SOME DIMENSIONAL CHARACTERISTICS OF FIVE VARIETIES OF APPLES¹

W.S. Reid and G.E. Timbers

Engineering Research Service, Research Branch, Agriculture Canada, Ottawa, Ontario K1A 0C6
Received 22 September 1975


An assessment of the problems related to improvement upon commercial practice for processing apples is given. Investigation of the minimum loss that can be expected if only unwanted material is removed has shown that a mean weight loss of only 5.30% is theoretically possible. No practical technique is presently available to achieve this minimal loss.

Measurement of apple parameters of importance in processing machine design indicated that apple weight or maximum height were the most valuable to predict the value of other less easily measured features. It is also shown that for best machine performance, each variety would require special machine settings and all varieties should be sized before processing as in current commercial practice.

INTRODUCTION

Mechanical peeling and coring of apples has been practiced for many years, but is still, along with orientation and trimming, an area where improvements in efficiency could be made. Recent developments in the industry have produced fully and partially automatic orientation, peel and core systems. Lye peeling for apples has been introduced. In order to advance the development of apple processing equipment, more detailed information is required by equipment designers on the dimensional characteristics of the fruit. This more detailed information should permit design for adequate processing with a minimum of product loss.

The object of this investigation was to relate current commercial practice to published literature on apple processing, techniques, procedures and properties and extend the knowledge in areas of special interest to the problems of orientation and peeling of processing apples.

REVIEW OF LITERATURE

Frechet et and Azhradrik (1965), Moustafa and Stout (1967), Vis (1968) and Wolf (1967) discuss mathematical models, or record and analyze the physical dimensions of the apple for various approaches to the problems of processing and marketing apples.

Investigations into systems of apple orientation described by Stout et al. (1968), Timbers and Reid (1971) and Vis et al. (1968) included inclined tables and water orientation. Rehkgugler (1969) describes an optical bruise detection technique important in reduction of trimming labor requirements. Timbers and Reid (1971) draw attention to a number of patents related to mechanical orientation which have been incorporated in some of the later machines, notably the Atlas Pacific unit.

From product appearance and subsequent ease of core material removal, apple orientation is a critical operation. Orientation can be accomplished manually and mechanically for all apple varieties with good results. Water orientation is effective for some varieties but is poor for others and is of limited value to most processors. Optical or ultrasonic methods for orientation detection have not been utilized, but they do offer a possibility for improving orientation accuracy and thereby possibly offer some reduction of product loss.

In all existing machinery, coring is performed mechanically, with the coring operation occurring after the apple is oriented along the coring axis. An alternative technique, which has not been used, was proposed by Dean (1968). This involves halving the apple prior to coring. While some theoretical improvement in product loss was predicted, the increased machine complexity would seem to preclude this approach.

An aspect of machine design, directly related to machine complexity and the apple specifically, is the biological nature of the fruit and the resultant variability both in size, shape and internal conformation. The possibility of designing a machine that copes adequately with all processing sizes and varieties of apples must be considered. Elimination of classifying machines and set-up time of the system would be a significant advantage.

Product handling into and out of the processing machine is important, as it affects product quality, and may be either by flume or a mechanical belt. Water flumes are most common for processing machine input with inspection belts or flumes for the processed product.

The apple is basically an irregular sphere with two principle depressions at the stem and calyx ends. While McIntosh conforms reasonably well to this form, others such as the Delicious depart radically from the spherical model.

A mathematical model for the apple (Fig. 1) was proposed by Moustafa

¹Contribution no. 552 from Engineering Research Service.

Figure 1. Diagram of model of apple using the envelope of an offset and rotated ellipse (from Moustafa and Stout 1967).
and Stout (1967) which is essentially the volume of the envelope obtained by rotating the axis of an ellipse about the nominal core axis of the apple. Agreement with experimental results is quite good. This is useful for predicting volume and surface area, size of calyx and stem end cavities, and perhaps core length. Other aspects of interest for apple processing equipment are core size, its location and variability (Fig. 2).

The discussion will now be confined to apple conformation related to orientation. Peel removal, bruise detection and removal will be considered in a later report. For apple orientation, it is essential to detect the stem and blossom end depressions, which means it is necessary to scan the surface of the apple and to have a criterion for orientation selection and mechanical means of orientation.

**MATERIALS AND METHODS**

Investigations were carried out on five varieties of apples to determine the location of apple features and to define machine design parameters. The work was carried out on the 1970 and 1971 crops to establish the following: (a) internal and external dimensions, (b) weights, (c) center of gravity, (d) volume, (e) density, (f) height, (g) maximum and minimum diameter, (h) core diameter, (i) diameter of circumscribing circle, (j) core location, (k) skin thickness (five varieties, 1970; four varieties, 1971), (l) weights of skin, (m) stem, (n) core material, (o) seed (two apple varieties), (p) stabilization time in water (one variety, 1970); and (q) peeling head response (four varieties, 1971). Various techniques were used to record the internal dimensions of apples. The simplest and cheapest is to section the apple in the plane desired and make a print on paper after putting the sectioned apple on an ink pad. This section plane through the core axis and the center of gravity was determined by pushing a steel pin through the core axis, and then placing the pin on and between two horizontal knife edges. The apple was then sectioned in the vertical plane through the axis of the pin and core. An X-ray technique (Fig. 3) was also used as a non-destructive technique of recording internal dimensions. A General Electric model F-3 portable X-ray instrument was employed at an exposure time of 20 sec and a mean object distance of 75 cm. The Kodak Industrial M X-ray film was placed immediately behind the apple giving a 1:1 scale.

To determine peeling head response requirements, radial displacement was measured at the maximum diameter of the apple as it was rotated about the core axis, using a linear transducer attached to a lightly spring-loaded roller in contact with the apple surface, and a rotary transducer coupled to the core axis. The results were plotted on an X-Y recorder. The X axis represented core axis rotation and the Y axis represented roller displacement from the core axis (Fig. 4 and Table 1), which gives a measure of hypothetical peeling head or blade radial travel.

Other tests were carried out to determine the minimum possible waste on a selected number of apples by dissecting out the unwanted components such as skin, core and seeds.

**RESULTS AND DISCUSSION**

By physical dissection of 10 McIntosh apples (mean weight 97.2 g range 90 - 113 g), the mean loss in weight recorded as a result of removing (carefully) the
skin, stem, seeds and calyx from the whole apple material was 13.9%. However, the actual mean weight removed was 4.4% skin, 0.5% stem and core material and 0.4% seed, a total of 5.3%. This is significantly different from the recorded mean loss in weight of the whole apple, and is presumed to be due to the physical damage of separating these items and the rapid loss of moisture due to cell fracture. In fact, the processing losses are inevitably going to be greater than this because the techniques for coring remove significant amounts of apple around the seed cell and through the core axis. Since the peeled apples are often transported by water flume, loss due to dehydration would be minimal. The minimum theoretical loss by volume was predicted for a small apple, assuming a minimum core radius and seed cell radius.

Stabilization times in water after specific disturbances were obtained on two varieties of apple, McIntosh and Spy. For McIntosh when dropped from a position where it touched the water surface, stabilization took 4.8 sec. Stabilization took 2.5 sec after releasing the apple from 2.9 mm below the stable position. An angular rotation of 0.26 rad from the stable position resulted in a stabilization time of 3-6 sec. The times for Spys were, in general, even longer. The times are so long that they present a serious problem if water orientation is to be used, or if water feed to a processing station is considered except in bulk handling.

Skin thickness of fresh apples lies in the range 0.02-0.04 cm. The need for good peeling head response (Fig. 4 and Table 1) is emphasized by the radial travel necessary during peeling.

Limited data on peeling head response are given in Table 1, but really need extension to obtain fully validated data which could be used in modern peeling head design. However, some data may be extracted for initial design analysis. To peel Spys, the peeling head and possibly the bruise detection head should have a travel capability to handle apples of 2.63-cm radius up to 4.20-cm radius, a range of 1.57 cm. To peel all apples, the minimum contact radius should be 2.45 cm. In practical terms, this should probably be 2.0 cm with a maximum of 5.0 cm to cover all sizes of apples. The maximum travel rate recorded was -0.02 cm/degree of rotation. Velocity of the peel head would, of course, be a function of speed of rotation of the apple, which would in turn be determined by the time allowed for peeling. The negative sign represents the return of the head towards the apple axis. This maximum velocity usually occurred at a radius between 5-15% below the maximum equatorial radius of the apple. The test installation was not good enough to give anything other than preliminary data, and a mock-up should be constructed which simulates in detail the projected apple rotation speed together with the dynamic response of the head, including component inertia, damping and contact load control features. A preliminary computer analysis would reveal some of the problems not already identified from the limited data already obtained in Table 1, especially with regard to overshoot, resulting in under-peeling as peeling radius increases. It would, however, be preferable to work with more precise data on more apples.

Work was carried out using ultrasonics to determine the surface reflectance of an apple for detection of stem and calyx depression, with the general conclusion that the detector configuration required would be too large for practical reasons, and work was discontinued.

Selective interrelation analysis of the measurements taken on the sectioned apples was undertaken. Emphasis was given to those parameters considered essential in improving product processing efficiency and their measurement. Independent variables were considered to be those dimensions or properties of an apple which could be measured easily and accurately without damaging the apple, such as weight and maximum diameter prior to orientation, with maximum height and external core length after orientation. Dependent variables such as core diameter, internal core length and location were then analyzed statistically against the independent variables to give correlation coefficients and linear regression equations for one independent variable only. Regression analyses were only performed on those variables with a correlation coefficient of greater than 0.75. Some of the independent and dependent variables and their regression equations are given in Table 2. The mean, maximum, minimum, variance and correlation coefficients were calculated for each of the 22 variables measured and analyzed. Some variables were measured or observed but not analyzed. In some instances the data are inadequate to be fully representative for all varieties of apples, and specific parameters, but are presented as a technique to handle the problems of apple variability related to machine design. Considering the results of Table 2, several conclusions can be drawn with regard to the requirements of a machine. It should be noted that designers have already met some of these requirements in their latest machines, which means that the potential for improvement is therefore reduced. For the regression equation of maximum apple diameter on weight (Table 2), the regression equation for all apples would be suitable for all varieties except Courtland, where the constant is significantly higher and the independent variable coefficient is lower than the other varieties. This variability in the regression equations is, in general, true for all varieties and most parameters within the data taken, which implies that separate settings for each variety would be required to optimize equipment performance.

The data sampled give an indication that variability due to size or weight is sufficient to affect the regression equations and that size or weight grading would improve processing performance as is usual in current commercial practice.

Correlation between apple height and weight is good, although the regression equations for each variety are sufficiently different to suggest the necessity of separate design and processing requirements. The independent variable weight, in fact gave correlations >0.75 for 7 of the 22 variables considered of interest, maximum height giving 12. These two variables are by far the easiest to measure.
Note: Diameter and height measured in cm, weight in g, diameter is dimension (E-Ej) X 2, Fig. 2; maximum height is dimension B-Ka = 90°.

Similarly, measurement of maximum height gave good correlation with the distance between planes of rest at blossom and stem ends. For coring, the regression equations giving only two and three parameters, respectively, with correlations >0.75. Similarly, measurement of maximum height gave good correlation with the distance between planes of rest at blossom and stem ends. For coring, the regression equations giving only two and three parameters, respectively, with correlations >0.75. Similarly, measurement of maximum height gave good correlation with the distance between planes of rest at blossom and stem ends. For coring, the regression equations giving only two and three parameters, respectively, with correlations >0.75.

Identifcation of stem and core end is desirable if optimum processing efficiency is required. Practically, the minimum peeling and coring waste is not less than 12-15% unless the waste products alone can be removed, when waste would not be less than 5.3%.

Further work on detectors for apple orientation and bruising could give a worthwhile overall improvement in efficiency.

**CONCLUSIONS**

Floatation in water is not suitable for apple orientation or for rapid feeding of individual apples to processing stations. Ultrasonic means of detecting apple orientation do not seem practical at this time. The current mechanical means of apple orientation are quite effective; therefore unless orientation detection means can be coupled with bruise detection to offer economies in equipment operation, further progress in this area will be limited.

Selected regression analyses and correlation coefficients have been carried out on apple parameters which indicate that due to apple variability, machine design must be capable of dealing with sized apples of each specific variety used for processing, in line with current practice for optimum efficiency. The method of analysis is a useful technique in dealing with biological product variability in relation to processing machine design. In processing machine design, if regression equations are to be used as the basis for actuator action, it is relatively simple to compensate for changes in the constants of the equation; but to compensate for the coefficient of the dependent variable is more difficult.

Identification of stem and core end is desirable if optimum processing efficiency is required. Practically, the minimum peeling and coring waste is not less than 12-15% unless the waste products alone can be removed, when waste would not be less than 5.3%.

Further work on detectors for apple orientation and bruising could give a worthwhile overall improvement in efficiency.

**SUMMARY**

Work has been completed on waste in apple processing as well as water orientation in conjunction with regression analysis of the physical dimensions of some processing apple samples. To improve on current commercial apple processing capability in speed and reduction of waste is an extremely difficult problem and will involve the continuous efforts of research and design personnel. Work has confirmed the decisions of the industrial designers in equipment design and indicates the problems inherent in attempting further improvement.

**TABLE II REGRESSION EQUATION ANALYSIS FOR SELECTED APPLE DIMENSIONS AND PHYSICAL PARAMETERS**

<table>
<thead>
<tr>
<th>No. of samples</th>
<th>Dependent variable description</th>
<th>Independent variable</th>
<th>Regression equation</th>
<th>Standard deviation dependent variable</th>
<th>Mult. corr. coeff.</th>
<th>Standard error independent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>Max diam perpendicular to core axis</td>
<td>Wt All</td>
<td>( y = 4.69 + 0.01824x )</td>
<td>0.16648</td>
<td>0.951</td>
<td>0.06113</td>
</tr>
<tr>
<td>30</td>
<td>Max diam perpendicular to core axis</td>
<td>Wt Courtland</td>
<td>( y = 5.18 + 0.0157x )</td>
<td>0.1368</td>
<td>0.953</td>
<td>0.152</td>
</tr>
<tr>
<td>30</td>
<td>Max diam perpendicular to core axis</td>
<td>Wt Delicious</td>
<td>( y = 4.469 + 0.0186x )</td>
<td>0.1086</td>
<td>0.947</td>
<td>0.152</td>
</tr>
<tr>
<td>30</td>
<td>Max diam perpendicular to core axis</td>
<td>Wt Gravenstein</td>
<td>( y = 4.691 + 0.0189x )</td>
<td>0.1853</td>
<td>0.915</td>
<td>0.1807</td>
</tr>
<tr>
<td>30</td>
<td>Max diam perpendicular to core axis</td>
<td>Wt McIntosh</td>
<td>( y = 4.476 + 0.0208x )</td>
<td>0.1182</td>
<td>0.895</td>
<td>0.1954</td>
</tr>
<tr>
<td>30</td>
<td>Max diam perpendicular to core axis</td>
<td>Wt Spy</td>
<td>( y = 4.712 + 0.01785x )</td>
<td>0.1009</td>
<td>0.952</td>
<td>0.1256</td>
</tr>
</tbody>
</table>

Note: Diameter and height measured in cm, weight in g, diameter is dimension (E-Ej) X 2, Fig. 2; maximum height is dimension B-Ka = 90°.

quickly prior to or during processing, and would suggest themselves for derivation of as many other parameters as possible. Size, as measured by the minimum diameter or diameter of the circumscribing circle, provided significantly lower correlations giving only two and three parameters, respectively, with correlations >0.75. Similarly, measurement of maximum height gave good correlation with the distance between planes of rest at blossom and stem ends. For coring, the regression equations of distance of the plane of rest of the blossom end to maximum core diameter and maximum height are again sufficiently different to warrant different equipment settings for different varieties for maximum economy. The regression equations for determining the distance of the maximum core diameter from stem and blossom ends are sufficiently different to indicate that for best optimization of core location, it is necessary to know which end is the blossom end and which the stem.


