An Innovative Mechanical Peeling Method of Vegetables

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ABSTRACT

Mechanical peeling of fruits and vegetables is carried out mostly using either abrasive tools or knife and blades. Combining the basic functions of these two types of peeler tools led to the development of a new innovative tool named the abrasive-cutter brush. The new tool can utilize the benefits of the two mentioned peeling tools. The production and effect of peeling using abrasive cutter brush on Jap variety of pumpkin as a case study was examined. The experimental studies showed high flexibility of abrasive-cutter brush could provide easy access to different uneven areas of the produce. The cutting action caused effective peeling while the abrasive action showed higher production compared with the existing tools. The recorded results revealed peeling effects of 18.60% and 20%/min for concave and convex areas respectively at 0.18%/min peel losses.

Keywords: *Abrasive, abrasive-cutter, mechanical peeling, peeling*

1. INTRODUCTION

Decreasing losses and increasing the processing efficiency of fruits and vegetables is a matter of interest for the managers of food industries. Peeling as the preliminary and main stage of post harvest processing is currently conducted by mechanical, chemical, and thermal methods (Luh & Woodroof, 1988; Toker & Bayindirli, 2003). Although each method has own benefits and limitations, but mechanical methods are preferred because of keeping edible portions of produce fresh and damage free (Emadi *et al.*, 2007). Many researchers and inventors have been tried to improve the efficiency of mechanical peeling methods (Boyce *et al.*,1961; Gardiner *et al.*, 1963; Polk, 1972; Couture & Allard, 1979; 'He' *et al.*, 1999; Cailliot *et al.*, 1988; Singh & Shukla, 1995; Radhakrishnaiah Setty *et al.*, 1993; Emadi *et al.*, 2007). Despite all attempts have been made in this area, there are still several limitations such as low flexibility which demands more research.

Using abrasive or cutting tools are the most common ways for mechanical peeling of fruits and vegetables. The result of applying abrasive peelers is evenly peeling regardless uneven surfaces or irregular shape of produce. Despite high peeling production rate as the main advantage, loading sensitivity and high waste of edible portions are the main limitations. Peelers which apply cutting tools are lesser common than abrasive ones. Knifes, blades, and rotary cutters are the most common cutting tools for those peelers. Rotary cutters are the only flexible one among cutting tools showing good access to different parts of uneven surfaces (Boyce *et al.*, 1961, Gardiner *et al.*, 1963, Polk, 1972, Cailiot *et al.*, 1988, Emadi *et al.*, 2006). Although one of the main limitations of those peelers is possibility of clogging of rotary cutter during peeling but the capability to peel tough-skinned vegetables is high because of applying cutting forces. It is believed to make a new peeling method that would be industrially applicable; the peeling production rate should still be increased.

Applying abrasive and cutting forces in one tool led to a new innovative peeling tool named abrasive-cutter brush. The objective of this research was to investigate the capability of abrasive-cutter brush for even peeling of tough-skinned vegetables, with unevenness surface and irregular shape, and the rate of peeling production.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The Jap variety of pumpkin (Cucurbitaceous family), as a case study, from different local farms around Brisbane (Queensland, Australia) was used for the experiments. The produce was randomly selected from ripe, defect-free and quite similarly sized (18-23 cm diameter) pumpkins.

Experiments were conducted on a test rig that was designed and fabricated at the School of Engineering Systems, QUT (Emadi *et al*., 2004). The test rig was a chamber insisting two main sections named vegetable holder and peeler head. The vegetable holder (Fig.1a) was a disk for carrying circularly the produce on a horizontal plane and in an anticlockwise direction. It was supplied rotational velocities up to 300 rpm by a D.C. motor. The peeler head equipped with an attachment and this provided the peeling tool with perpendicular access to the produce's surface (Fig.1b). A different D.C. motor was used with a higher upper speed limit (2000 rpm) that could carry the abrasive-cutter brushes (Fig.2a) on its output shaft. The whole peeler head attachment was mounted on a pivoted bracket to give more flexibility during peeling.

a	b

Figure.1. Test rig components

The peeling tool named abrasive-cutter brush was basically twisted stainless steel wires with grater strips (different grades) wrapped around (Fig.2b). The stainless steel wires were already double twisted wires of the same materials. Two abrasive-cutter brushes were installed between solid discs of the peeler head attachment for each trial. The brushes could be fine, coarse, or a combination of the two depending on the status of the planned experiment.

a	b

Figure.2. Abrasive-cutter brush

The total length of each brush was 165 mm and the weight 14.75 grams. The materials and methods used to fabricate the brush provided high flexibility of the brush.

2.2 Design of Experiments

L9 array of Taguchi method as a fracture factorial experiment was planned and used. It enabled experiments for four factors in three levels each. Factors were the rotational velocity of the abrasive-cutter brush (p. speed), rotational velocity of the vegetable holder (v. speed: 5, 10, 15 rpm), vertical position of the brush (position: -20, 0, 20 mm) and the coarseness of the brush (coarseness: C for coarse; F for fine; and M. for medium coarseness types of brush). Experiments were carried out in four time intervals (t_1 to t_4) each 1 minute. The dependent variables were measured after each time interval and the mean in percentage per unit time (minute) was used for assessment.

2.3 Peel Losses

Peel losses in percentage calculated by using the weight of the produce before and after peeling (Willard, 1971), by applying the following formula:

$$y_1 = \frac{W_1 - W_2}{W_1 \times t} \times 100 \qquad (1)$$

where, y_1 is peel losses in %/min; t is the time of peeling in minute; W_1 and W_2 are the weight of the unpeeled and peeled produce respectively. W_2 is not equal either to zero or to W_1.
Produces were weighed before and immediately after peeling by analogue scale with ± 1 gram accuracy.

2.4 Peeling Effect

Peeling effect is the percentage of peel that is removed from the initial skin per unit time (min). Three places (120° including angle) at the circular affected area on the produce for each convex and concave area were considered for the measurement of the peeling effect. The peeling effect (%/min) after each time interval (t_1 to t_4) of peeling was measured at the same place, and the mean value was calculated for further discussion. A ring indicator with an internal diameter of 15 mm was used to identify the area of measurement on each place. Optical judgement was made by three observers and the average value was reported. Remaining peel inside the indicator was recorded noting the different colours of skin layers, thickness and area, and these were the main criteria for assessment. The suggested formula by Singh and Shukla (1995) was used and modified for the calculation of the peeling effect as follows:

$$y_2 = \frac{A_1 - A_2}{A_1 \times t} \times 100 \tag{2}$$

where, y_2 is peeling effect in %/min; t is peeling time in minute; A_1 is the fraction of peel inside the internal area of the ring indicator before peeling (assumed to be 100); and A_2 is the fraction of remaining peel inside the internal area of the ring indicator after peeling.

2.5 Estimated Responses at the Optimum Conditions

The estimation of the mean response in optimum conditions (optimization) was carried out on the basis of Taguchi analysis of variance (ANOVA) by applying following equation (Roy, 1990):

$$\breve{\mu} = \bar{T} + \left(\overline{LS_{x1}} - \bar{T}\right) + \left(\overline{LS_{x2}} - \bar{T}\right) + \cdots + \left(\overline{LS_{xn}} - \bar{T}\right) \tag{3}$$

where:

$\breve{\mu}$ = estimate of the mean response;

$\bar{T}$ = mean of all experimental data;

$\overline{LS_{xn}}$ = optimal level sum response for the significant factor at the level of interest.

2.6 Data Analysis

Analysis of variance has been carried out on the basis of the Taguchi method. It was used to calculate the percentage contribution of independent variables and their effect on the response variables. Estimation of the results in optimum conditions also was carried out using the suggested method by Taguchi.

3. RESULTS AND DISCUSSION

The contribution of four independent variables involving p. speed, v. speed, position and the coarseness to three dependent variables while neglecting the interactions was statistically calculated and is shown in Figure 3.

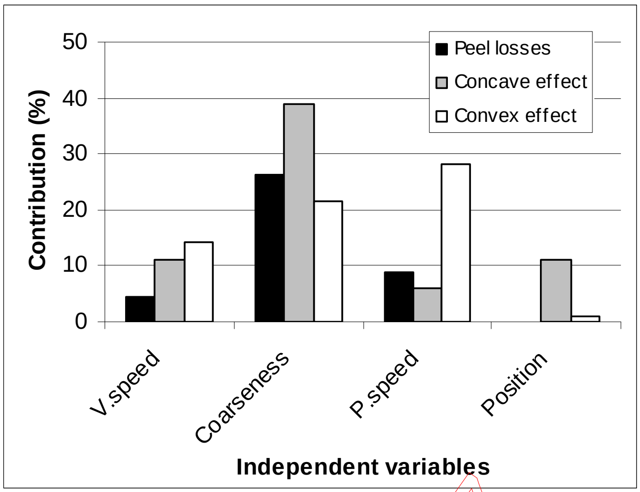

Figure 3. The contribution of independent variables to responses

As the aim of this study was to investigate the method and not the peeler, the manufactured test rig was designed to enable peeling on a circumferential band (40.66 mm average width) around the whole produce and experimental data relates to that area.
The main influences of independent variables on dependent variables involving peel losses (%/min), peeling effect (%/min) at concave and convex areas are illustrated in Figure 4. In this figure logarithmic scale for y axes was used to enable comparison between peel loses and peeling effects.

The higher contribution (%) of independent variables to peel losses than other responses (Figure 3) also confirms peel removal is highly dependant to those variables. The coarsened type of abrasive-brush showed higher contribution (25%) to peel losses compared to the other types. Although the effect of coarseness on peeling at concave and convex areas is very close (Figure 4.b) but the higher contribution of coarseness to concave than convex effects reveals the possibility of reaching to more even peeling by improving the coarseness of brush. The reason for higher contribution of coarseness to concave than convex peeling effects may result from more affected areas by each brush's impact inside grooves. P. speed is the second higher contributor to responses. This variable, as seen in Figure 4.c, highly affected peel losses and peeling effects at the third level (850 rpm). Although the effect of peeling is remained even for different levels of p. speed but all responses highly effected at the third level (850 rpm). It may means increased p. speed leads to stronger impacts and higher peel removal in both concave and convex areas. Higher contribution of p. speed to convex than concave effects allows monitoring peeling at convex areas for getting more even peeling. The next higher contributor after p. speed to response variables is v. speed. The order of contribution to the responses is peel losses, convex and concave effects respectively. Although the peeling effect in different areas for all three levels of v. speed was almost the same (Fig. 4a) but the mid level of v. speed (10 rpm) revealed higher impact on responses than other levels. The upper v. speed may reduce access to the unevenness areas of produce because of escaping produce from the smashes of brush. Position as the last contributor to the responses showed significant higher peeling effect (Fig. 4d) in convex than concave areas for the third level (20 mm). Both v. speed and position variables affected more peel losses at the mid-level.

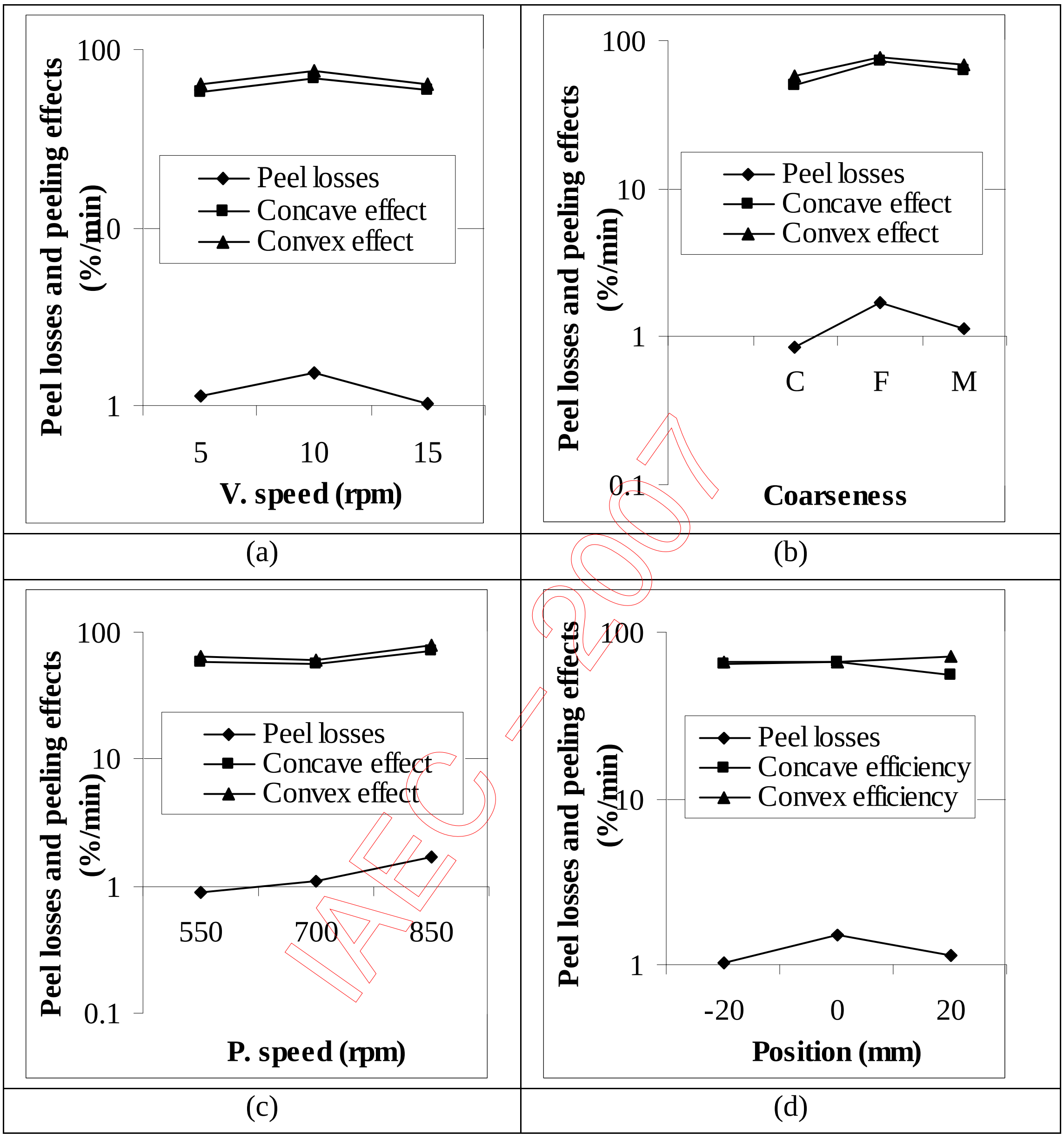

Figure 4. The effects of independent variables on responses

The contribution of all variables except coarseness to responses was less than 5% and could be neglected. It means the peel removal in concave areas can be controllable in micro and macro levels by coarseness.

Medium type of coarseness for type of brush, v. speed of 5 rpm, p. speed of 550 rpm, and -20 mm for position were chosen as the optimum levels of independent variables. The selection was made regarding to criteria of experiments which was low peel losses and more even peeling effects on concave and convex areas. Estimated mean responses for concave and convex peeling effect were obtained as 18.60 and 20%/min respectively at 0.18%/min peel losses per minute.

4. CONCLUSION

The capability of a new innovative peeling tool named abrasive-cutter brush to approach even peeling on Jap variety of pumpkin was investigated. Estimated responses at optimum conditions showed close values of peeling effect in concave and convex areas. It was statistically calculated as 18.60 and 20%/min for concave and convex areas respectively at 0.18%/min peel losses.

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