PREDICTION AND QUANTIFICATION OF APPLE BRUISING

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LIST OF SYMBOLS

A .... Contact area (cm^2)

A_{ais} .... Peak acceleration by adjusted calibration file (g)

$A_b(A_b)$ .... Bruise area (cm^2)

A_{cb} .... Contact area or bruise area (cm^2)

A_r .... Acceleration recorded by the accelerometer (g)

A_{ois} .... Peak acceleration by original calibration file (g)

a .... Radius of contact surface (m)

a_n .... Normal component of the acceleration of mass centre

a_t .... Tangential component of the acceleration of mass centre

BD .... Bruise diameter (mm)

$BDAH$ .... Adjusted Hertz bruise diameter (mm)

D .... The surface diameter of bruise (mm)

D_a .... Apple diameter (mm)

d .... Depth of bruise at the centre of bruise region (mm)

d_1 .... Major diameter of bruise area or contact area (mm)

d_2 .... Minor diameter of bruise area or contact area (mm)

E_a .... Energy absorbed (J)

E_i .... Impact energy (J)

E_1 .... Elasticity modulus of the first sphere (kg/m^2)

E_2 .... Elasticity modulus of the second sphere (kg/m^2)

e .... Coefficient of restitution

F .... Magness-Taylor force (kg)

g .... Acceleration due to gravity ($9.81 m/s^2$)

H (h) .... Drop height (m)

H_1 .... Rebound height (mm)

h_b .... Depth of bruising below the contact plane (mm)

h_1 .... Depth of bruise (mm)

h_2 .... Depth of bruise region (mm)
I .... Moment of inertia (kg m^2)
K .... Two-fifths power of impact energy (J$^{2/5}$)
k_p .... Initial drop height (mm)
k_1 .... Bruise susceptibility (cm^3/J)
k_2 .... Constant
l .... Length of the arm (m)
m .... Mass of apple (kg)
m_i .... Mass of a particle (kg)
m_p .... Mass of aluminium arm (kg)
m_1 .... Mass of first sphere (kg)
m_2 .... Mass of second sphere (kg)
PA .... Peak acceleration (g)
q_p .... Geometrical progression factor
R .... Radius of apple (mm)
R_1 .... Radius of first sphere (m)
R_2 .... Radius of second sphere (m)
r_i .... Distance from the particle to rotating point O (m)
V .... Velocity of approach (m/s)
V_{a1} .... Total volume (cm^3)
V_{a2} .... Bruise volume above the contact plane (cm^3)
V_b .... Bruise volume (cm^3)
VC .... Velocity change (m/s)
W .... Apple weight (kg)
X .... Height of bruise above contact plane (mm)
α .... Approach of two impacting objects (m)
α_a .... Angular acceleration
λ .... Regressed ration
υ_1 .... Poisson's ratio of the first sphere

υ_2 .... Poisson's ratio of the second sphere

ψ .... Ratio of total velocity change to the maximum acceleration

ω .... Angular velocity

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ABSTRACT

Mechanical handling subjects fruit to impacts which often cause bruising. Such bruising is a major source of quality loss in the fruit industry. In this study, a range of experiments was carried out to investigate the quantification of bruises and the prediction of bruising in relation to mechanical handling systems.

In order to understand apple bruising, a study of free normal impact between pairs of apples was conducted. There was a 2/5 power relationship between contact area and impact energy. The coefficient of restitution varied in a non-linear manner with impact energy, decreasing as impact energy increased.

Bruise damage produced by a typical New Zealand-made fruit grader was critically analysed. A large percentage of individual bruises was under 1 cm^2 in area and it was rare to have any bruises above 3 cm^2. The total number of bruises was found to be the best indicator of bruise susceptibility. A new method of predicting such bruises has been developed involving a new term, the Bruise Factor, which was related to bruising sustained during handling operations, allowing for the variation in fruit size, shape and mass.

An Instrumented Sphere (IS) was used to characterize impacts on commercial packing lines. It was found that the IS could be used to identify apple-to-apple impacts likely to cause bruising in commercial packing operations, providing care is taken with interpretation of the data. Typical impacts on packing lines were represented by impacts onto a flat steel surface, a rubber pad, a plastic tube, a solid plastic bar, and onto another fruit. Impact tests were conducted on freshly picked Gala, Splendour, Fuji, Braeburn, and Granny Smith apples, all grown in Hawkes Bay, New Zealand. Bruise areas produced by impact onto flat steel, rubber, plastic tubing, and a solid plastic bar were found to be linearly correlated with the peak acceleration recorded by an Instrumented Sphere dropped from the same heights.

Following fruit-to-fruit impacts, bruising was generally more severe on one of the two apples. When the results of apple-to-apple and IS-to-apple impacts were compared, it was found that the area of the larger of the two bruises produced in fruit-to-fruit impacts was directly related to the peak acceleration recorded by the IS when it was dropped onto a fruit from the same height.

For each variety and each surface the drop height required to produce a critical bruise with a surface area of 1 cm^2 (as measured with the skin removed) was determined. By joining the threshold points on each surface response line, a threshold potential bruise boundary was formed on a velocity change against peak acceleration graph. The boundary curve, which included apple-to-apple impact, was hyperbolic in shape, rather than the linear boundary described in other studies.

The implications of the results to the fruit industry are discussed in this study.