System for Count 88 Fruit.	47
Figure 4.10 Support System for Count 100 Fruit.	47
Figure 4.11 Siemens Somatom CT Scanner with Carton of Fruit in Place	49
Figure 4.12 Diagrams of Scanned Sections Count 88 Cartons	49
Figure 4.13 Diagrams of Scanned Sections Count 100 Cartons	51
Figure 4.14 CT Scans of Longitudinal Sections through the Cartons	53
Scan 1 Longitudinal Section of Count 88 Granny Smith Apples	53
Scan 2 Longitudinal Section of Count 100 Gala Apples	53
Figure 4.15 CT Scans of End Sections through the Cartons	55
Scan 1 End Section of Count 88 Granny Smith Apples	55
Scan 2 End Section of Count 100 Gala Apples	55
Figure 4.16 CT Scans Diagonal Sections through the Cartons	57
Scan 1 Diagonal Section of Count 88 Granny Smith Apples	57
Scan 2 Diagonal Section of Count 100 Gala Apples	57
Figure 4.17 CT Scans Showing Effect of Moisture on the Trays	59
Scan 1 Longitudinal Section Newly Packed Count 88 Braeburn Apples	59
Scan 2 Longitudinal Section Previously Packed Count 88 Braeburns	59
 Chapter 5 - TENSILE STRENGTH TESTS	 63
Figure 5.1 Position of Samples on a Count 88 Friday Tray	64
Figure 5.2 Sample dimensions	66
Table 5.1 Mean Data 8% Moisture Content	67
Table 5.2 Mean Data 15% Moisture Content	67
Table 5.3 Mean Values for Results of Tensile Strength Tests at 8% MC and 15% MC	68

Chapter 6 - DROP TESTS EXPERIMENTAL DETAILS AND RESULTS	71
Figure 6.1 Fruit Position within each Carton	74
Figure 1. Position of Count 88 Fruit within each carton	74
Figure 2. Position of Count 100 Fruit within each carton	75
Figure 6.2 Tray and Row Identification	77
Photograph 1 Tray and Row identification Count 88 Fruit	77
Photograph 2 Tray and Row identification Count 100 Fruit	77
Figure 6.3 Bruise Position	80
Figure 6.4 Bruise Dimensions	81
Table 6.1 Summary of Mean values for Number of Bruised Fruit, Number of Individual Bruises and Energy Absorbed per Carton.	83
Figure 6.5 Graphs of Bruise Distribution Count 88 15% MC	84
Graph 1 Count 88 Cartons 1-10 at 15% MC Tray 1	84
Graph 2 Count 88 Cartons 1-10 at 15% MC Tray 2	84
Graph 3 Count 88 Cartons 1-10 at 15% MC Tray 3	85
Graph 4 Count 88 Cartons 1-10 at 15% MC Tray 4	85
Figure 6.6 Graphs of Bruise Distribution Count 88 Cartons 8% MC	86
Graph 1 Count 88 Cartons 11-20 at 8% MC Tray 1	86
Graph 2 Count 88 Cartons 11-20 at 8% MC Tray 2	86
Graph 3 Count 88 Cartons 11-20 at 8% MC Tray 3	87
Graph 4 Count 88 Cartons 11-20 at 8% MC Tray 4	87
Figure 6.7 Graphs of Bruise Distribution Count 100 Cartons 1-9 8% MC	88
Graph 1 Count 100 Cartons 1-9 at 8% MC Tray 1	88
Graph 2 Count 100 Cartons 1-9 at 8% MC Tray 2	88
Graph 3 Count 100 Cartons 1-9 at 8% MC Tray 3	89
Graph 4 Count 100 Cartons 1-9 at 8% MC Tray 4	89
Figure 6.8 Mean Percentage of Bruised Fruit in each Tray Count 88 at 15% MC	90
Figure 6.9 Mean Percentage of Bruised Fruit in each Tray Count 88 at 8% MC	90
Figure 6.10 Mean Percentage of Bruised Fruit in each Tray Count 100 at 8% MC	92
Figure 6.11 Average Number of Bruises on Top and Bottom of Fruit in each Tray Count 88 at 15 % MC	92
Figure 6.12 Average Number of Bruises on Top and Bottom of Fruit in each Tray Count 88 at 8 % MC	92

Figure 6.13 Average Number of Bruises on Top and Bottom of Fruit in each Tray Count 100 at 8 % MC	93
Figure 6.14 Bruising Patterns in Vertical Section Count 88 Fruit	95
Photograph 1 Bruise Patterns Count 88 fruit Vertical section A	95
Photograph 2 Bruise Patterns Count 88 fruit Vertical section B.	95
Photograph 3 Bruise Patterns Count 88 fruit Vertical section C	97
Photograph 4 Bruise Patterns Count 88 fruit Vertical section D	97
Figure 6.15 Typical Bruise Patterns by Trays Count 100 Fruit	99
Photograph 1 Bruise Patterns Count 100 fruit Tray 1	99
Photograph 2 Bruise Patterns Count 100 fruit Tray 2	99
Photograph 3 Bruise Patterns Count 100 fruit Tray 3	101
Photograph 4 Bruise Patterns Count 100 fruit Tray 4	101
Photograph 5 Bruise Patterns Count 100 fruit Tray 5	103
Figure 6.16 Graph of Diameter vs Weight Count 88 Fruit	105
Figure 6.17 Graph of Diameter vs Weight Count 100 Fruit	105
Table 6.2 Correlation and Variance for Diameter and Weight for samples of one carton and 1000 fruit	106
Table 6.3 Mean Number of Tray Splits and Length of Splits per Carton.	106
Table 6.4 Correlation and Variance of Total length of Tray splits against Energy Absorbed in Bruising .	107
Figures 6.18 Count 100 Apple Carton During Descent	109
Figures 6.19 Apple Boxes Bouncing on Impact	111
Table 6.5 One Off Trial Data	113
Figure 6.20 Graphs of Numbers of Bruised Fruit in One Off Tests	114
Graph 1 Standard Trays	114
Graph 2 Double Trays	114
Graph 3 Thickened Trays	115
Graph 4 Rigid Trays	115
Figure 6.21 Graphs of Numbers of Individual Bruises in One Off Tests	116
Graph 1 Standard Trays	116
Graph 2 Double Trays	116
Graph 3 Thickened Trays	117
Graph 4 Rigid Trays	117
 Chapter 7 - ANALYSIS OF RESULTS	 119
Figure 7.1 Relationship between Apples, Bruises and Splits	123

Appendices

Figure 1.1	Idealised bruise from Schoorl and Holt (1980)	141
Table 5.1	Bruising Coefficient for Count 88 1 to 10 + One-off Tests	145
Table 5.2	Bruising Coefficient for Count 88 Cartons 11 to 20	155
Table 5.3	Bruising Coefficient for Count 100 Cartons 1 to 10	156
Tables 6.1	Data for Count 88 Cartons 1-10	159
Tables 6.2	Data for Count 88 Cartons 11-20	201
Tables 6.3	Data for Count 100 Cartons 1-10	243
Tables 6.4	Data for Count 88 One Off Tests	295
Table 7.1	Summary of Drop Test Data Count 88 Cartons at 15% MC	310
Table 7.2	Summary of Drop Test Data Count 88 Cartons at 8% MC	314
Table 7.3	Summary of Drop Test Data Count 100 Cartons at 8% MC	318
Table 7.4	Summary of Drop Test Data Count 88 Cartons One Off Tests	323
Table 8.1	Summary of Drop Test Data Count 100 Cartons at 8% MC Including Carton No 2	327
Figure 9.1	Split Site Positions on Count 88 Trays	333
Figure 9.2	Split Site Positions on Count 100 Trays	333
Table 9.1	Split Positions and Length (mm) in Count 88 Cartons with Trays at 15% MC	334
Table 9.2	Split Positions and Length (mm) in Count 88 Cartons with Trays at 8% MC	335
Table 9.3	Split Positions and Length (mm) in Count 100 Cartons 1-5 with Trays at 8% MC	336
Table 9.4	Split Positions and Length (mm) in Count 100 Cartons 6-10 with Trays at 8% MC	337
Figure 9.3	Typical Split Sites on Count 88 Trays at 8% MC	339
	Photograph 1 Typical Splits in Count 88 Tray 2 at 8% MC	339
	Photograph 2 Typical Splits in Count 88 Tray 3 at 8% MC	339
Table 10.1	Tensile Strength Data	342
Table 10.2	Duncan's Multiple Range Test	345
Table 11.1	Chi Squared Tests Count 88 at 15% Moisture Content	347
Table 11.2	Chi Squared Tests Count 88 at 8% Moisture Content	347
Table 11.3	Chi Squared Tests Count 100 at 8% Moisture Content	347
Figure 12.1	Coefficient of Variation against Summed Cartons	350
	Graph 1 Coefficient of Variation Count 88 Fruit Cartons 1-10	350
	Graph 2 Coefficient of Variation Count 88 Fruit Cartons 11-20	350
	Graph 3 Coefficient of Variation Count 100 Fruit Cartons 1-9	351