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Research Paper

Design of machine to size java apple fruit with minimal damage

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Java apple fruit features attractive skin, sweet and crispy flesh, and a high susceptibility to mechanical damage. The java apple produced in Thailand has gained popularity in local and foreign markets, is available almost all year round and is sold at good prices. Fruit export drives postharvest mechanisation, of which fundamentally important machines such as a mechanical sizer for java apple are still not available. This research was aimed at designing, constructing, testing, and evaluating an efficient sizing machine for java apple. Design concepts featured a) a sizing parameters which were determined by the diameter of the fruit and b) a sizing mechanism which causes minimum damage. The sizing machine comprised a feeding unit and a diverging belt sizing unit that are powered by two 187 W 220 V 50 Hz electric motors, gear reducer and pulleys. Performance tests indicated that velocity and inclination angle of the sizing belt; feeding belt velocity and the fruit orientation significantly affects the sizing performance at $p < 0.05$. The optimum conditions for continuous mechanical sizing depended on the variety. The optimum sizing performance was characterised by a contamination or error ratio of 10.8–16.5%, and a throughput capacity of 149.7–195.1 kg h^{-1} with no significantly noticeable damage to the sized fruits. Manual sizing of the exported java apple featured an error ratio of 27.9%, a damage percentage of 13.3%, and a capacity of 107.2 kg h^{-1}. Therefore, the java apple sizing machine can be operated without adding more mechanical damages to the sized fruit.

1. Introduction

Java apple fruit is popular in Thailand and abroad due to its beautiful skin colour as well as sweet and crispy flesh. The fruit is also of high nutritional value. In the year 2005, exports of the flesh java apple from Thailand reached as much as 44.6 million US $, which made it the third ranking export fruit after durian and longan.

Amongst postharvest operations of the fresh fruit, sizing is considerably labour intensive. Sizing is necessary, because the sized fruit a) has higher value than fruit that is sold unsorted b) it attracts buyers and c) it facilitates packaging

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Nomenclature

D_m	Diameter of the java apple fruit head, mm
β	Diverging angle of the sizing belt, °
α	Inclination angle of the belt, °
X_{12}	Diameter of separation of aperture between java apple grade 1 and 2, mm
X_{23}	Diameter of separation of aperture between java apple grade 2 and 3, mm
μ_1	average diameter of java apple fruit grade 1, mm
μ_2	average diameter of java apple fruit grade 2, mm
σ_1	standard deviation of java apple fruit grade 1
σ_2	standard deviation of java apple fruit grade 2
E_w	Sizing efficiency
Q	Throughput capacity, kg h^{-1}
$\overline{C}_R$	Mean contamination ratio or error
G_i	Outflow rate of grade i, kg h^{-1}
K_i	Fraction of cost as related to grade i
N_i	Number of grade i fruit of the total assortment at the beginning of sizing
N_{ij}	Number of grade j fruit in the grade i receiver
N_{gi}	Number of grade i fruit in grade j receiver
N_{ti}	Total fruit in grade i receiver, kg
P_i	Fraction of grade i fruit of the total mixture at the beginning of sizing
P_{gi}	Fraction of correct fruit in grade i receiver
t	Feeding time, h
W_i	Weighting function
w_i	Total weight of fruit in grade i receiver, kg
w_t	Total fruit weight fed into sizing system, kg

designs (Jarimopas, Toomsaengtong, Singh, Singh, & Sothornvit, 2007; Peleg, 1985). Manual sizing is beset by slow sizing rates, considerable errors and mechanical damage. For example, the manual sizing of fresh mangosteen (Jarimopas, Toomsaengtong, & Inprasit, 2007) and durian (Jarimopas, Siriratchatapong, Sukharom, Sihavong, & Goto, 1992) was found to cause error ratios of 34 and 43% respectively. Sizing machines developed to work with tropical fruit are usually composed of a perforated conveyor sizer, a belt, a board sizer, and a diverging belt. Jarimopas, Kongwatananon, Rangdang, and Yamashita (1988) tested a commercial tangerine sizing machine with a mechanism based on the perforated conveyor sizer. Their machine consisted of five perforated cylinders of varying diameters and sized 6 grades of the fruit at a capacity of 1.5 tonne h^{-1} and a sizing efficiency of 87.5%. The high sizing efficiency was perhaps due to the non-deformable aperture. Although commercially applicable, single layer feeding has to be manually controlled and this constitutes an undesirable feature. The sizing of a small number of tangerines is persistently impeded by fruits caught on the inclined plane between the cylinders, so that the operator has to manually move the fruit to the next rotating cylinder to continue sizing. This is a cause of exasperation to the operators and it slows down the sizing process. The rotary sizing machine (GREEFA, Geldermalsen, Netherlands), which is the developed model of the belt and board sizer, was used to size mangosteen (Jarimopas, Toomsaengtong, & Inprasit, 2007; Jarimopas, Toomsaengtong, Singh, et al., 2007). The mangosteen sizer could sort 3 grades (small, medium, large) at a continuous capacity of 1026 kg h^{-1} and an error rate of 23%. The Rotary Greefa concept has also been applied to size other sphere-shaped fruit and vegetables, e.g. guava (Jarimopas, Rachanukroa, & Chen, 2002). The advantage of the apparatus is its ease of transportation, such as on a pick-up truck. However, its performance is limited to single layer feeding and it is characterised by errors due to the inconsistent aperture. Jarimopas et al. (1988) developed a diverging belt sizer to sort mangosteen. The diverging belt is comprised of two 75 mm wide belts which are inclined at an angle of 25° to the horizontal surface. The machine graded mangosteen at a capacity of 1100 kg h^{-1} at an efficiency rate of 80%. The low inclination of the sizing belt required mangosteen to travel considerable distances before calibration of the fruit diameter and the descent from sizing belt posed a major disadvantage of the machine. This resulted in a long machine, which made transportation difficult. Furthermore, its aperture was inconsistent because of the non-uniformity of the sizing belt.

For the frustum-shaped fruit, such as pears and carrots, Peleg (1985) suggested using the diverging belt sizer for efficient sorting. A proper sizing machine ought to feature fast sizing rates, acceptable error ratios with insignificant mechanical damage. Mohsenin (1996) stated that mechanical damage was the by-product of the use of agricultural machinery. Possibly, the aforementioned machines caused mechanical damage but the related evaluations were not reported. Bupata, Jarimopas, & Changtong (2007) reported that the diameter of java apple fruit varies proportionally with the fruit weight. The variation of the java apple fruit diameter respective to size and cultivar was presented by Sarakan, Jarimopas, and Changtong (2007). Based on the compression rupture force of java apple skin, its

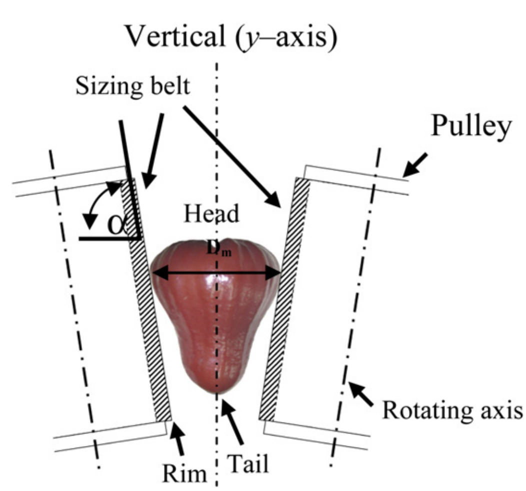

Fig. 1 – Design concept of the java apple fruit sizing machine showing the inclination angle α and front view of the sizing configuration (horizontal plane is perpendicular to the paper).

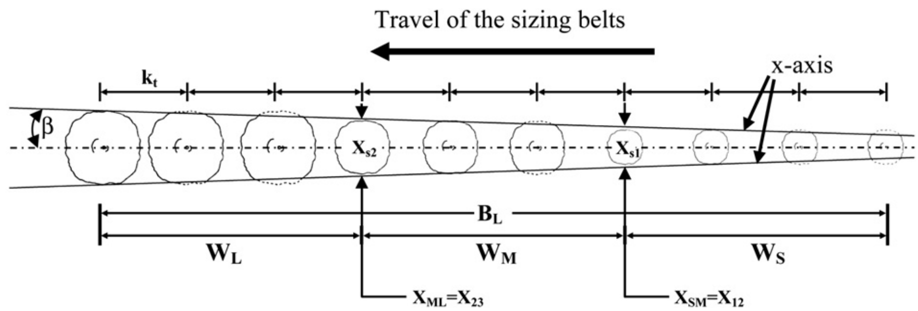

Fig. 2 – Aperture profile of the sizing belt (B_L = belt length, W_L = sizing length of grade L, W_M = sizing length of grade M, W_S = sizing length of grade S, k_t = interval of fruits (200 mm)).

skin was found more susceptible to damage than apple (Jarimopas, Toomsaengtong, & Inprasit, 2007; Jarimopas, Toomsaengtong, Singh, et al., 2007). Abrasion and bruising were potentially found on packaged java apples under simulated transport vibration whilst greater abrasion was observed. (Jarimopas, Toomsaengtong, & Inprasit, 2007; Jarimopas, Toomsaengtong, Singh, et al., 2007).

Commercially java apple yields high prices, and is gaining popularity in foreign markets where it is available almost all year round. Fruit production is rather uniform butshortages and costs of labour are becoming crucial. Therefore, the demands for sizing machines have increased. A specific sizing machine for java apple fruit is not available. The development of a simple, compact, rugged mechanical sizer to work with the highly susceptible fruit is a challenge. Thus, this research is aimed at designing, constructing, testing, and evaluating a sizing machine for fresh java apple fruit with acceptable error rates and minimal damage.

2. Materials and methods

2.1. Design and operation

2.1.1. Design

The design concept comprised four criteria: a) the sizing parameter was to be determined by the diameter of the java apple fruit head (D_m in Fig. 1), b) the sizing mechanism had to incurre minimum damage, c) the sizing machine had to provide mechanisms to consistently meter the fruit diameter and to uniformly release the measured fruit into receiving container of the corresponding size, and d) the machine should be simple, compact, rugged and transportable. A diverging belt design was selected because (i) the sizing belts provide two contact points that measure the java apple diameter whilst the fruit progresses along the belts. (ii) the sizing belts travel simultaneously diverging during movement; and as a result, the measured fruit descends on the belts and left the belts at their base (aperture) when the aperture loses contact with the measured fruit; the fruit descends to the receiving container of the corresponding size. (iii) the shape of java apple fruit fairly resembles that of pear. Fig. 2 showed the base view of the diverging belt sizing machine; the solid line shows the rim of the aperture.

Preliminary drop tests of 15 fresh intact java apple fruit (of uniform size) from 150, 200 and 250 mm height onto a hard surface cushioned by 20 mm foam rubber revealed that fruit damaged occurs at a minimal plunge height of 200 mm. For an assumed uniformly accelerated motion, this corresponds to 0.2 s drop time (Meriam, 1975). The travel velocity of the sizing belt of 200 mm s^{-1} and the combined time of fruit descent and fruit removal from of the receiving tray of 0.5 s, dictates a feasible placement of the fruits at $200 \times 0.5 = 100$ mm intervals. The diverging belt sizing machine was designed as to allow 3 fruits of the same grade to travel in sequence along the belt (the small grade permits 4 fruits) (Fig. 2). Three grades (large, medium, and small) are required. The active length was to be 900 mm plus 100 mm of additional space for the fruit rebound (if any) on each side, giving a total length of 1100 mm is designates. The diverging angle of the belt is β in Fig. 1. As per Bupata et al. (2007), β was equal to 0.29, 0.55 and 0.34° for the varieties of java apple Toonklao, Tubtimjan and Tongsamsri respectively. The inclination angle of the belt is shown as α in Fig. 1. The diverging belts need to be inclined to the horizontal plane, because the inclination causes 2 point contact for every fruit during movement regardless of size. Thus, every fruit is measured at its head diameter. Should α be

Table 1 – Statistics of aperture and β angles of the sizing belts.

Variety	Maximum Diameter for the fruit size (mm)			X_{12} (mm)	X_{23} (mm)	β (°)
	S	M	L			
Toonklao	52.92 ± 1.57	57.70 ± 0.89	64.12 ± 1.37	59.96 ± 4.16	53.01 ± 7.30	0.29
Tubtimjan	45.30 ± 2.93	58.08 ± 1.53	65.80 ± 1.36	62.87 ± 9.40	94.86 ± 32.73	0.55
Tongsamsri	51.15 ± 2.20	58.47 ± 1.53	63.07 ± 1.82	65.33 ± 10.02	47.39 ± 13.29	0.34

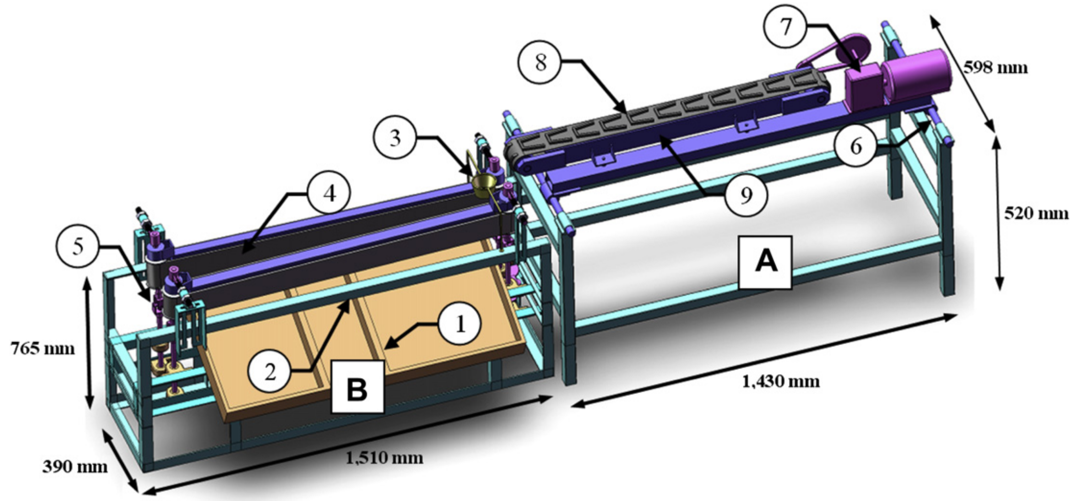

Fig. 3 – Schematic diagram of java apple fruit sizing machine (*A* = feeding unit; *B* = diverging belt sizing unit; 1 = receiving tray; 2 = steel frame; 3 = conical cloth tube; 4 = cushioned sizing belt; 5 = universal joint; 6 = cylindrical shaft; 7 = electric motor and reduction gear; 8 = U-shape rubber holding java apple; 9 = feeding belt).

too large the fruit falls and does not symmetrically lie on the belts with respect to the y-axis and the head diameter is therefore not measured. If the α is too small, the fruit shoulder might stay at the rim, and diameter measurement does not occur. The appropriate inclination angle (α) therefore needed to be determined. Eq. (1) (Peleg, 1985) suggests the estimate of diameter of separation (X_{12} and X_{23}) between java apple fruits of adjacent grades from the mean and the standard deviation of each adjacent grade. The values of X_{12} and X_{23} are given in Table 1.

$$X_{12} = \frac{(\mu_2\sigma_1^2 - \mu_1\sigma_2^2)}{(\sigma_1^2 - \sigma_2^2)} \pm \left[\left(\frac{\mu_2\sigma_1^2 - {}_1\sigma_2^2}{\sigma_1^2 - \sigma_2^2}\right)^2 - \frac{(\mu_2^2\sigma_1^2 - \mu_1^2\sigma_2^2 - 2\sigma_1^2\sigma_2^2\ln(\sigma_1/\sigma_2))}{\sigma_1^2 - \sigma_2^2}\right]^{\frac{1}{2}} \quad (1)$$

where

X_{12} = diameters of separation of aperture between java apple grade 1 and 2
μ_1 = average diameter of java apple fruit grade 1
μ_2 = average diameter of java apple fruit grade 2
σ_1 = standard deviation of java apple fruit grade 1
σ_2 = standard deviation of java apple fruit grade 2

Fig. 3 shows the developed java apple fruit sizing machine with the feeding unit and the diverging belt sizing unit. The feeding unit, 598 mm wide by 1430 mm long by 520 mm high, was made of steel. Two 25.4 mm diameter cylindrical shafts were mounted at the top of the frame to facilitate belt adjustments. The feeding belt, Ammeraal type Belt Flexam EM 10/2 Green FG (Ammeraal Beltech, Heerhugowaard, Netherlands), was 100 mm wide by 2400 mm long and parallel

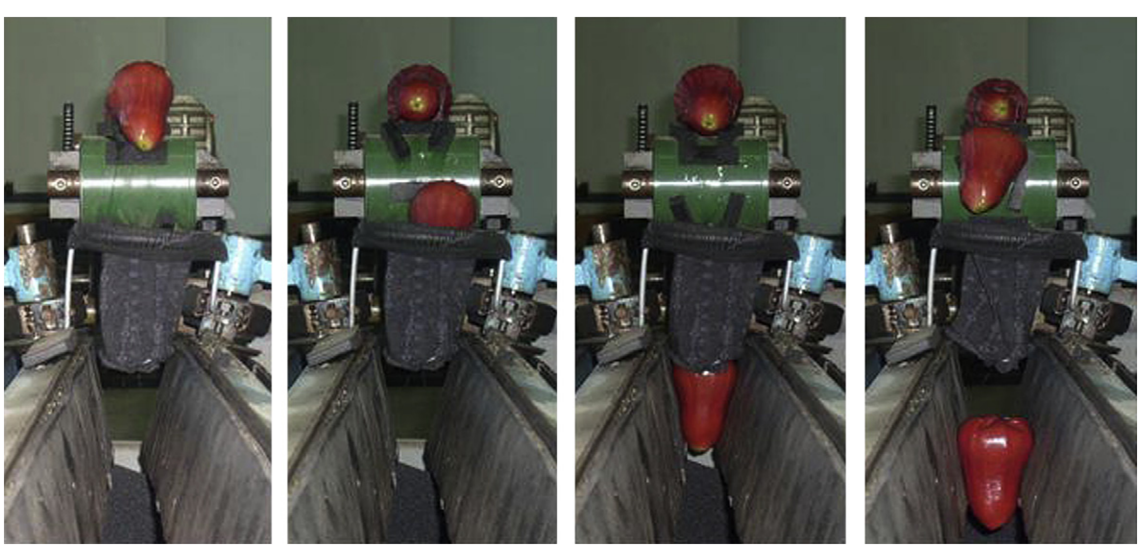

Fig. 4 – Typical motion of java apple fruit and the conical cloth tube of the sizing machine.

to the floor. The feeding unit was driven by a 0.19 kW 220 V 50 Hz electric motor, a 1: 20 gear reducer, a chain and a pulley. A U-shape rubber cushion was attached to the surface of conveyor belt with 80 mm spacing of the partial containers of the fruit for uniform semi-automatic fruit feeding. The sizing machine, made of steel and 390 mm wide, 1510 mm long and 765 mm high, featured a galvanised steel receiving tray 600 mm wide 1100 mm long, and 80 mm deep. The receiving tray was cushioned with 20 mm rubber foam with two adjustable partitions for the desired fruit size separation. The sizing belts diverged and were inclined to the horizontal plane at α degree. Each of the two sizing belts, Ammeraal type Nonex EM 8/2 Blue FG were 100 mm wide and 2500 mm long. The outer surface of the belts was lined with 4 mm latex foam. Each belt was driven at the same velocity by a 220 V 50 Hz electric motor operating at 1450 rpm with reducing gear and a universal joint to facilitate the adjustment of belt angle. A cloth conical tube was placed between the end of the feeding belt and the beginning of the sizing belt to control the vertical descent of the java apple fruits, to decelerate fruit drop onto the sizing belt thereby reducing damage to the fruit. The movement of the fruit on the sizing belt was below horizontal thereby minimising vertical sliding. The conical cloth tube was 120 mm long and made of yarn. It had a 100 mm aperture diameter at the top and 60 mm aperture diameter at the bottom. The feeding machine and the sizing machine were placed in proximity to the cloth conical tube and were well aligned.

2.1.2. *Operation*

Java apple fruits were manually continuously fed into the U-shaped rubber of the feeding belt by an operator in such a way that the stem end of the fruit was parallel to the belt movement. This provides a uniformly automatic feed of the fruits to the sizing belt. However, the feeding machine capacity was limited by the operator's competence. The conveyed fruit left the feeding belt and dropped vertically into the conical cloth tube (Fig. 4). The conical cloth tube not only carried the fruit vertically, but it also decelerated the fruit to minimise the impact on the sizing belt. The appropriate alignment and symmetry of the feeding belt, the cloth conical tube, and the sizing belt improved the vertical orientation of the java apple during its descent at the start of the sizing process.

The sizing belt carried the java apple fruits past 2 contact points. The forward motion, divergence of the sizing belts and the fruit weight caused the fruit to descend towards the lower end or the aperture of the belts. Therefore, the two contact points on the sizing belts and fruit surface were continuously. Such phenomenon could cause skin rubbing on the fruit and might give rise to abrasion. This was prevented by cushioning on the surfaces of the sizing belts. When the fruit reached the aperture that infinitesimally exceeded the fruit diameter, the fruit lost contact with the belts and fell into the correct receiving tray.

2.2. *Performance test*

Sample preparation for the determination of optimum working conditions included the random selection of newly-harvested, uniform and damage free java apple fruit. Thirty sample fruits of each size (three sizes: small, medium, large) of each variety (three varieties: Toonklao, Tubtimjan and Tong-samsri) were collected. Maximum fruit head diameter, length and weight of each sample were measured with a vernier calliper and an electronic balance (Sartorius G 6000, Sartorius AG, Goettingen, Germany).

2.2.1. *Determination of the optimum angle of inclination and the velocity of sizing belt*

Samples of java apple fruit were prepared as mentioned above. Testing conditions included two control factors; the angle of inclination of the sizing belt (3 levels: 75°, 80° and 85°) and the sizing belt velocity (3 levels: 10, 20 and 30 m min^{-1}). Uniform feeding of java apple samples to the sizing belt was regulated at 15 m min^{-1}. Five replications were carried out for a combination of the control factors. Performance of the sizing machine was evaluated with Eqs. (2–4). Analysis of variance (ANOVA) and Duncan Multiple Range Test (DMRT) were applied to determine the influence of the control factors.

$$E_w = \sum\left(\frac{p_{gi}W_iG_i}{QP_i}\right) \tag{2}$$

$$Q = \frac{w_t}{t} \tag{3}$$

$$\overline{C}_R = \frac{\Sigma N_{ij}}{\Sigma N_i} \tag{4}$$

where

$$P_{gi} = \frac{N_{gi}}{N_{ti}}$$

$$N_{ti} = N_{gi} + N_{ij}$$

$$W_i = \frac{K_iP_i}{\Sigma K_iP_i}$$

$$P_i = \frac{N_i}{\Sigma N_i}$$

$$G_i = \frac{w_i}{t}$$

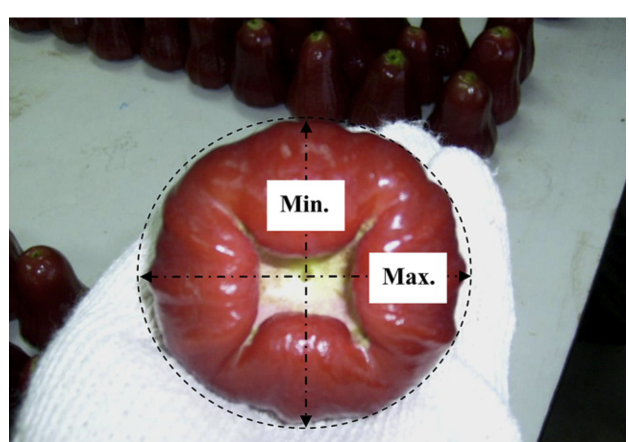

Fig. 5 – Shape of the head of a java apple fruit.

Table 2 – Effects of velocity and inclination angle of the sizing belt on the performance of the java apple fruit (Toonklao variety) sizing machine.

Inclination angle (°)	Sizing belt velocity (m min^{-1})	$\overline{C}_R$* (%)	E_w*(%)
75	10	26.35 ± 4.00^{ab}	76.13 ± 8.07^{ab}
	20	26.48 ± 7.53^{ab}	80.32 ± 10.49^{ab}
	30	27.44 ± 3.48^{bc}	81.97 ± 7.82^{a}
80	10	25.71 ± 2.91^{ab}	80.11 ± 10.95^{ab}
	20	33.14 ± 6.28^{bc}	75.24 ± 7.23^{ab}
	30	33.37 ± 2.45^{a}	74.91 ± 4.92^{ab}
85	10	30.19 ± 4.58^{abc}	70.19 ± 4.45^{b}
	20	23.30 ± 4.19^{bc}	79.74 ± 5.21^{ab}
	30	25.26 ± 3.91^{ab}	76.24 ± 6.07^{ab}

*Means with the same letter in the same column designate insignificant difference at $p < 0.05$.

Table 3 – Effects of velocity and inclination angles of the sizing belt on the performance of the java apple sizing machine (Tubtimjan variety).

Inclination angle (°)	Sizing belt velocity (m min^{-1})	$\overline{C}_R$* (%)	E_w* (%)
75	10	17.70 ± 5.33^{abc}	91.97 ± 5.47^{ab}
	20	12.13 ± 3.39^{a}	92.77 ± 2.63^{b}
	30	16.89 ± 1.89^{ab}	88.22 ± 1.96^{ab}
80	10	20.74 ± 9.17^{bcd}	85.42 ± 7.96^{ab}
	20	24.25 ± 5.86^{cd}	88.85 ± 11.07^{ab}
	30	19.15 ± 3.61^{abcd}	91.22 ± 5.33^{ab}
85	10	25.25 ± 5.09^{d}	76.18 ± 8.26^{a}
	20	24.64 ± 5.14^{cd}	86.76 ± 6.83^{ab}
	30	15.99 ± 0.47^{ab}	92.49 ± 5.79^{ab}

*Means with the same letter in the same column designate insignificant difference at $p < 0.05$.

and where E_w is sizing efficiency, Q is throughput capacity, $\overline{C}_R$ is mean contamination ratio or error, G_i is outflow rate of grade i, K_i is the fraction of cost as related to grade i, N_i is the number of grade i fruit of the total assortment at the beginning of sizing, N_{ij} number of grade j fruit in the grade i receiver, N_{gi} is the number of grade i fruit in grade j receiver, N_{ti} is the total fruit in grade i receiver, P_i Fraction of grade i fruit of the total mixture at the beginning of sizing, P_{gi} is the fraction of correct fruit in grade i receiver, t is feeding time, W_i is a weighting function, w_i is the total weight of fruit in grade i receiver and w_t is the total fruit weight fed into sizing system.

2.2.2. *Determination of the optimum feeding belt velocity*

The sample preparation as described above was repeated for these tests. The determined condition of velocity and inclination angle of the sizing belt for a specific variety was not altered throughout the determination. The control factors were the feeding belt velocities (3 levels: 15, 20 and 25 m min^{-1}). Five replications were carried out. The sizing machine performance was analysed using ANOVA and DMRT.

2.2.3. *Determination of the optimum fruit orientation and the associated mechanical damage*

The shape of the java apple fruit (Fig. 5) determined the maximum and the minimum dimensions of the fruit head. Both parameters were significantly different (Bupata et al., 2007). The fruit shape influenced the test condition of fruit orientation in regard to the sample placement on the feeding belt (2 possibilities: random placement and horizontal maximum diameter placement). Each fruit sample was placed with its stem orientated towards the sizing unit. The determined conditions of velocity and inclination angle of the sizing belt, and feeding belt velocity for a specific variety were not altered throughout the experiment. Sample preparation was as reported earlier. The testing procedure and statistical analysis of results were as used in the earlier tests.

Following the tests 90 java apple samples of all sizes were randomly collected and stored at 15 °C for 6 h (Jarimopas, Toomsaengtong, & Inprasit, 2007; Jarimopas, Toomsaengtong, Singh, et al., 2007). The damage characteristics of java apples that were sized by the machine, both with and without conical cloth tube, and a control set of fruits (which was not processed by the machine) were comparatively analysed using Eqs. 5, 6 and 7.

$$\text{Damage area}(\%) = \frac{\text{Damaged area of a fruit}}{\text{Fruit surface area}} \times 100 \quad (5)$$

$$\text{Average fruit damage}(\%) = \frac{\text{Total of Damage area}}{\text{Total java apple fruit}} \times 100 \quad (6)$$

$$\text{Damage percentage}(\%) = \frac{\text{Number of damage dfruit}}{\text{Total java apple fruit}} \times 100 \quad (7)$$

The damage of java apple was assessed into 3 levels: level 1; no apparent damages, level 2; damage area <0.5%, and level 3; damage area <0.5%.

2.2.4. *Continuous operation test*

The appropriate conditions of velocity and inclination angle of the sizing belt, the feeding belt velocity, the fruit orientation on the feeding belt previously obtained were fixed for this test. Five hundred, newly-harvested, uniform and damage free java apple fruits of each variety were randomly harvested from an export orchard in Nakornpathom, Thailand. Measurements of the physical characteristics of each fruit sample were carried

Table 4 – Effects of velocity and inclination angles of the sizing belt on the performance of the java apple sizing machine (Tongsamsri variety).

Inclination angle (°)	Sizing belt velocity (m min^{-1})	$\overline{C}_R$* (%)	E_w* (%)
75	10	24.07 ± 2.76^{ab}	94.96 ± 3.76^{b}
	20	29.01 ± 5.05^{b}	95.55 ± 4.73^{b}
	30	23.85 ± 3.25^{ab}	95.10 ± 3.16^{b}
80	10	22.50 ± 3.66^{ab}	88.42 ± 8.73^{ab}
	20	18.91 ± 3.26^{a}	88.22 ± 7.64a^{b}
	30	19.91 ± 7.94^{a}	93.54 ± 5.15^{b}
85	10	28.60 ± 4.95^{b}	87.09 ± 8.92^{ab}
	20	21.49 ± 4.46^{a}	92.39 ± 6.28^{ab}
	30	20.49 ± 5.58^{a}	84.16 ± 4.94^{a}

*Means with the same letter in the same column designate insignificant difference at $p < 0.05$.

Table 5 – Effects of feeding belt velocity on the performance of the java apple fruit sizing machine.

Variety	Feeding belt velocity (m min^{-1})	$\overline{C}_R$* (%)	E_w *(%)
Toonklao	15	5.80 ± 2.05^b	96.80 ± 1.22^b
	20	11.35 ± 2.16^a	92.26 ± 1.99^a
	25	16.02 ± 1.66^c	89.69 ± 5.36^a
Tubtimjan	15	12.13 ± 3.39^b	92.77 ± 2.63^a
	20	24.24 ± 2.40^c	86.68 ± 5.80^b
	25	23.16 ± 4.15^c	85.77 ± 4.94^b
Tongsamsri	15	18.91 ± 3.26^a	88.22 ± 7.64^a
	20	20.58 ± 10.26^a	80.93 ± 12.08^a
	25	20.30 ± 3.44^a	83.13 ± 6.08^a

*Means with the same letter in the same column designate insignificant difference at $p < 0.05$.

out as reported earlier. All the fruit samples of each variety were continuously sorted by the prototype machine and the performance of the machine evaluated.

3. Results and discussion

3.1. *Optimum velocity and inclination angle of the sizing belt*

For specific varieties, the velocity and the inclination angle of the sizing belt significantly affected the mean contamination ratio ($\overline{C}_R$) and sizing efficiency at $p < 0.05$; based on the priority of contamination ratio. The optimum velocity and the inclination angle were 20 m min^{-1} and 85° for Toonklao variety, resulting in the lowest $\overline{C}_R$ of 23.3% and an E_w of 79.7% (Table 2). For the Tubtimjan variety, the appropriate velocity and the inclination angle were 20 m min^{-1} and 75°, resulting in the lowest $\overline{C}_R$ of 12.1% and E_w of 92.8% (Table 3). Although the velocity of the feeding belt was kept constant at 15 m min^{-1}, the optimum velocity and the inclination angle of the sizing belt for the Tongsamsri were between 20 and 30 m min^{-1} and 80°, resulting in the lowest $\overline{C}_R$ of approximately 18.9% and E_w of 88.2% (Table 4).

3.2. *Optimum feeding belt velocity*

Operation of the java apple sizing machine under i) the controlled condition of optimum velocity and inclination angle of the sizing belt for each variety and ii) the variation of feeding belt velocity due to uniform feed the fruit on U-shape rubber by the operator, revealed that the feeding belt velocity significantly affected $\overline{C}_R$, E_w and Q at $p < 0.05$ for specific varieties. As indicated by the highest E_w and the lowest $\overline{C}_R$ the optimum feeding belt velocity for the Toonklao, Tubtimjam and Tongsamsri varieties was identical at 15 m min^{-1}. The corresponding performance parameters were $\overline{C}_R = 5.8\%$ and $E_w = 96.8\%$ for the Toonklao variety; $\overline{C}_R = 12.1\%$ and $E_w = 92.8\%$ for the Tubtimjam variety; $\overline{C}_R = 18.9\%$ and $E_w = 88.2\%$ for the Tongsamsri variety (Table 5). $\overline{C}_R$ tended to be significantly higher for feeding belt velocities >15 m min^{-1} for the Tubtimjan variety, because at high velocity, some fruits left the belt in an unsymmetrical manner when passing through the conical cloth tube. As a result, the fruits were not vertical when they contacted the sizing belt which caused sizing errors.

3.3. *Optimum fruit orientation and damage analysis*

With respect to the optimum velocity, inclination angle of the sizing belt and the feeding belt velocity for a specific variety, assessment of the sizing machine indicated that fruit orientation significantly affected the performance of the machine at $p < 0.05$. Table 6 exhibits the maximum diameter placement on the U-shape rubber produced smaller $\overline{C}_R$ and smaller Q for all varieties when compared to the $\overline{C}_R$ and Q for random placement. The smaller Q might be due to the care of the operator in keeping the position of the fruit in the U-shape rubber in conformity with to the B-orientation, however this practise caused some loss in time. This problem could be solved by more practise with fruit placement.

Table 7 shows the group of java apple fruit sized by the diverging belt sizing machine both with and without the conical cloth tube and the control group of Tubtimjan, Tongsamsri and Toonklao varieties. All varieties of sized fruits sorted by the machine with installed conical cloth tube exhibited less damage than fruit sorted by the machine without the conical cloth tube installed. In case of the Tongsamsri variety, there was damage at level 3 when sorted by the machine without the conical cloth tube while no level 3 damage was observed for sorting by the machine with the cloth conical tube. The apparent damage on the fruits was either within normal parameters or absent. The most frequently observed levels of damage were in the minimal damage level (level 2: damage area < 0.5 percent).

3.4. *Continuous performance*

The diverging belt sizing machine was tested by continuously sizing 500 java apple fruits from each of the Tubtimjan,

Table 6 – Effects of fruit orientation on the performance of the java apple fruit sizing machine.

Variety	Fruit orientation	Q *(kg h^{-1})	$\overline{C}_R$*(%)	E_w *(%)
Toonklao	Random	263.92 ± 11.30^b	17.21 ± 2.09^b	93.52 ± 3.00^a
	Maximum diameter	179.87 ± 4.90^a	9.84 ± 1.93^a	93.62 ± 1.83^a
Tubtimjan	Random	333.09 ± 28.51^b	6.47 ± 2.46^b	91.23 ± 10.41^a
	Maximum diameter	214.22 ± 8.37^a	3.16 ± 1.07^a	97.94 ± 0.97^b
Tongsamsri	Random	326.70 ± 33.49^b	14.26 ± 3.69^b	88.63 ± 5.30^a
	Maximum diameter	187.44 ± 5.69^a	8.66 ± 1.80^a	91.51 ± 2.70^b

*Means with the same letter in the same column designate insignificant difference at $p < 0.05$.

Table 7 – Damage of the mechanically sized java apple fruit (both with and without conical cloth tube on the machine) in comparison with the control sample.

Variety	Level of damage	Control set		Sizing with cloth conical tube		Sizing without cloth conical tube	
		Damage percentage (%)	Average fruit damage (%)	Damage percentage (%)	Average fruit damage (%)	Damage percentage (%)	Average fruit damage (%)
Toonklao	Level 1[a]	74.44	–	65.56	–	32.22	–
	Level 2	25.56	0.12 ± 0.09	34.44	0.09 ± 0.04	67.78	0.11 ± 0.07
	Level 3	–	–	–	–	–	–
Tubtimjan	Level 1	36.67	–	65.56	–	26.67	–
	Level 2	61.11	0.13 ± 0.10	32.22	0.14 ± 0.11	71.11	0.15 ± 0.10
	Level 3	2.22	0.71 ± 0.12	2.22	0.94 ± 0.26	2.22	0.66 ± 0.06
Tongsamsri	Level 1	88.89	–	85.56	–	68.89	–
	Level 2	11.11	0.06 ± 0.04	14.44	0.23 ± 0.11	30.00	0.08 ± 0.08
	Level 3	–	–	–	–	1.11	0.85 ± 0.04

a The damage of java apple was divided into 3 levels – level 1: no apparent damage, level 2: Damage area less than 0.5 percent and level 3: Damage area in excess of 0.5 percent and over.

Tongsamsri and Toonklao varieties. $\overline{C}_R$ and Q for the Tubtimjan variety were 12.2% and 195.1 kg h^{-1} while those for the Tongsamsri variety were 16.5% and 181.7 kg/h and for Toonklao 10.8% and 149.7 kg h^{-1} respectively. For a given variety, $\overline{C}_R$ and Q were relatively lower than those obtained in the previous determination in paragraph 2.3.3. This might occur because in Section 2.3.3, there were equal in numbers for each size; whereas the sample preparation of the continuous performance test was dependent on what the fruit growers provided. The weight ratios of the java apple fruits of small: medium: large size of the Tubtimjan variety were 0.2: 1: 0.24, those of the Tongsamsri variety were 1: 0.99: 0.57 and those of the Toonklao variety were 0.48: 1.00: 0.33, respectively. Manual sizing of the java apples of the Tongsamsri variety, destined for export, on average achieved a performance of 107.2 kg h^{-1} with a contamination ratio ($\overline{C}_R$) of 27.9% and a mechanical damage (Eq. (7)) of 13.3% (Treeamnuk, Jarimopas, & Jantong, 2008). Percent of damaged area was found to be insignificantly different at $p < 0.05$ for the mechanically sized fruit when compared with the control for every variety. This implies that the sizing machine did not incur additional noticeable damage to the sized fruits. Alternatively, the java apple fruit mechanical sizer could be operated at zero noticeable damage. Fewer errors, improved capacities and, in particular, zero noticeable damages in the sorting of fruit are considered to be a significant advantage of the diverging belt sizing machine.

4. Conclusions

The performance test of the java apple fruit sizing machine indicate that velocity and inclination angle of the sizing belt, feeding belt velocity and the fruit orientation significantly affects the sizing performance at $p < 0.05$. The optimum conditions for continuous mechanical sizing were dependant on the variety of the fruit. The optimum sizing performance was characterised by an error ratio of 10.8–16.5% and a throughput capacity of 149.7–195.1 kg h^{-1}. Manual sizing of java apple destined for export feature average ratios of 27.9% in error, 13.3% in damage and a capacity of 107.2 kg h^{-1}. The developed java apple sizing machine could be operated at "zero noticeable damage", and therefore no additional mechanical damage to the sized fruits.

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