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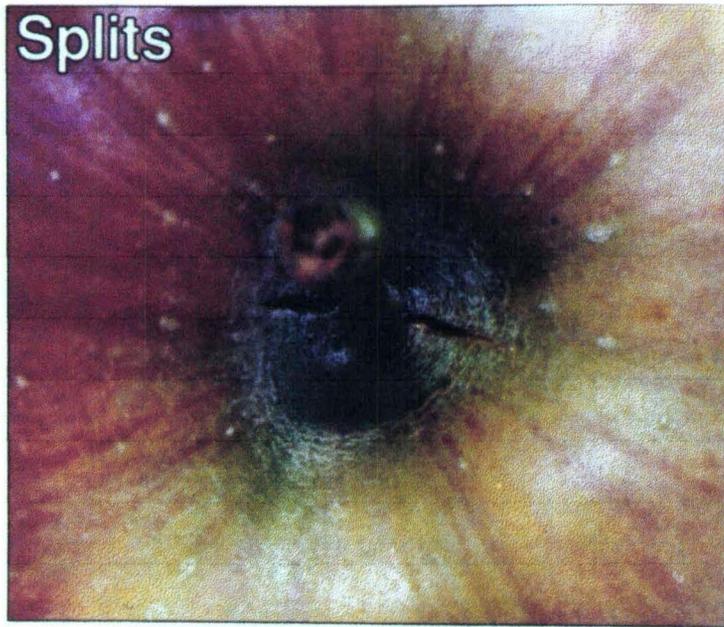
**A STUDY OF STEM-END SPLITTING  
IN APPLES**

**UMETZURUIKE LINUS OPARA**

**1993**

*But, my son, be warned:  
there is no end of opinions  
ready to be expressed.  
Studying them can go on forever,  
and become very exhausting.*

*Ecclesiastes 12:12*

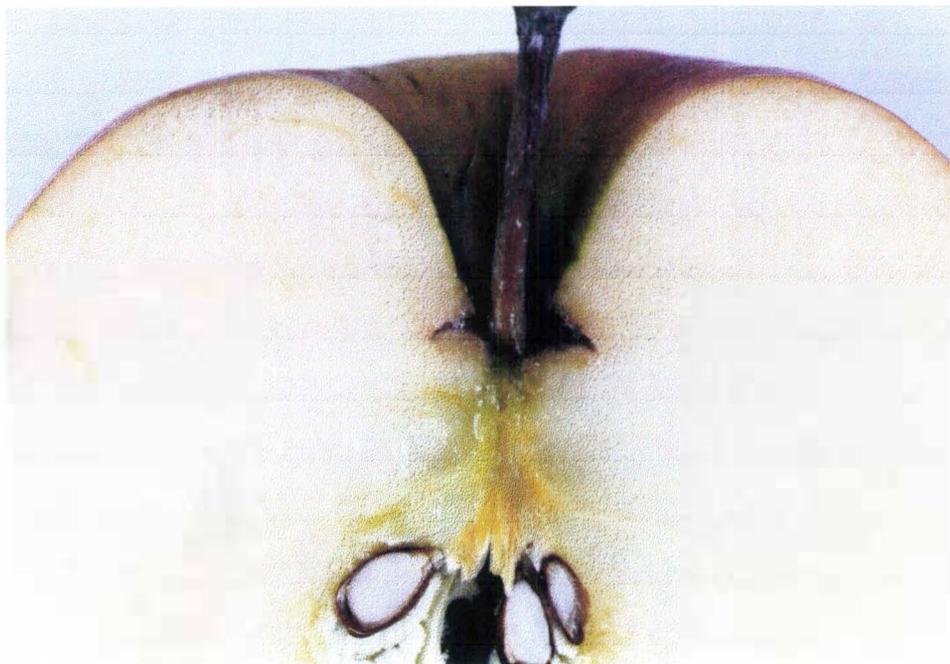


Apple with stem-end splits.

(NZAPMB, 1989)

When Newton saw an apple fall, he found ...  
A mode of proving that the earth turn'd round  
In a most natural swirl, called gravitation,  
And thus is the sole mortal who could grapple  
Since Adam, with a fall or with an apple.

*Don Juan 10, 11*



Apple with internal ring-crack.

... like a villain with a smiling cheek,  
A goodly apple rotten at the heart:  
O, what a goodly outside falsehood hath!

*Shakespeare*

**A STUDY OF STEM-END SPLITTING  
IN APPLES**

A thesis submitted in partial fulfilment  
of the requirements for the degree of

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in Agricultural Engineering

at

Massey University

New Zealand

**Umetzuruike Linus Opara**

**1993**

## ABSTRACT

One of the most widespread physical defects limiting the production and delivery of sound, blemish-free fruits is the cracking of the skin and splitting of the underlying flesh while the fruit is still attached to the tree. This occurs extensively in both pome and stone fruits. Of particular concern in this study is the problem of stem-end splitting which occurs in 'Gala', 'Royal Gala', and 'Fuji' apples. The production of these cultivars has expanded rapidly in New Zealand and overseas due to their productivity, good quality and high consumer acceptance. Thus, orchardists continue to produce these apples, accepting the risk that in some years splitting may be a serious quality problem.

The objective of this thesis was to investigate the causes and mechanism of occurrence of stem-end splitting in apples by (1) providing a detailed review of the literature on fruit cracking and splitting in apples, (2) studying the effects of orchard management practices on the incidence of stem-end splitting and making field observations to determine the physical characteristics of stem-end splitting of fruit, and (3) studying the growth characteristics and physical properties of fruit.

A review of the literature showed a dearth of information focused towards understanding the phenomenon of stem-end splitting whereas a considerable amount of literature was found on the causes of other forms of fruit cracking in apples, namely skin-cracking, star-cracking and general splitting of the fruit. Frequently in the literature, the information did not clearly differentiate the types of fruit cracking in apples and the word "cracking" was often used as a generic term to refer to several disorders, possibly including stem-end splitting.

This study has confirmed preliminary observations which suggested possible association between stem-end splitting and the presence of an internal "ring-crack" in fruit. Ring-cracks extended from the base of the stem outwards into the flesh of the apple in a plane at an angle of 90 degrees to the stem. By sectioning fruit at different stages of maturity, it was found that every fruit with stem-end splitting had internal ring-cracking at the stem-end but that some fruit without stem-end splitting had internal ring-cracks. No published research was found which noted the presence of this internal ring-cracking and it was concluded that ring-

cracking was a necessary precursor to the development of stem-end splitting.

Experimental studies on the effects of management practices showed that frequent irrigation significantly increased the incidence of stem-end splitting and ring-cracking by about 50% compared to a no irrigation treatment. Neither crop load nor foliar nitrogen had a significant effect on stem-end splitting or ring-cracking, although low crop load slightly increased both defects. Results from mechanical tests on fruit suggested that the increase in stem-end splitting due to frequent irrigation may be attributable to its effects in reducing the stress required to crush the flesh as well as increasing fruit size. These results suggested that orchard management practices which increase fruit size and reduce the mechanical strength of the flesh are likely to increase the susceptibility to stem-end splitting.

None of the management practices had a significant effect on the mineral status of fruit. However, comparison of good and damaged fruit showed significantly higher concentrations of calcium, phosphorous and potassium in fruit with ring-cracking or stem-end splitting. These findings contradicted previously published results which implicated mineral deficiencies (such as calcium) or excessive concentrations (such as nitrogen) as the cause of fruit cracking and similar physiological disorders in apples. The present results do not suggest any possible direct involvement of calcium and the other minerals with respect to resistance to stem-end splitting and it is probable that the higher concentration of minerals in affected fruit is a secondary response which may have occurred after cortical cells began to break down rather than before the onset of ring-cracking.

By monitoring the chronological development of stem-end splitting using random samples of fruit at 2-week intervals, both stem-end splitting and ring-cracking were first observed on the same day, about 3 weeks before the first commercial harvest or 115 days after full bloom (DAFB). The higher incidence of internal ring-cracking compared to stem-end splitting on this day supported the conclusion that stem-end splits develop from ring-cracks. It also suggested that the initiation of both defects occurred some days or hours earlier.

Evidence from studies on the growth and development of 'Gala' apples showed that the onset of stem-end splitting coincided with critical growth periods during the season. This suggested

that the development of stem-end splitting may be related to the imbalance in growth of the whole fruit or its constituent parts. No profound changes were observed in lineal dimensions of fruit size (length and diameter) at the onset of stem-end splitting; however, this period was associated with disproportionate growth rates of fruit length and diameter on the one hand, and the attainment of the final shape of fruit on the other. Also during this period, there was a sudden increase in longitudinal growth strain. It is suggested that ring-cracking might well arise due to greater tensile stresses that are exerted upon the fruit due to the growth imbalance at a time when each affected cell is least able to accommodate itself to withstand the additional stress. The presence of a ring-crack, therefore, forms a free edge of the fruit skin which is then predisposed to crack as predicted by fracture mechanics.

Results obtained from the end of season harvest of 'Gala' apples showed that fruit exposed to sunlight during growth (compared to shaded fruit) had a 45% higher incidence of ring-cracking although there were no significant differences in the amount of stem-end splitting. The insignificant effect on the amount of stem-end splitting was attributed to the loss of about 35% of the initial samples of the well exposed shading treatment.

From laboratory immersion tests using water and four non-ionic surfactants, it was shown that submerging fruit in surfactant solutions increased both the rate and total amount of water uptake compared with the water treatment (control). During the time-course of immersion, the cumulative water uptake (percent weight gain) of fruit increased significantly while the daily rate of water uptake declined, with the maximum intake occurring during the first 24 hours of immersion. Significant uptakes of water did not induce stem-end splitting although skin-cracking occurred. These results suggested that stem-end splitting and skin-cracking are distinct phenomena and that excessive water absorption alone does not appear to be the whole explanation for the incidence of stem-end splitting in apples. It was concluded that while skin-cracking may result from excessive swelling and bursting of the skin following sudden and rapid intake of water by the underlying flesh, a stem-end split is a growth crack which appears to be related more to changes associated with disproportionate fruit growth rates.

A tentative model of stem-end splitting in apples is presented based on the cumulative relationships between management practices and fruit properties. The model identifies factors

which increase or reduce the risk of stem-end splitting, and emphasises the significance of fruit growth rates and the influence of the micro-environment. Possible mechanisms of stem-end splitting and skin-cracking are also discussed based on theoretical considerations of cell failure and the pathway of water uptake in both intact growing fruit or detached fruit.

*DEDICATED TO*

*Papa Uzoma Opara*  
for his love for education and  
selfless community service;

*Mama Okaraonyemma? Opara, (nee Nwokoma)*  
for her prayers, love and patience;

*Dede Agbakwuruibe Opara*  
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and in memory of

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for his foresight, courage  
and exemplary fortitude.

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## LIST OF ABBREVIATIONS

$\alpha_{af}$	=	fruit-stem adhesion force, N
$\beta$	=	maximum twist angle at failure, degrees
$\Gamma_{max}$	=	maximum tensile stress, Pa
$\epsilon$	=	tensile strain
$\epsilon_{max}$	=	maximum tensile strain
$\zeta_{bs}$	=	skin bursting stress, Pa
$\theta$	=	angle of rotating arm, degrees
$\Pi$	=	pi, 3.1416
$\sigma_{cr}$	=	flesh crushing stress, Pa
$\sigma_t$	=	tensile stress, N.m <sup>-2</sup>
$\chi^2$	=	chi-square
$\Psi$	=	moment of couple, N.m
$\Omega_{br}$	=	skin bursting force, <b>N</b>
a	=	blade radius, m
A	=	arcsin transform of percentage ring-cracked fruit
AGR	=	absolute growth rate
ANOVA	=	analysis of variance
b	=	width of twist blade, m
$b_a$	=	width of apple specimen, m
B	=	percentage ring-cracked fruit
C/D	=	cavity:diameter ratio of fruit
C/L	=	cavity:length ratio of fruit
Ca	=	Calcium
CG	=	cumulative growth
Cu	=	Copper
d	=	distance from the centre of the pivot to the point of support in the horizontal position, m
D	=	thickness of apple specimen, m
D-L	=	difference between fruit diameter and length
DAFB	=	days after full bloom

DMRT	=	Duncan's Multiple Range Test
$d_p$	=	diameter of penetrometer probe, m
E	=	Young's Modulus, Pa
F	=	tensile force, N
FC	=	Field capacity
Fe	=	Iron
$F_{max}$	=	maximum tensile force, N
g	=	acceleration due to gravity, $9.807 \text{ m.s}^{-2}$
I	=	second moment of area, $\text{m}^4$
IRC	=	Internal ring-cracking
K	=	Potassium
kg	=	kilogramme
l	=	length of rectangular fruit specimen, m
L	=	total length of rotating arm, m
L/D	=	length:diameter ratio or fruit shape
LSD	=	least significant difference
$L_{wp}$	=	leaf water potential, Pa
m	=	mass of arm, kg
m	=	metre
M	=	maximum moment produced when the arm is horizontal (i.e. $\theta = 90^\circ$ ), N.m
Ma	=	Moment of the rotating arm, N.m
MAF	=	Ministry of Agriculture and Fisheries
Mb	=	Moment of the whole blade, N.m
Mg	=	Magnesium
Mn	=	Manganese
MRGR	=	mean relative growth rate
N	=	Nitrogen
N	=	Newtons
p	=	distance from the lower end of the arm to the centre of the axle, m
P	=	Phosphorous

q	=	distance from the top end of the arm to the centre of the axle, m
R	=	radius of curvature of the neutral axis, m
RCBD	=	randomized complete block design
RGR	=	relative growth rate
s	=	second
SAS	=	Statistical Analysis Systems
SES	=	Stem-end splitting
SPD	=	split plot design
T1	=	Treatment one - low water
T2	=	Treatment two - low to high water
T3	=	Treatment three - medium water
T4	=	Treatment four - high water
TDR	=	Time Domain Reflectometer
$t_{sk}$	=	thickness of fruit skin, m
vs	=	versus
$W_t$	=	total weight of arm, N
x	=	deformation of apple specimen, m
X	=	percentage stem-end split fruit
$x_1$	=	mass of fruit, kg
$x_2$	=	penetrometer reading, kg
y	=	distance to fibre from neutral axis, m
Y	=	arcsin of the square-root transform of percentage stem-end split fruit
Zn	=	Zinc
°C	=	Degrees Centigrade