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Effect of varying knife speed and contact area on peak cutting force during slicing of peeled potato *(Solanum tuberosum)*

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Abstract

Relation of peak cutting force with varying contact area and cutting speed is needed to design an efficient and versatile slicer or cutter to cut the potato in desired shape without any textural deformation with lest energy consumption. Peak force for transverse cutting of peeled potato, consisted homogeneous textural characteristics of flesh, has been determined at cutting speeds of 20, 30, 40 mm/min using single-cut knife-edge angle of 15 degree fixing in Universal testing machine. The relation of different knife speed (20, 30, 40 mm/min) and contact area of 200, 300, 400 and 500 mm^2 on peak cutting force were observed for constant angle of cutting edge of knife. Peak cutting force with lowest speed (20 mm/min) were noticed minimum (8.74±0.94N) for lowest contact area (200 mm^2) and maximum (18.84±0.76N) for 500 mm^2 contact area respectively, indicates less cutting force required during cutting operation for lower knife speed and simultaneously cutting force for constant contact area was noticed maximum and minimum for knife speed of 40 and 20 mm/min respectively. Effects of cutting speed and contact area of sample were found significant ($p<0.05$). Quadratic regressions equation (regression model) was good fit for explaining the relation of two variables (knife speed and contact area) on the response (peak cutting force).

Introduction

Potatoes *(Solanum tuberosum)* are usually peeled and cut into different shapes like cubes, thin slices or rings to facilitate secondary processing and materials of construction, sharpness, rigidity of cutting tools and knife speed were effective parameters in cutting operations and strongly influences the energy required, production rate and final surface finish of the sliced vegetables (McCarthy *et al.*, 2007; McGorry *et al.*, 2003). Cutting force for different materials like beets, carrots and potatoes were decreased as cutting speed reduces (Dowgiallo, 2005). Cutting resistance during knife movement is related to the sharpness of the cutting edge (Ciulica *et al.*, 2012). Relative movement of object and cutting device (either object or knife is stationary) as well as cutting resistance depends upon the intrinsic texture of the material and vegetables slicing rate were decreased with increasing hardness (Yee *et al.*, 2012; Saravacos *et al.*, 2011). Horizontal and vertical types of cutting devices with multi directional movement of blades are used for cutting the fruits and vegetables (Jiang, 2013).

In the case of some fruits, size reduction with the help of high speed cutting equipments was not suitable because it can destruct the cut surface. Sharpness of the cutting tool implies significant impact on the shelf life of the fresh vegetables (Bolin *et al.*, 1991). Pear sliced with the help of sharpened knife retained longer visual quality than cutting with dull knife (Grony *et al.*, 2000). Vegetables have moisture less than 10% categorized as brittle caused frequent cracked texture during slicing. Cut or sliced fruits and vegetables are popular due to easy processing and achievable (Hui, 2006). Changed in moisture content also affect the internal structures of fruits and vegetables, high moisture content results soften texture (Onwulata *et al.*, 2013). The vegetables of high moisture content facilitated the précised slicing without any texture deformation because moisture reduces the friction during cutting (Gamble *et al.*, 1988). Ultrasonic, water-jet and lesser cutter etc. also used for accurate cutting and shaping but efficiently can be used only for some specific food materials (Arnold *et al.*, 2011). Ultrasonic cutter is suitable only for fragile, sticky and confectionary food materials (Arnold *et al.*, 2009; Schneider *et al.*, 2002). Some researchers stated that less work has been performed on energy involved for cutting of different food materials (Saravacos *et al.*, 2002). Limited published literatures on specific energy in cutting of fruits and vegetables are available (Brown *et al.*, 2005). Literature related to cutting or slicing of fruits and vegetables are limited (Mitcham

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et al., 1996). Different food cutting devices have been designed empirically based on the physical properties of food materials (Atkins, 2009). It becomes apparent that not enough data are available related to cutting force characteristics of potato those could be utilized for design of cutting system or device with optimum energy requirement. Considering contact area and speed of knife during cutting are important operating parameter than others, the present study attempted to measure force deformation characteristics of peeled potato and observed the relation between cutting force, knife speed and contact area of potato.

Materials and Methods

Freshly harvested, healthy (without any visible defects) and uniform size Potatoes of homogeneous physical structure were procured from the Technology market, Indian Institute of Technology, Kharagpur, West-Bengal, India and cleaned with water to remove all dirt adhering to the material before slicing. Length and thickness were measured with the help of dial mounted slide calliper (model no-D30TN, Mitutoyo Corporation, Japan, least count 0.02 mm and measuring range 0-300 mm). Moisture content of test sample (potato cuboids) was noticed 78.5 ±3.67% on wet basis, measured with the help of oven drying method (AOAC, 2003) (Table 1). Contact area indicates surface area of potato in the contact of knife during vertical movement of knife while slicing operation (i.e. for sample a, length and thickness were measured 20 and 10 mm respectively and because of these two dimensions only will come in contact of knife during cutting, resistance force will occurred on 20 mm length up to knife travel of 10 mm indicated contact area of 20×10 resulted 200 mm^2). Contact area has been calculated as product of length and thickness of individual potato samples (200, 300, 400 and 500 mm^2, Table 1). Selected potatoes slices of defined dimension were subjected to cutting with use of knife (cutting edge angle of 150) attached with Universal tensile testing machine (UTB-9052, Hi-tech DAK system, load range-500 N).

Cutting fixture in the universal testing machine

The universal tensile testing machine (UTB-9052, Hi-tech DAK system, load range-500 N) used in this study consists of a cross-head attached to load-cell (LVDT type) with lowest resolution of 0.12N. A desired cross-head speed ranging between 1 mm/min to 500 mm/min could be set and knife installed with the help of special fixture in universal tensile testing machine was allowed to move up and down with perfect alignment (Figure 1). The material to be cut was held on the platform and the knife was brought down until it touched the surface of the potato sample then knife move down with desired speed for cutting the sample up to complete separation of tested sample into two parts. The similar test repeated for three speeds, 20, 30 and 40 mm/minute. Force exerted on the test sample with knife travel during cutting was displayed on the personal computer attached with universal tensile testing machine and peak cutting force was read from the digital display of the machine. All these experiments were carried out separately taking fresh vegetable at each time and three replicates have been considered.

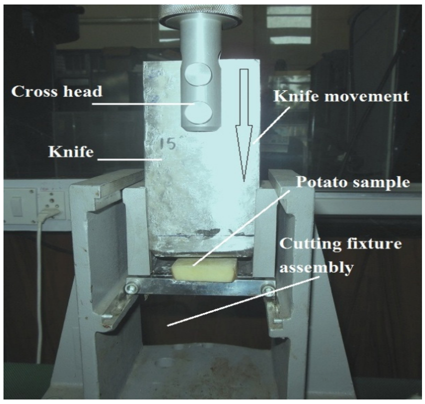

Figure 1. Knife movements in Universal tensile testing machine (UTB-9052, Hi-tech DAK system, load range-500 N) during cutting the potato sample

Measurement of cutting resistance force for potato

Cutting knife (sharpen angle of 150, single cut) attached with the knife holder and tightening with the help of screws bellows the load cell. Test sample kept on the centre of base plate. Knife attached with universal tensile testing machine operated at three different speeds (20, 30, 40 mm/min) for different contact surface area (200, 300, 400 and 500 mm^2) of potato sample at constant load of 500 kilogram. Cutting resistance force has been measured by output device and graph of same also can be found out for particular test sample. Correlation of knife speed with contact area of sample for different potato slices has been obtained.

Statistical analysis

General factorial design of experiments was followed using a software program (Design expert version 7.0, Stat – Ease INC., 2009, USA). Three tests (one for each knife speed e.g. for sample of 200 mm2 constant contact area, experiment were repeated thrice for knife speed of 20, 30 and 40 mm/min respectively) for each tested sample of potato having same contact area (same contact area indicated the

Table 1. Measured parameters of Potato slice and tabulation of average peak cutting force for peeled potato of different dimensions at different speed

Knife angle	@Average peak Cutting force, N			Length, mm	Thickness, mm	A, mm^2	¥M.C,(%),w.b
	20 mm/min	30 mm/min	40 mm/min				
	π8.74±0.94	9.88±0.32	10.40±0.46	20	10	200	
15^0	11.56±0.60	11.86±0.60	14.17±0.35	30	10	300	78.5±3.67
	15.05±0.47	16.62±0.33	18.45±0.44	40	10	400	
	18.84±0.76	22.06±0.45	25.91±0.25	50	10	500	

@Value based on three replicates, A=Contact area (surface area of sample in contact with knife during cutting). π8.74±0.94 indicates average peak cutting force (8.74 N) with standard deviation (0.94 N), ¥based on three replicates of potato sample, M.C (wb) = Moisture content (wet basis),

sample of same length and thickness) along with three replications were carried out. Significance of the effects of all the independent variables (knife speed and contact area), on dependent variable (cutting force), was evaluated using analysis of variance. Regression equations correlating these variables (Eqn. 1) have been obtained using the same software program.

Polynomial regression equation (equation-1) was fitted for expressing the relation of independent (X_1 and X_2) with response (Y: dependent variable).

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+...+b_{12}X_1X_2+b_{13}X_1X_3+...+b_{23}X_2X_3+b_{11}X_1^2+b_{22}X_2^2+b_{33}X_3^2... (1)$$

Effect of cutting angle and knife speed on peak cutting force were expressed with equation-2

$$Y = b_o + b_1A + b_2B + b_{12}AB + b_{11}A^2 + b_{22}B^2 ... (2)$$

Where b_0, b_1, b_2, b_{12}, b_{11} and b_{22} are coefficients of constant term, contact area (A), knife speed (B), interaction term of contact area and speed (A×B), square term of contact area (A^2) and knife speed (B^2) of the regression equation respectively. Y is response (peak cutting force).

Results and Discussion

Cutting characteristics of vegetables

Typical force and deformation (depth of cut) characteristics of potato (one of each contact area sample) are presented in Figures 3(a–c). Almost similar natures of curves were obtained with different cutting speed for tested sample of different contact area. Potato showed steady increase in cutting force (Figures 3 a-e and 4a-e) that attained a peak value and then gradually decrease as the depth of cut was increased. This type of increase in force nearly up to mid point and decrease thereafter is attributed to increase or decrease in shearing area (contact area

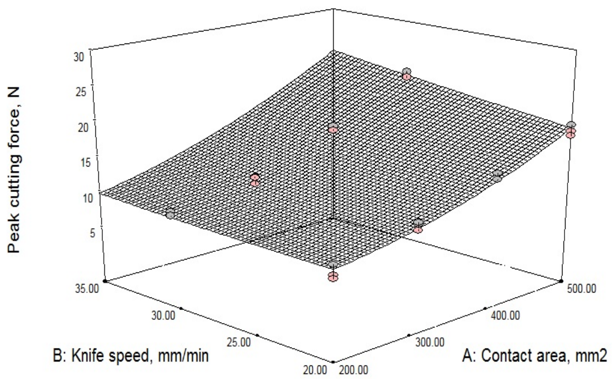

Figure 2. Response surface graph for peak cutting force during transverse cutting of potato as function of contact area (surface area of sample in contact with knife during cutting) and knife speed

between potato sample and knife during cutting) during penetration of the knife. There was least fluctuation in the curve describes the homogeneity of potato texture as well as close values of peak cutting force (e.g. 8.74±0.94, 9.88±0.32 and 10.40±0.46N for contact area of 200 mm^2 at 20, 30 and 40 mm/min respectively) and less deviation in the values of replicates (e.g. for 20 mm/min knife speed and contact area of 200 mm^2, values of peak cutting force were noted (8.74±0.94N, indicated standard deviation of 0.94N only for three replication) also reveals about less deviation in the values of peak cutting force indicates homogeneous texture of potato.

Effect of cutting speed and contact area on peak cutting force

Mean cutting force for potato sample is given in Table 1. Tested sample has been shown apparent increase in peak force with increase in cutting speed and contact area between sample and knife (Figure 2). Less fluctuation in peak-cutting force was describes the nature of uniform texture (homogeneous characteristics of flesh) and obtain profile of cutting force with knife travel for potato sample had shown the cutting characteristics with different knife

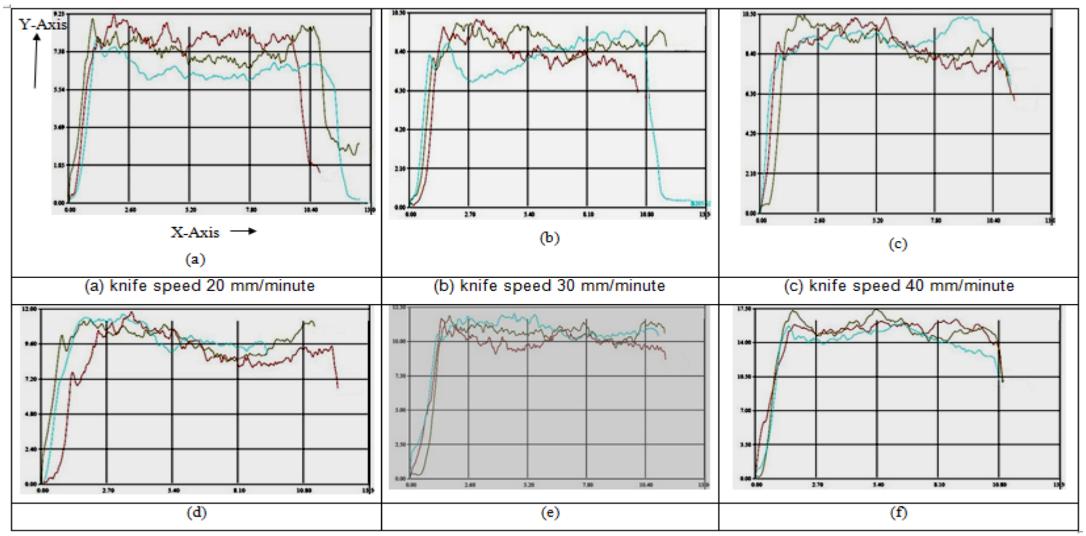

Figure 3. (a-c) and (d-f), Cutting force (Newton, Y-axis) vs. Depth of cut (millimetre, X-axis) for Potato cuboids of contact area (200 and 300 square millimetres respectively), *Three individual colour lines in graph showing the 3 replicates for each experimental sample.

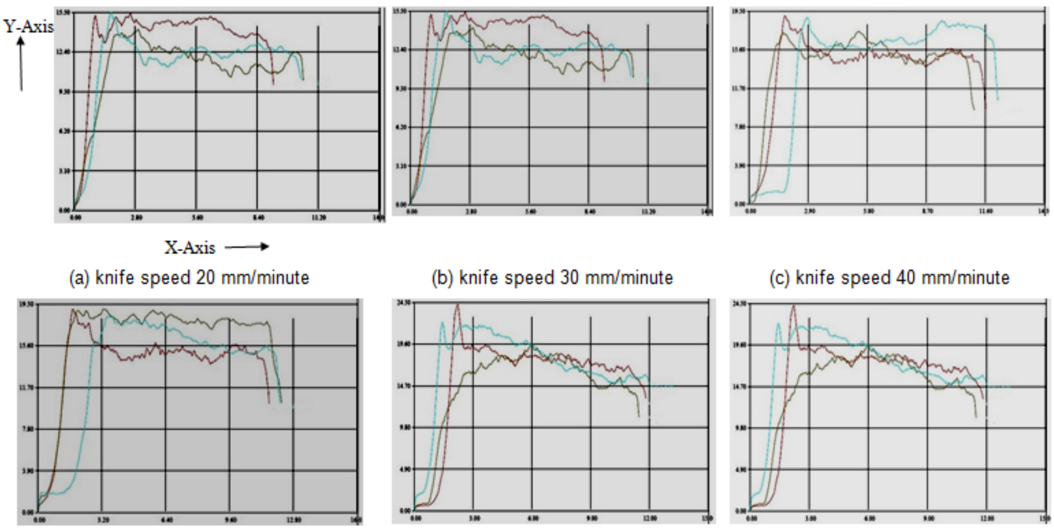

Figure 4. (a-c) and (d-f) Cutting force (Newton, Y-axis) vs. Depth of cut (millimetre, X-axis) for Potato cuboids of contact area (400 and 500 square millimetres respectively),*Three individual colour lines in graph showing the 3 replicates for each experimental sample

speed. Values of cutting force for each replicates were found close to other simultaneously individual lines of cutting force for all self generated graphs during vertical movement of knife across the potato sample also indicating less variation (Figures 3(a-c) and (d-f), 4(a-c) and (d-f)). Minimum peak cutting resistance force noticed “8.74”, “9.88”, “10.40”N for 200 mm2 and highest peak cutting force observed “18.83”, “22.06” and “25.91”N for 500 mm^2 contact surface area at 20, 30 and 40 mm/min knife speed respectively (Table 1). The effects of knife speed and contact area on peak cutting force have been evaluated for analysis of variance at 95% confidence level. Significant effects with these independent variables on the response are studied by analysis of variance.

Correlation of peak cutting force with independent variables for Potato sample

Value of Peak cutting force for different speed of knife and contact area was correlated with the second order polynomial equation-2.Value of Coefficient of determination (R^2), Adj.R^2, Pred. R^2 and S.D obtained 0.99, 0.98, 0.96 and 0.61 respectively. The Pred. R^2 of 0.96 is in reasonable agreement with the Adj. R^2 of 0.98.

$$F = 14.31 + 6.23 \times A + 1.90 \times B + 1.37 \times A \times B + 1.43 \times A^2 + 0.22 \times B^2 \quad (3)$$

ANOVA for potato cuboids implies the significant model (P<0.05).This analysis shows the value of contact area (A), speed of knife (B), product of contact area and speed of knife (A×B) and square term of contact area (A^2) significantly influences the peak cutting resistance force ($P<0.05$). Effect of square term of knife speed (B^2) is not significantly influence the peak cutting resistance force ($P>0.05$) reveals that the value of contact area have a more influence than knife speed on peak cutting force because all the terms of contact area (A, A×B and A^2), are significant and values of linear and square coefficient of contact area (A and A^2) is observed 6.23 and 1.43 respectively higher than the coefficient of linear (B) and square term (B^2), of knife speed (Equation-3)

Conclusion

Peak force in cutting of potato slices of different contact surface area depends upon the texture of rind, flesh and its homogeniety (uniform texture without random distribution of seed in fleshy part as well as hard rind of fruits and vegetables). Knife cutting speed and contact surface area of sample significantly influences mangitude of force required to cut. Low speed (20 mm/min) of cutting and less contact surface area (200 mm^2) favoured for lower value of cutting force. Potato slices of more contact surface area requires high peak force with vertical cutting mechanism. Good correlations (significant values of independent variables for optimizing the dependent variable) among the variables could be used to predict the optimum value of cutting force. Minimum cutting resistance force noticed 8.74±0.94N for least contact surface area (200 mm^2) and minimum knife speed (20 mm/min). Highest cutting resistance force observed 25.91±0.25N for highest contact surface area (500 mm^2) at maximum knife speed (40 mm/min) respectively. For constant contact area of 200, 300,400 and 500 mm^2, highest peak cutting force was observed for 40 mm/min indicates high energy consumption during cutting or slicing operation. Contact surface area and knife speed influence the peak cutting force significantly ($P<0.05$). Correlation of knife speed and contact surface area of sample was shown with the second order polynomial equation.

References

AOAC. 2003. Official Methods of Analysis (16th ed.). Maryland: Association of Official Analytical Chemists.

Arnold, G., Leiteritz, L., Zahn, S. and Rohm, H. 2009. Ultrasonic cutting of cheese: composition affects cutting work reduction and energy demand. International Dairy Journal 19: 314-320. Arnold, G., Zahn, S., Legler, A. and Rohm, H. 2011. Ultrasonic cutting of foods with inclined moving blades. Journal of Food Engineering 103(4): 394-400.

Atkins, T. 2009. The science and engineering of cutting: the mechanics and process of the separating, scratching and puncturing biomaterials metals and non-metals, p. 283-284. UK: Butterworth-Heinemann, Elsevier.

Bolin, H.R. and Huxsoll, C.C. 1991. Effect of preparation procedures and storage parameters on quality retention of salad-cut-lettuce. Journal of Food Science 56: 60-67.

Brown, T., James, S.J. and Purnell, G.L. 2005. Cutting force in foods: experimental measurements. Journal of Food Engineering 70 (2): 165-170.

Ciulica, L.G. and Rus, F. 2012. Experimental regarding the determination of the optimum cutting angle using single edge knife. Bulletin of the Transylvania University of Brosov Series II: forestry, Wood industry. Agricultural Food Engineering 5(54): 135-140.

Dowgiallo, A. 2005. Cutting force of fibrous materials. Journal of Food Engineering 66: 57-61.

Gamble, M.H. and Rice, P. 1988. The effect of slice thickness on potato crisp yield and composition. Journal of Food Engineering 8: 31-46.

Gorny, J.R., Cifuentes, R.A., Hess-Pierce, B. and Kader, A.A. 2000. Quality changes in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size, and storage regime. International Journal of Food Science and Technology 65: 541-544.

Hui, Y.H. 2006. Handbook of Fruits and Fruit Processing, p. 129-130. Iowa, USA: Blackwell publishing.

Jiang, X. 2013. Design and research on household food slicer. Advance Journal of Food Science and Technology 5(10): 1296-1300.

McCarthy, C.T., Hussey, M. and Gilchrist, M.D. 2007. On the sharpness of straight edge blades in cutting soft solids: Part I-indentation experiments. Engineering Fracture Mechanics 74(14): 2205-2224.

McGorry, R.W., Dowd, P.C. and Dempsey, P.G. 2003. Cutting moments and grip forces in meat cutting operations and the effect of knife sharpness. Applied Ergonomics 34(4): 375-382.

Mitcham, B., Cantwell, M. and Kader, A. 1996. Methods for determining quality of fresh commodities. Perishables Handling Newsletter 85.

Onwulata, C.I., Pimentel, M.R., Thomas, A.E., Phillips, J.G., Tunick, M.H., Mukhopadhyay, S., Sheen, S., Liu, C.K., Latona, N. and Cooke, P.H. 2013. Instrumental textural perception of food and comparative biomaterials. International Journal of Food Properties 16(4): 928-948.

Saravacos, G.D. and Maroulis, Z.B. 2011. Food Process Engineering Operation, p. 168, CRC Press, Greece.

Saravacos, G.D., Kostaropoulos, A.E. 2002. Hand Book of Food Processing Equipments, pp 138-141. New York: Kluwer Academic / Plenum Publishers.

Schneider,Y., Zahn, S. and Linke, L. 2002. Qualitative

process evaluation for ultrasonic cutting of food. Engineering in Life Sciences 2: 153-157.
Yee, L.C., Mazlina, M.K.S. and Tuah, B.T.H. 2012. Relationship between selected properties of starchy vegetables on grating and slicing production rate. American Journal of Agricultural and Biological Sciences 7(2): 232-238.