# Multiple Regression Based on Impact Parameters for Bruising Prediction in Apple

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## ABSTRACT

*Impact parameters were explored to be used for bruising predictions in apple by employing multiple regression analysis. All impact parameters observed were potential to be involved in the predictions except mass of fruit and impact duration. The multiple regression analysis based on maximum acceleration, velocity change, initial velocity, absorbed energy, maximum deformation and residual deformation produced a coefficient correlation (R) of 0.95 and 0.04% error for the relation between predicted bruise diameter and measured bruise diameter, a coefficient correlation (R) of 0.94 and 0.09% error for the relation between predicted bruise depth and measured bruise depth, a coefficient correlation (R) of 0.95 and 3.64% error for the relation between predicted bruise volume and measured bruise volume. The multiple regression based only on the maximum acceleration and velocity change still produced reliable bruising predictions.*

Keywords: apple, bruising, impact parameter

## INTRODUCTION

Bruising become a major problem in fresh market of apples (Siyami et al., 1988; Studman, 1990; Peleg, 1984). Bruising in fruits may occur because of impact or compression beginning from harvest in field until final mastication. However, a study of handling system reported that majority of bruising is produced by impact of fruit against various surfaces and impact of fruits, among themselves (Banks, 1991; Bollen & Dela Rue, 1990).

The mechanic of bruising has been studied by impacting fruits against different surfaces and various approaches have been established to interpret the results (Schoorl & Holt, 1980; Diener et al., 1979; Franke & Rohrbach, 1981; Horsfield et al., 1972; Brown et al., 1990). By using a force transducer the force generated during impact can be recorded and then various impact parameters may be derived from this impact curve (Barquins & Charmet, 1994a, & 1994b; Franke & Rohrbach, 1981; Lichtensteiger et al., 1988; Meredith et al., 1990; Zhang & Brusewitz, 1991; Zhang et al., 1994).

Some researchers have explored impact parameters in relation with bruising in fruits (De Baerdemaeker et al., 1978; Delwiche et al., 1989; Gan-More & Galili, 1987). Diener et al., (1979) noted that bruise volume correlated linearly with drop height of 10, 16 and 34.29 cm. Lang (1994) established a relation between impact energy that did not produce bruising, impact velocity and mass of fruit for some apple varieties. He concluded that the energy utilised in deformation consisted of dynamic and static energies but he did not show experimentally. Brusewitz & Bartch (1989) tried to develop a relation between bruise volume and some impact characteristics for five varieties of apples stored in modified and non-modified atmospheres for 250 days. Bruising was produced by impacting fruits from 5 to 25 cm drop heights. They indicated that the ratio bruise volume/impact energy increased during storage, impact duration increased with storage time and logarithm of the ratio maximum force/time varied linearly with logarithm of impact energy.

Siyami et al., (1988) studied the influence of drop height of fruit and types of impact surface for Ida Red apple. They found that among Hertz's theory, modified Hertz's theory and plastic theory, multiple regression was more effective in predicting bruise diameter. Chen & Yazdani (1991) suggested that for Golden Delicious apple impacted against some impact surfaces, impact parameters which were more correlated with bruise volume were the maximum slope of velocity-time curve, It would be advantages if the multiple regression analysis involve less impact parameters but still produce reliable results. To see this possibility we took a procedure of analysis as follows: all potential impact parameters were involved in the regression, one by one the impact parameters were eliminated and we observed the changes in coefficient correlation (R) and the errors produced by the relations between predicted bruise values and the measured bruise values.

Table 3 presents the multiple regression for bruise diameter prediction while table 4 presents the multiple regression for bruise depth prediction.

Table 3. **Model of multiple regression for bruise diameter prediction**

| Model $\longrightarrow d_p = \alpha . a_m^{\beta_1} . \Delta v^{\beta_2} . v_i^{\beta_3} E_a^{\beta_4} . d_m^{\beta_5} . d_r^{\beta_6}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NP | α | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | $\beta_5$ | $\beta_6$ | R | Error(%) |
| 6 | 5.2587 | -0.5113 | 1.4872 | -0.7439 | 0.3197 | -0.1324 | -0.0454 | 0.951 | 0.04 |
| 5 | 5.4636 | -0.5831 | 1.7292 | -0.8062 | 0.3022 | -0.2444 | | 0.951 | 0.02 |
| 4 | 4.463 | -0.3517 | 1.6079 | -1.1949 | 0.3143 | | | 0.952 | 0.01 |
| 3 | 4.7341 | -0.5123 | 0.5305 | 0.7235 | | | | 0.942 | 0.01 |
| 2 | 4.3863 | -0.5262 | 1.3007 | | | | | 0.939 | 0.02 |

Note :

NP = number of parameter
R = coefficient of correlation of the relation between predicted bruise diameter and measured diameter

Table 4. **Model of multiple regression for bruise depth prediction**

| Model $\longrightarrow h_p = \alpha . a_m^{\beta_1} . \Delta v^{\beta_2} . v_i^{\beta_3} E_a^{\beta_4} . d_m^{\beta_5} . d_r^{\beta_6}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NP | α | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | $\beta_5$ | $\beta_6$ | R | Error(%) |
| 6 | 4.6859 | -0.6137 | -0.5500 | 1.5849 | 0.2666 | 0.2988 | -0.3517 | 0.944 | 0.09 |
| 5 | 6.2746 | -1.1694 | 1.3251 | 1.1027 | 0.1308 | -0.5697 | | 0.944 | 0.10 |
| 4 | 3.9425 | -0.6302 | 1.0424 | 0.1967 | 0.1590 | | | 0.944 | 0.14 |
| 3 | 4.0797 | -0,7115 | 0.4972 | 1.1674 | | | | 0.943 | 0.12 |
| 2 | 3.5186 | -0.7339 | 1.7399 | | | | | 0.939 | 0.21 |

Note :

R = coefficient of correlation of the relation between predicted bruise depth and measured depth.

Table 5 presents the multiple regression for bruise volume prediction

Table 5. **Model of multiple regression for bruise volume prediction**

| Model $\longrightarrow V_p = \alpha . a_m^{\beta_1} . \Delta v^{\beta_2} . v_i^{\beta_3} E_a^{\beta_4} . d_m^{\beta_5} . d_r^{\beta_6}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NP | α | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | $\beta_5$ | $\beta_6$ | R | Error(%) |
| 6 | 7.5767 | -1.6312 | 2.6609 | -0.0611 | 0.9158 | 0.0072 | -0.4177 | 0.950 | 3.54 |
| 5 | 9.4634 | -2.2912 | 4.8878 | -0.6338 | 0.7545 | -1.0241 | | 0.951 | 2.74 |
| 4 | 5.2707 | -1.3219 | 4.3795 | -2.2626 | 0.8052 | | | 0.953 | 2.48 |
| 3 | 5.9653 | -1.7332 | 1.6192 | 2.6523 | | | | 0.944 | 2.71 |
| 2 | 4.6906 | -1.7843 | 4.4425 | | | | | 0.940 | 2.35 |

Note :
R = coefficient of correlation of the relation between predicted bruise volume and measured volume.

Table 1, 2, and 3 indicate that reliable predictions can be obtained by involving only the maximum acceleration and velocity change in the multiple regression analysis.

## CONCLUSION

All impact parameters were potential to be used as bruising predictions in apple except mass of fruit and impact duration. The multiple regression analysis based on maximum acceleration, velocity change, initial velocity, absorbed energy, maximum deformation and residual deformation produced a coefficient of correlation (R) of 0.95 and 0.04% error for the relation between predicted bruise diameter and measured bruise diameter, a coefficient of correlation (R) of 0.94 and 0.09% error for the relation between predicted bruise depth and measured bruise depth, a coefficient of correlation (R) of 0.95 and 3.64% error for the relation between predicted bruise volume and measured bruise volume. The multiple regression based only on the acceleration maximum and velocity change still could produce reliable bruising predictions.

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