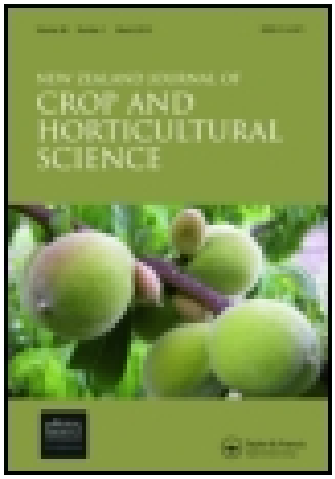

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Colour changes in bruised apple fruit tissue

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Abstract A study of changes with time in aspects of bruise colour in 'Granny Smith' apples (*Malus domestica*) was undertaken in an attempt to identify the optimum time for assessment of bruise severity in experiments on apples. Bruised cortical tissue became darker (decreased lightness), browner (decreased hue angle), and increased in colour intensity (increased chroma) in the first few hours following impact. Discoloration subsequently faded gradually with time. Bruises became further discoloured with delays between sectioning and measurement, even when bruising had occurred 48 h beforehand. Colour data on bruises should therefore be collected at a standard time interval after cutting them open. Moisture and dry matter began to migrate out of bruises within 1 h of impact, providing a mechanism for "bruise recovery" in which bruises are observed to fade and develop a dry appearance with time. To assess bruises at their most intense degree of discoloration, they should be allowed to develop for a period of 4–14 h before sectioning.

Keywords apple; *Malus domestica* Borkh.; 'Granny Smith'; lightness; chroma; hue angle; bruise recovery; optimum; assessment; half-time; weight; impact

INTRODUCTION

Bruising is currently one of the most important reasons for rejection of apples from export grade at quality inspection (S. McLeod pers. comm. 1993). Perceived severity of bruises depends upon both size and colour of the bruised area. Variation in bruise size for a given impact energy occurs between cultivars and with a number of factors such as maturity and temperature (Hyde & Ingle 1968; Saltveit 1984; Klein 1987; Johnson & Dover 1990). To date, there have been virtually no reports on relationships between severity of discoloration and horticultural factors which might be manipulated to reduce severity of observed bruising.

Ingle & Hyde (1968) examined rate of change of colour of apple bruises with time. They indicated that, for 'Red Delicious' and 'McIntosh', 50% of the discoloration occurred within c. 20 min. This contrasts with the widely held view in the New Zealand apple industry that colour of bruises takes 1 or 2 days to develop. Discoloration of apple tissue is mainly the result of oxidation of phenolic compounds by polyphenoloxidase, a process that would be expected to be complete within minutes rather than days (CoSeteng & Lee 1987; Burda et al. 1990). However, commercial fruit assessment is made by inspection of the fruit surface, rather than by sectioning bruises and it seems feasible that development of surface discoloration could lag behind changes occuring within the damaged cortical tissue. Many industry personnel have also observed that, after initial development of colour, bruises subsequently fade, leading to a belief in the phenomenon of "bruise recovery" in which bruises become less visible with time. Neither data nor a physiological mechanism for this putative "healing" effect have been reported.

Detection of bruises is critical both to researchers and industry personnel in their work on developing procedures to reduce this serious cause of loss. This study was designed to characterise changes in bruise colour with time following impact and to examine whether or not these changes were related to short-term changes in bruise fresh and dry weights.

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MATERIALS AND METHODS

A series of three experiments was carried out on 'Granny Smith' apples (*Malus domestica* Borkh.) in 1991. Fruit for Experiments 1 and 2 were hand picked early in the morning from the Fruit Crops Unit Orchard, Massey University, New Zealand between 3 and 9 May 1991. They were equilibrated at 20°C for 1 h before treatment. Fruit for Experiment 3 (count 80, average weight = 230 g) were obtained from the New Zealand Apple and Pear Marketing Board in Hastings in early May 1991, stored in air at 0°C for between 4 and 6 weeks, and then equilibrated in the laboratory at 20°C for 24 h.

Experiment 1

To examine changes in colour with time, bruises on five fruit per replicate were measured immediately after sectioning at different periods after impact. This experiment was of randomised block design, with four replications and nine sectioning times (0, 1, 2, 4, 8, 14, 24, 48, and 96 h). Fruit were subjected to a standard impact (0.15 J) applied by dropping a 25 mm diameter stainless steel ball (weight = 0.110 kg) down a tube from a height of 0.139 m onto the greenest part of the fruit surface.

A Minolta Chromameter (model CR–100 Minolta Camera Limited, Osaka, Japan) calibrated to a white plate (Francis 1980) was used to obtain measures of bruise lightness (L'), chroma (C'), and hue angle (H'). Internal colour of bruised flesh was determined by applying the chromameter to the cut surface of the bruise. External colour was assessed on the bruise itself and compared with that of an immediately adjacent, non-bruised area of skin. The chromameter aperture was reduced to 8 mm, using a perforated aluminium disc, and placed at the centre of the discoloured tissue to avoid taking in undamaged areas of the fruit. Colour data presented here are therefore relative rather than absolute.

Experiment 2

To determine the effects of delays between sectioning and colour assessment, colour of bruises was measured on five fruit per replicate at different delays (0, 1, 24, and 48 h) after impact and then following varying delays (0, 0.25, 0.5, 1, 2, 4, and 8 h) after sectioning. There were four replications per treatment in a randomised block design. The same fruit were measured once at each of the different periods of delay following sectioning. Fruit were sectioned longitudinally through the bruise centre; fruit halves were put together and wrapped in plastic film to prevent dehydration. Impacts and colour measurements were made as above.

Experiment 3

Changes in fresh and dry weights of bruises with time after impact were examined in this randomised block design experiment. There were six assessment times (0, 1, 3, 6, 12, and 24 h), with five uniform, weighed fruit at each assessment time for each of three replications. Fruit were suspended on a pendulum, swung back and then released to provide an impact (0.34 J) against a steel block (Pang et al. 1992; drop height = 0.15 m). Bruised tissues were excised by razor and fresh weights were recorded; they were then freeze-dried before oven-drying at 101°C to constant weight.

Statistical analysis

Analysis of variance was carried out using the general linear models procedure of SAS (Statistical Analysis System—Littell et al. 1991). In both Experiments 1 and 2, effects of time after bruising were tested against the interaction of time after bruising with blocks. Effects of time after sectioning in Experiment 2 were tested using orthogonal polynomial contrasts in "repeated measures" analysis of variance (Littell et al. 1991). In Experiment 3, trends in weight with time were examined by linear and quadratic regression, with block effects removed as dummy variables (Freund & Littell 1991).

RESULTS

Experiment 1

In bruises measured immediately after sectioning, L' showed a rapid initial decline with time ($P < 0.001$; Fig. 1A) before slowing to a continuous downward drift between 30 and 96 h. Hue angle decreased sharply in the first hour, continued to decline until 4 h after impact ($P < 0.001$ for effects of time after bruising; Fig. 1B) and then increased gradually during the remainder of the experiment. Bruise chroma increased sharply until 4 h, reached a maximum at c. 14 h and then decreased gradually for the remainder of the experiment (Fig. 1C). Of the components of bruise colour measured through the skin, C' changed significantly but only by 12% (from 45.5 to 40.2 between 0 and 96 h; SED = 1.68, 24 d.f.). L' and H' remained constant at 54.5 ± 0.46 and 115.2 ± 0.24, respectively.

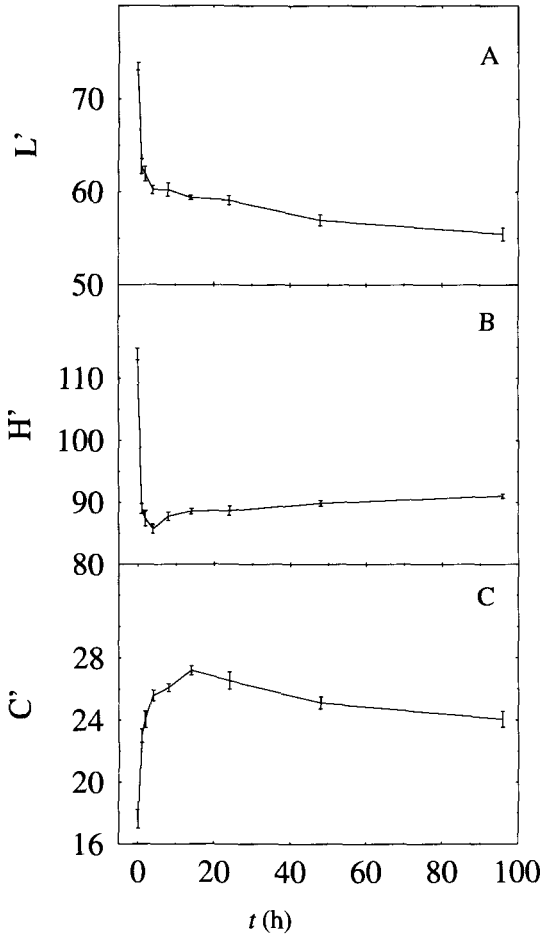

Fig. 1 Measures of **A**, lightness (L'); **B**, hue angle (H'); and **C**, chroma (C') of 'Granny Smith' apple bruises at assessment times (*t*) 0, 1, 2, 4, 8, 14, 24, 48, and 96 h after impact.

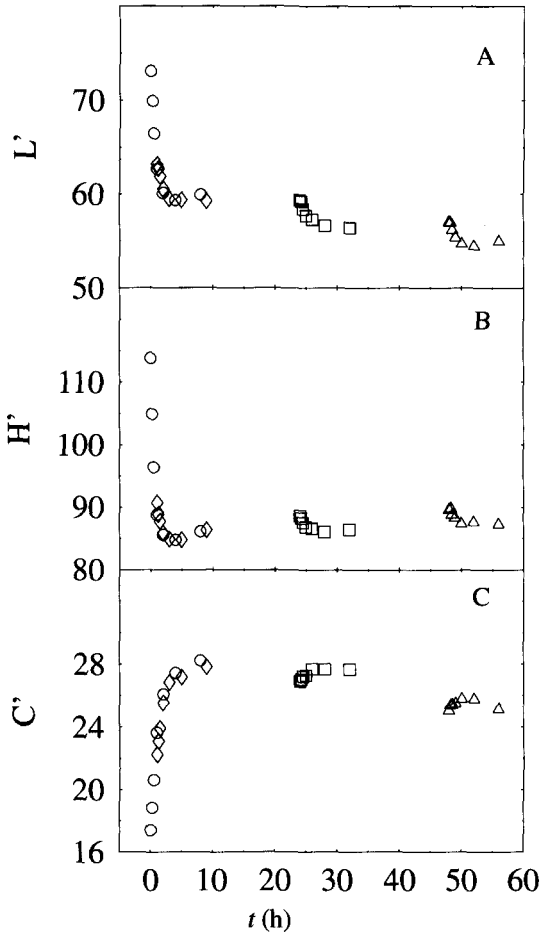

Fig. 2 Measures of **A**, lightness (L'); **B**, hue angle (H'); and **C**, chroma (C') of 'Granny Smith' apple bruises at assessment times (*t*) after impact. Assessments were made 0, 0.25, 0.5, 1, 2, 4, and 8 h after sectioning for bruises applied 0 (○), 1 (◇), 24 (□), or 48 (△) h before sectioning.

Experiment 2

For each of the bruise colour variables studied, analysis of variance detected significant mean polynomial effects of time after sectioning up to the sixth power ($P < 0.001$, 0.001, 0.001, 0.01, 0.05, and 0.01, respectively). In addition, the magnitudes of these polynomial effects up to the fourth power were dependent upon the delay between the impact on the fruit and sectioning ($P < 0.001$, 0.001, 0.001, and 0.01, respectively). Clearly, therefore, the analysis of variance of polynomial contrasts was effective in demonstrating that there were definite changes in colour with time after sectioning but the complexity of these changes meant that the polynomial model itself was of little further use in interpreting the data.

Bruise lightness (L') declined approximately exponentially with time after sectioning, in similar fashion to Experiment 1 (Fig. 2A). For all periods of delay before sectioning, there appeared to be a half-time of between 30 and 60 min for loss of L'. Delays between bruising and sectioning allowed greater proportions of total change in L' to occur before sectioning. Following the longer delays (24 and 48 h), L' appeared to remain steady for 15 min before starting to decline. When measured immediately after sectioning, bruise lightness also declined

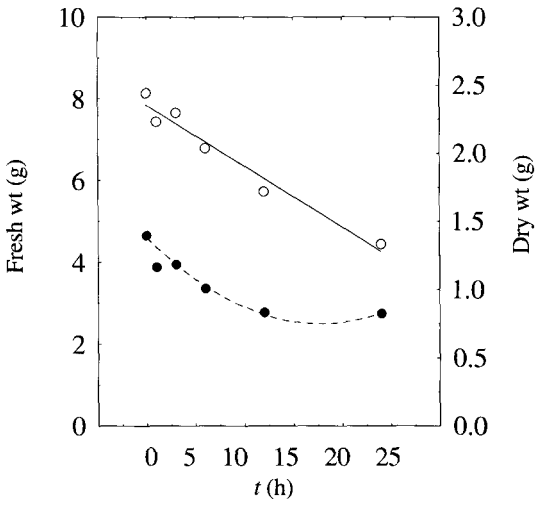

Fig. 3 Fresh (○) and dry (●) weights of bruises on 'Granny Smith' apples at assessment times (t) 0, 1, 3, 6, 12, and 24 h after a 0.34 J impact onto a steel block. Lines show fitted polynomials.

approximately exponentially but appeared to drift downwards with extended time, rather than reaching a firm asymptote, as would be the case for a true exponential relationship.

Hue angle (H') also declined sharply in the first hour after sectioning, eventually reaching a new low level c. 4 h after sectioning in freshly bruised fruit and apparently recovering slightly with further time (Fig. 2B). These effects were less dramatic in fruit in which the bruise had been allowed to develop for longer periods before sectioning, reflecting the greater proportion of total hue angle change that occurred before fruit were cut.

Chroma developed slightly more slowly than L' and H', with an approximate half-time for the change of 1 h (Fig. 2C). Changes in C' with time after sectioning became progressively smaller in magnitude with increased delays between bruising and sectioning. Rather than continuing to develop in the same direction as for L', C' appeared to reach a maximum at somewhere between 10 and 20 h after bruising and then to decline slowly.

Experiment 3

Bruise fresh weight declined approximately linearly with time (Fig. 3; $P < 0.001$). Bruise dry weight also declined but the rate at which it did so became less with time ($P < 0.05$ for the quadratic effect of time).

DISCUSSION

Most discoloration of bruised 'Granny Smith' apple tissue occurred within a few hours of applying the impact to the fruit surface. Tissues became darker (decreased L' value), browner (decreased H'), and increased in colour intensity (increased C' value) after bruising, presumably as a result of cell rupture, oxidation of phenolics, and watersoaking in damaged tissue.

Overall patterns of change with time in the various components of colour of bruised tissues indicate that an exponential model of discoloration with time is only loosely appropriate. However, this approach does allow some comparison with earlier work in this area. Our findings on bruise discoloration of 'Granny Smith' apples indicate a half-time ($t_{0.5}$) of 40 min, approximately twice that reported by Ingle & Hyde (1968) for discoloration of bruised 'McIntosh' apple flesh. If final discoloration for any of the colour variables is expressed as D^{∞} then the percentage of D^{∞} achieved at time t after bruising (D^t) can be estimated as:

$$D^t = 100\ (1 - 0.5^{-t/t_{0.5}}) \quad (1)$$

Re-arranging Equation 1 permits estimation of the time required for 99% of final discoloration to occur ($t_{0.99}$):

$$t_{0.99} = \frac{\ln(0.01)}{\ln(0.5)} t_{0.5} \quad (2)$$

Ingle & Hyde's data suggest that the time required for 99% discoloration in 'McIntosh' apples would be 133 min; for 'Granny Smith' apples about twice that period would be required. Burda et al. (1990) examined discoloration of apple slices 7 min after slicing. The approach outlined above indicates that the amount of discoloration in their slices would only have been between c. 11 and 22% of the final value at this time (for 'Granny Smith' and 'McIntosh', respectively) and the rate of colour change would still have been quite rapid (1.5–2.7% of final discoloration per min). These effects are likely to have been greater still if the delay in initial discoloration following sectioning seen for the later sectioning times in Experiment 1 applies also to the non-bruised tissue at the cut surfaces of their slices. Notwithstanding other factors which could influence rate of browning, it seems very likely that delay of considerably more than 7 min would be necessary to ensure accurate determination of the true browning potential of such slices.

The different values for $t_{0.5}$ obtained in these studies presumably relate at least in part to differences

in polyphenol oxidase activity within the fruit tissues under study (Prabha & Patwardhan 1985; CoSeteng & Lee 1987). On the other hand, variations in the final intensity of discoloration would depend upon the concentration of phenolics and other cofactors within the tissue (Walker 1962) and the proportion of cells ruptured in the bruised area. Christensen (1985) reported that intensity of browning in apple fruit flesh is inversely related to ascorbic acid content. Bruises on the blushed side of red-skinned apple cultivars are generally more intensely discoloured than those on the green side of the same fruit (Samim & Banks unpubl. obs.), presumably because of a difference in the concentration of phenolic precursors for anthocyanin pigments in red areas (Klein 1987). However, the red pigmentation in the skin masks this more intense discoloration quite effectively so that red-skinned cultivars are often perceived to be less bruise-susceptible than green or yellow-skinned fruit.

There was a continued downward drift in L' and some recovery in H' and C' after the initial, rapid phase of discoloration. That bruise colour intensity peaked a few hours after impact and then declined supports the belief that fruit recover from bruises with time. This perception must arise from changes in bruise visibility as changes in bruise size with time after impact are very small (Samim & Banks unpubl. data). The fading demonstrated here coincided with loss in both fresh and dry weight from the bruise area presumably because of loss of sap from the bruise to surrounding healthy tissues. This could have contributed in two ways to the observed fading in colour intensity with time. Migration of oxidised phenolics out of the bruised zone, along with other dry matter, could have contributed directly to loss of colour intensity. Bruises sectioned after 96 h had become dry in appearance, having lost the water-soaking seen immediately after impact. This presumably also contributed to the change in perceived intensity of discoloration of bruises with time, as initially translucent bruised tissue became opaque with loss of moisture in a similar way to the appearance of a moistened paper tissue drying with time. This may also have led to decreased reflectance of the sectioned bruise and explain why L' continued to drift downwards with time and exhibit a different trend with time to the other two colour variables.

Whilst development and subsequent fading of bruise discoloration viewed through the skin were observed with time after impact, these effects were barely discernible in the chromameter data. Presumably, this effect related to the depth within the tissue from which the chromameter gathered light: it is probable that skin pigmentation was the dominant feature of colour measurements made through the skin surface. This precludes making firm statements about the optimum time for subjective (visual) assessment of bruises in commercial quality inspection, in which peeling or sectioning of fruit to check for bruises would be destructive and excessively labour-intensive. There would certainly need to be a period allowed for bruise colour development—elimination of fruit at the sorting table and subsequent inspection of fruit for damage induced by grading equipment should not be attempted until perhaps more than 4–14 h after the fruit would last have been bruised. Subsequently, fruit should be inspected reasonably swiftly to prevent excessive fading impairing their visibility. Such bruises would presumably be even less obvious to consumers but could still have a marked effect on consumer satisfaction at the time of consumption. Different criteria apply in experimental work in which bruises are sectioned. In this instance, discoloured tissue should be easily detectable within an hour of impact. Given that colour changed following sectioning even 48 h after impact, colour data should be collected immediately upon sectioning.

REFERENCES

Burda, S.; Oleszek, W.; Lee, C. Y. 1990: Phenolic compounds and their changes in apples during maturation and cold storage. *Journal of agriculture and food chemistry 38*: 945–948.

Christensen, P. E. 1985: The effects of cultivation methods on the quality of apples. I. Investigations into methods of measuring fruit quality. Pp. 115–121 *in*: The effects of modern production methods on the quality of tomatoes and apples. Gormley, T. R.; Sharples, R. O.; Dehandtschutter, J. *ed.* Luxembourg, Office for Official Publications of the European Communities.

CoSeteng, M. Y.; Lee, C. Y. 1987: Changes in apple polyphenoloxidase and polyphenol concentrations in relation to degree of browning. *Journal of food science 52*: 985–989.

Francis, F. J. 1980: Colour quality evaluation of horticultural crops. *HortScience 15*: 58–59.

Freund, R. J.; Littell, R.C. 1991: SAS system for regression, 2nd edition. Cary, North Carolina, USA, SAS Institute.

Hyde, J. F.; Ingle, M. 1968: Size of apple bruises as affected by cultivar, maturity and time in storage. *Proceedings of the American Society for Horticultural Science 92*: 733–738.

Ingle, M.; Hyde, J. F. 1968: The effect of bruising on discoloration and concentration of phenolic compounds in apple tissues. *Proceedings of the American Society for Horticultural Science 93*: 738–745.

Johnson, D. S.; Dover, C. J. 1990: Factors affecting the bruise susceptibility of 'Bramley's Seedling' apples. Pp. 87–94 *in*: *Proceedings of the International Conference on Agricultural Mechanization, 27–30 March, Zargoza, Spain*. Vol. 2. Workshop on Impact Damage of Fruits and Vegetables.

Klein, J. D. 1987: Relationship of harvest date, storage condition and fruit characteristics to bruise susceptibility of apple. *Journal of the American Society for Horticultural Science 112*: 113–118.

Littell, R. C.; Freund, R. J.; Spector, P. C. 1991: SAS systems for linear models, 3rd edition. Cary, North Carolina, USA, SAS Institute. 329 p.

Pang, W.; Studman, C. J.; Banks, N. H. 1992: Analysis of damage thresholds in apple-to-apple impacts using an instrumented sphere. *New Zealand journal of crop and horticultural science 20*: 159–166.

Prabha, T. N.; Patwardhan, M. V. 1985: A comparison of the browning potential of some Indian cultivars of ripening apples II. *Journal of food science and technology 22*: 431–433.

Saltveit, M. E. 1984: Effect of temperature on firmness and bruising of 'Starkrimson' and 'Golden Delicious' apples. *HortScience 19*: 550–551.

Walker, J. R. L. 1962: Studies on the enzymic browning of apple fruit. *New Zealand journal of science 5*: 316–324.