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ORIGINAL ARTICLE

Development of composite mechanical peeler cum juice extractor for kinnow and sweet orange

Manoj Kumar Mahawar[1] · **Kirti Jalgaonkar**[1] · **Bhushan Bibwe**[1]

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Abstract A mechanical peeler cum juice extractor was designed and developed for simultaneous peeling and juice extraction of kinnow and sweet orange fruits. Based on the designed components and prior optimization of operational parameters for peeling of both the fruits, a functional machine was developed. Major components of the machine include spur gear assembly (Φ 102 mm and Φ 76 mm), two fruit holders (Φ 30 mm), revolving shaft with length 570 mm, clearance of the tool for peeling 25 mm and cutting knife with length 80 mm, respectively. This peeler was operated using a motor, gear assembly and the combination of pulleys. The juice extractor was also fitted with a conical hopper having a flattened base to facilitate the juice extraction of peeled fruits. For performance evaluation, fruit rotation speed was considered as independent parameter and was varied at 220, 260, 280, 300, 360 rpm, whereas peeling time (s), peeling efficiency (%), peel remained on fruit (%) and juice loss (%) were taken as dependent parameters. The machine resulted in best performance at fruit rotational speed of 220 rpm (kinnow) and 260 rpm (sweet orange) with higher peeling efficiency and minimum juice loss. The capacity for peeling and juicing operation was 60–90 kg/h (kinnow) and 50–60 kg/h (sweet orange), respectively. This composite peeling cum juice extractor machine can find its applicability in cottage citrus fruit juice processing industries as well as for the domestic juice sellers.

Keywords Composite mechanical peeler · Performance evaluation · Rotational speed · Peeling efficiency

Introduction

Kinnow belongs to the *'Mandarin'* category of citrus fruits and is being extensively cultivated in India and Pakistan. The information about the first and foremost development of kinnow was reported from the University of California Citrus Experiment Station in 1935 and was released in India during the early 1940′s. Kinnow is a hybrid of two citrus cultivars i.e. 'King' (*Citrus nobilis*) and 'Willow Leaf' mandarin (*Citrus deliciosa*). In India, mandarins were cultivated over an area of 0.43 million hectares with the production of about 5.10 million tonnes (Anonymous 2018a). Considering the global citrus production, Sweet orange (*Citrus sinensis* L. Osbeck.) contributes to about 71% of the production with Brazil and India being first and third producer, respectively. In India, the production of 3.27 million tonnes was recorded from the area of 0.185 million hectares (Anonymous 2018a). Andhra Pradesh, Maharashtra, Telangana, Madhya Pradesh, Karnataka, Punjab, Jammu & Kashmir, Mizoram and Bihar are the states contributing significantly for the production of sweet orange in the country (Anonymous 2018b).

Both these fruits of northern states of India used to have their peak production during the winter and autumn months and are being processed into juice by the industry as well as fruit vendors. Most of this processing lies in semi-organized/unorganized sector where, utmost times fruit along with its peel and seeds are crushed while juice preparation

Manoj Kumar Mahawar and Kirti Jalgaonkar are equally contributed to the Manuscript.

✉ Manoj Kumar Mahawar
manojmahawar362@gmail.com

[1] Horticultural Crop Processing Division, ICAR-Central Institute of Post-Harvest Engineering and Technology, Abohar, Punjab, India

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which as a result degrades the quality of juice. This turns out to be a hindrance for the juice consumption as well as its acceptability. Therefore, it would have been a better option to remove these components by physical or mechanical means and then proceed further for juice extraction.

Peeling, therefore, appeared to be necessary for both kinnow and sweet orange before juice extraction. Orange (*Citrus sinensis*) and mandarin (*Citrus reticulata* Blanco) peels are reported to be a prominent source of macro as well as micronutrients (Czech et al. 2020). Owing to their potential functional properties, kinnow and sweet orange peel has versatile applications in food processing operations including extraction of bioactive compounds and incorporation as an ingredient in functional foods (Mahawar et al. 2017, 2020; Rafiq et al. 2018).

According to Somsen et al. (2004), ideally, peeling is a process which removes only the skin and surface defects, without damaging edible portions of pulps and remains intact as desirable in industries at processing stages. However, peeling such kind of fruits is a challenging task as the process is associated with a number of problems that come across. The round curvature sometimes prevent the fruit from rotation while peeling. The thick outer peel (albedo and flavedo) makes it suitable to be prefereably peeled with sharp tools like knives resulting towards the risk for manual injury (Mazlina et al. 2010). Another problem associated with this kind of manual peeling is the breakage of cellulose juice bearers resulting to the loss of juice. This manual peeling practice is also followed for kinnow and sweet orange and in addition to the injury concerns, the method is also restricted to low productivity per unit time. If the peeling operation is mechanized, it can be supplied to industry to be used in the form of raw material for added economic value or this machine can be made a part of the process line of the exisitng juice industries (Ademoh and Akaba 2015).

Though both sweet orange and kinnow are of commercial importance especially in northern states of the country, yet the peeling and juice extraction is done manually in most of processing lines or small scale industry/local vendors.

This existing process is laborious and time-consuming, and thus it is necessary to mechanize the peeling and juicing operation so as to improve upon the existing food processing techniques. Keeping in view of the above facts, this study was conducted to develop a composite peeler cum juice extractor for sweet orange and kinnow with a capacity suitable for small scale industry/local vendors.

Materials and methods

Design and development of machine

A mechanical peeler cum juice extractor for kinnow and sweet orange was developed based on principle of shearing and cutting. Considering the physical properties of both kinnow and sweet orange, structural requirements and fabrication ease, the operational and functional design was conceptualized and prepared. Preliminary trials were performed to standardize the individual machine components and fabrication was accomplished adhering to the designed specifications. The developed machine was equipped with various components that are expected to perform the following functions as listed below:

- Peeling blade: It is the most important component of the machine and portion of the blade that comes in contact with the fruit tissues while peeling. It was fabricated using food grade stainless steel. This will eliminate the probability of corrosion as it shears through the fruit peel and gets wetted by fluids oozing from the outer skin. It must be thin-edged, flexible, easy to bend and curved into semi-circular shape as dictated by the shape of the fruit. The dimensions of the peeling blade are, 38 mm (diameter), 5 mm (width) and 0.8 mm (thickness) as also shown in Fig. 1a. The blade assembly was fixed on a threaded shaft (572 mm length) which moves in parallel with the shaft used for fruit rotation. The fruit gets rotated between the holders, and the fruit gets rubbed against the sharp edged peeling blade to effect peeling by shearing cutting of outer skin. Provision was made for easy removal and replacement of blade whenever it skips, jams up, clogged with peels or gets worn out or blunt.
- Fruit holders: The two holders (Φ 30 mm) would function as arms that firmly hold and support the fruit placed for peeling (Fig. 1b). Two sets of hexa blades are fitted in the holders so as to facilitate in firmly holding the fruit while peeling. Both the holders are fitted parallel facing hexa baldes side to each other. One holder was in fixed position and the other one will perform the needed horizontal placement for keeping the fruit. Both the holders rotate in clockwise direction when connected with the power source. This adjustable holder was connected to an arm that can perform linear motions for fruit placement to adjust and support different size/shape of the fruits. The holders are connected to a spur gear arrangement that are mounted on the base.
- Set of spur and bevel gears: The spur gears system serves as an intermediary transmitter of motion and power between the shaft connected to the driven pulley

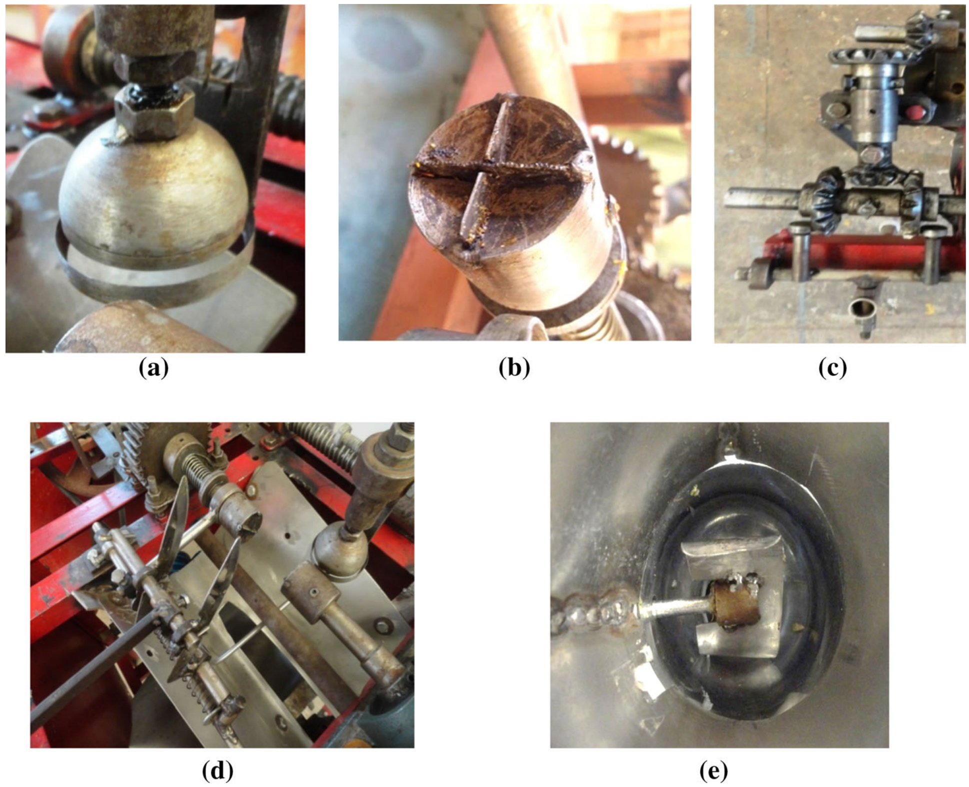


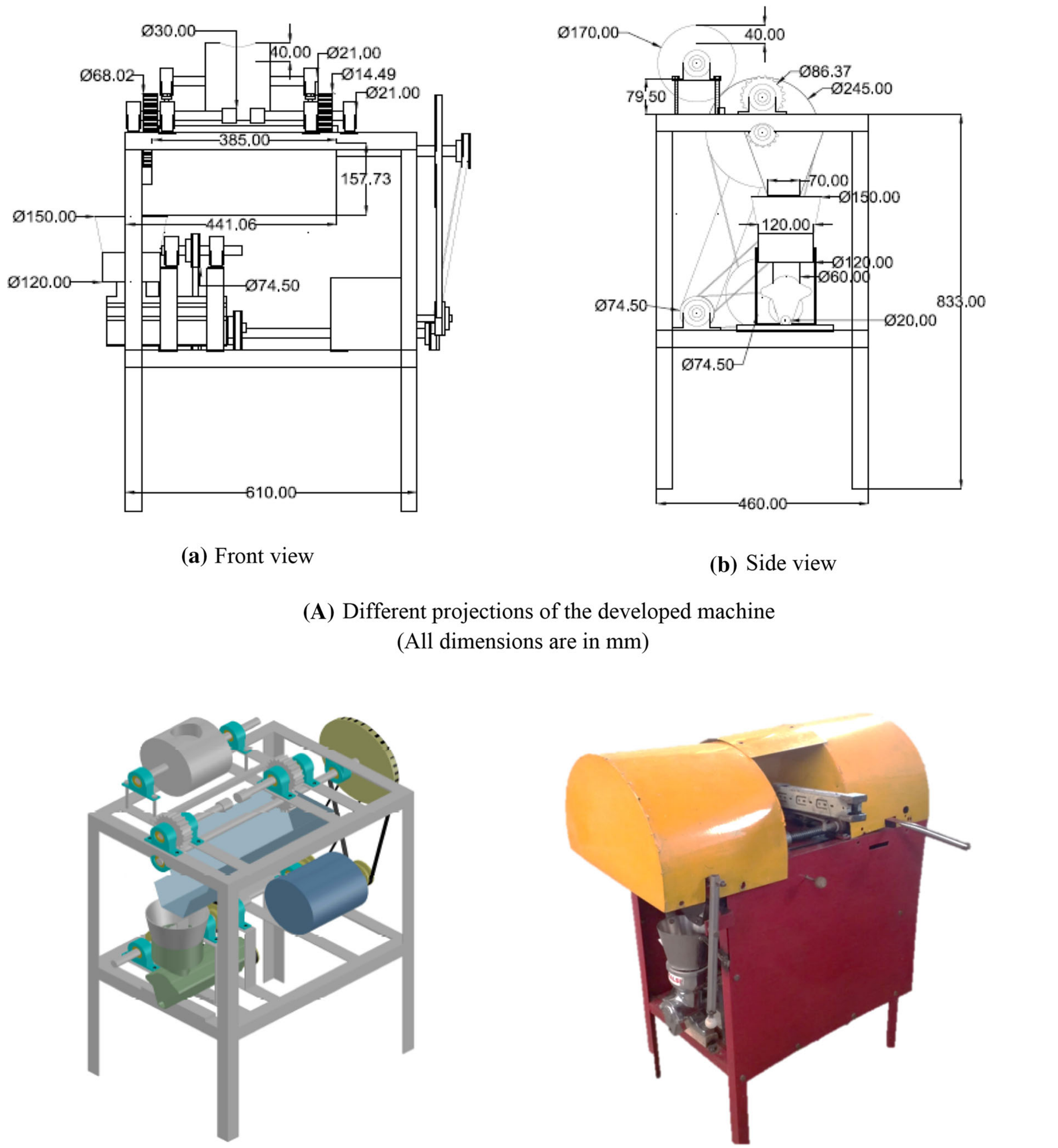
Fig. 1 Different components of the developed machine **a** peeling blade **b** fruit holder **c** bevel gear assembly **d** cutting knives assembly **e** fruit presser

and that on which the fruit holders are fitted. Four spur gears i.e. two each larger gear (Φ 102 mm) and smaller gear (Φ76 mm) and a set of bevel gear were fitted on the system as illustrated in Fig. 1c.

- Cutting knives assembly: This was consisted of two knives (80 mm length each) and were fitted on a separate shaft which was operated manually by a lever (Fig. 1d). The function of this assembly was to remove the unpeeled portion (peel remained on both side) which got covered by the fruit holders while peeling.
- Fruit presser: A sigmoidal shaped unit (40 mm (width) × 3 mm (thickness)) was fabricated using food grade stainless steel and connected with the motor. It is an important component of the machine with the function to automatically press the peeled fruit into the juicer (Fig. 1e). This component eliminates the requirement of additional plunger generally used by the operators for pressing the fruit for juice extraction.
- Power: A motor (M/s Crompton greaves, 0.5 HP, 1440 rpm) was fitted along with the systematic arrangement of pulleys to provide the synchronized and desired motion to the machine components.
- Machine base: The base frame provided the structural support/housing for all the component members of the machine including spur gears, bevel gears, motor, juicer, peeled fruit outlet and peel outlet. The frame was fabricated using mild steel with dimensions 610 × 457 × 762 mm.
- Operation of the machine linkages: By the arrangements of the machine component linkages, the motor was fitted such a way that it provides rotation to the shaft below fruit holders via a set of spur gears. The fruit holder shaft was connected to the threaded shaft (fitted with peeling blade) with the assembly of bevel and spur gears for its linear forth-back movement. The fruit presser and juicer were also operated using the motor. The fabricated components were then assembled to achieve an integrated machine.

Design considerations

The design assumptions which were considered are (i) fruit holder must hold the fruit firmly during peeling and the space between them must be adjustable according to fruit diameter/grade (ii) shape (width and thickness) of the peeling blade is most important, as it should remove the peel efficiently with minimum friction and fruit damage (iii) after peeling, the fruits must be pressed automatically into the juicer (iv) the speed of fruit rotation must be sufficient enough for peeling and the fruit must not drop out during peeling. Based on the fruit rotation, the range of speed was kept as 220, 260, 280, 300, 360 rpm. Speed



(a) Front view

(b) Side view

(A) Different projections of the developed machine (All dimensions are in mm)

(B) Three dimensional and pictorial view of the developed machine

Fig. 2 **A** Different projections of the developed machine (All dimensions are in mm). **B** Three dimensional and pictorial view of the developed machine

lower than 220 rpm and higher than 360 rpm was not effective for peeling operation (v) there should be forth and back movement of the threaded shaft on which the peeling blade was mounted so as to enhance the capacity of the machine (vi) frame must possess sufficient strength for the whole system during idle and peeling operations. The projections with dimensions and three-dimensional along with pictorial view of the machine is illustrated in Fig. 2a, b, respectively.

Raw material

Freshly harvested kinnow and sweet orange fruits were brought from the local market of Abohar (Punjab), India. The fruits were initially cleaned by washing them with the tap water before subjecting to peeling operation. The performance was evaluated by manually feeding of single kinnow or sweet orange fruit at an instant.

Physical properties

Physical properties including the fruit dimensions, thickness of peel were measured by a vernier caliper (M/s Mitutoyo, Japan, ± 0.01 mm) (Mahawar et al. 2019). The weight of whole fruit, peeled fruit, flavedo, albedo, pomace and juice content were determined by means of a digital electronic balance (M/s Shimadzu Corporation, Japan, ± 0.001 g). The firmness of kinnow and sweet orange fruits was measured using Texture Analyser (M/s Stable Micro Systems Ltd). The volume of fruits was determined by liquid displacement method. The moisture content of the peel was examined using AOAC (2000) (Method 925.10). Total soluble solids (TSS) and pH of juice was measured as °Brix using a hand refractometer (M/s Erma, Tokyo, Japan) and pH meter (M/s Eutech, range: 1–14), respectively.

Shearing stress

The average shearing stress corresponds for analyzing the stress that is required to be overcome by the peeling blade and was determined by the equation given below (Khurmi and Gupta 2005).

$$\delta = \frac{F}{A}$$

where, ‘δ’ is shear stress; ‘F’ is the force to initiate a cut on fruit skin and ‘A’ is the area of peeling blade.

Performance evaluation

The machine was operated using a motor with 0.5 hp (power) and speed (1440 rpm), Further, the variation in speed of fruit rotation was achieved by connecting the right combinations of driven pulleys (254–355 mm diameter) and drive pulleys (63–76 mm diameter) as desired. For performance evaluation, the fruit rotation speed was varied at 220, 260, 280, 300, 360 rpm and peeling time (s), peeling efficiency (%), peel remained on fruit (%) and juice loss (%) were taken as dependent parameters.

$$\text{Peeling efficiency} = \frac{\text{Amount of peel on fruit} - \text{fraction of peel on peeled fruit}}{\text{Amount of peel on fruit}} \times 100$$

Peel remained on fruit refers to the mass fraction of the peel remaining on the fruit after peeling and was calculated using the given formula:

$$\text{Peel remained on fruit} = \frac{(\text{weight of raw fruit}) - (\text{weight of peeled fruit})}{\text{weight of raw fruit}} \times 100$$

Juice loss occurred as a result of friction between fruit and cutting blade while peeling. The cutting blade movement was simulated as per the fruit shape with a provision of spring. However, due to the uneven fruit shape, some amount of pulp comes in contact with the blade surface which evidently becomes the reason for juice loss which was calculated by the given formula:

$$\text{Juice loss} = (\text{weight of raw fruit}) - (\text{weight of peeled fruit} + \text{weight of peel}) * 100$$

The cost of the developed machine was estimated by considering the material and fabrication cost of the machine components. The data of physical properties are presented as the mean of 15 replications ± standard deviation. Univariate analysis in general linear model was done for analysis of variance at 5% level of significance.

Results and discussion

Physical properties

The physical properties of both kinnow and sweet orange were evaluated by following the standard procedures and the data is shown in Table 1. The major, minor and intermediate intercept values were 60.00 ± 3.60 mm, 74.00 ± 4.60 mm, 73.01 ± 4.13 mm for kinnow and 72.17 ± 4.49 mm, 77.36 ± 3.00 mm and 77.14 ± 2.82 mm for sweet orange, respectively. The average fruit weight was recorded as 177.62 ± 21.10 g (kinnow) and 224.67 ± 21.44 g (sweet orange), respectively. The albedo weight portion was recorded higher (4.34 ± 0.85 g) for sweet orange as compared to kinnow (2.54 ± 0.36 g). Topuz et al. (2005) documented the physical properties of four orange varieties and reported the length as 69.21 ± 1.81 mm (*cv.* Alanya), 69.44 ± 0.79 (*cv.* Finike), 82.60 ± 0.88 (*cv.* W. Navel) and 81.74 ± 1.19 (*cv.* Shamouti), respectively. Veeravenkatesh and Vishnuvardhan (2014) evaluated some physical properties of sweet orange as a function of grade and reported major intercept (53.71–75.97 mm), minor intercept (58.41–84.32 mm) and intermediate intercept (58.02–84.00 mm), respectively. The authors also reported the weight and volume of fruits as 96.80–248.77 g and 88.73–285.55 cc, respectively. Sandhya et al. (2016) estimated the geometric properties of different grades of kinnow and observed arithmetic and

Table 1 Physical properties of kinnow and sweet orange *Source* Mahawar et al. (2020) for kinnow

S. no	Parameters	Kinnow	Sweet orange	F value
1	Fruit weight (g)	177.62 ± 21.10	224.67 ± 21.44	26.58^{S}
2	Fruit volume (cc)	218.40 ± 33.70	261.50 ± 25.02	16.53^{S}
3	Major intercept (mm)	60.00 ± 3.60	72.17 ± 4.49	32.60^{S}
4	Minor intercept (mm)	74.00 ± 4.60	77.36 ± 3.00	2.41^{S}
5	Intermediate intercept (mm)	73.01 ± 4.13	77.14 ± 2.82	9.16^{S}
6	Circumference (mm)	242.12 ± 16.90	246.80 ± 9.28	0.748 ^{NS}
7	Bulk density (g/cc)	0.82 ± 0.09	0.86 ± 0.06	2.33^{NS}
8	No. of seeds	19.40 ± 9.28	15.60 ± 4.65	3.78^{NS}
9	Weight of flavedo (g)	51.30 ± 21.45	57.44 ± 11.21	2.12^{NS}
10	Weight of albedo (g)	2.54 ± 0.36	4.34 ± 0.85	1.74^{S}
11	Peel thickness (mm)	4.01 ± 0.72	4.19 ± 0.83	0.36^{NS}
12	Peel (%)	28 ± 0.04	29 ± 0.11	1.60^{NS}
13	Juice (%)	38 ± 0.16	40 ± 0.06	0.64^{NS}
14	Pomace (%)	25 ± 0.11	28 ± 0.15	0.50^{NS}
15	Peel moisture content (% w.b.)	73.36 ± 3.12	70.19 ± 3.69	4.26^{NS}
16	Juice TSS (°B)	11.30 ± 4.80	7.88 ± 0.49	52.44^{S}
17	Juice pH	4.69 ± 1.92	5.03 ± 0.24	8.01^{S}

Values are mean ± standard deviation of 15 replications

geometric mean diameter in the range 58.80–80.90 mm and 58.60–79.81 mm, respectively.

Firmness

The firmness was observed to be 80.41 N (kinnow) and 92.56 N (sweet orange), respectively. The calculated area of peeling blade was 9 mm^2 and therefore the average shearing stress was 8.93 N/mm^2 (kinnow) and 10.28 N/mm^2 (sweet orange), respectively. Singh and Reddy (2006) recorded the firmness value of 44.9 N for orange (*cv.* Nagpur Mandarin) after storage of 1 day at ambient (28 °C and 58% RH) and refrigerated (7 °C and 78% RH) conditions.

Performance evaluation

The graded fruits were subjected to peeling using developed machine and different performance indicators with respect to kinnow and sweet orange were recorded (Table 2). The pictorial view of peeled kinnow and sweet orange fruits is shown in Fig. 3. For kinnow, it was observed that at higher rotational speed, the peeling time decreased (11.97–6.45 s) and juice loss increased (5.70–14.98%). Mazlina et al. (2010) has reported the peeling time 4.50 ± 0.07 s (orange) and 3.90 ± 0.13 s (lemon) using the developed apparatus which was significantly lower than the manual peeling time. The same authors reported the dependency of peeling time on the fruit size and skin texture.

Owing to the irregular roundness of the fruit, variation in the contact area of the peeling blade occurred which further resulted in increased oozing of juice. The weight of peel remained on fruit (2.00–3.09%) was linearly associated with rotational speed. It was evident that the adequate time and force required for uniform removal of peel was lacking at a higher speed. The peeling efficiency (95.63–90.24%) was inversely proportional to the rotational speed. The average peel thickness obtained during the peeling operation was 1.86 to 3.50 mm. For kinnow, the peeling and juicing operation requires 40–60 s/kg of fruit i.e. 60–90 kg/h capacity. Considering all the parameters, the optimum fruit rotation speed for kinnow was 220 rpm.

In case of sweet orange also, the peeling time (13.67–8.25 s) decreased and juice loss increased (6.60–15.74%) with an increase in fruit rotational speed. The weight of peel remained on fruit (2.16–2.97%) was linearly associated with rotational speed. Since the flavedo percentage is comparatively higher in sweet orange than kinnow, the peeling time was reported to be higher. Similar to the case in kinnow, the adequate time and force required for uniform removal of peel was lacking at higher speed. The peeling efficiency (96.43–95.82%) was inversely proportional to the rotational speed (Table 2). Yadav et al. (2013) evaluated the performance of hand-operated rind peeler for pomelo fruit and observed the peeling efficiency

Table 2 Performance evaluation parameters as a function of fruit rotational speed

	Kinnow				Sweet orange			
Fruit rotational speed (rpm)	Peeling time (s)	Peel remained on fruit (%)	Juice loss (%)	Peeling efficiency (%)	Peeling time (s)	Peel remained on fruit (%)	Juice loss (%)	Peeling efficiency (%)
220	11.97	2.00	5.70	95.63	13.67	2.16	6.60	96.43
260	10.86	2.71	7.66	94.50	11.18	2.58	8.78	99.01
280	8.29	2.85	8.48	93.88	9.37	2.72	9.86	97.43
300	7.60	2.92	10.74	90.69	8.90	2.80	11.92	99.02
360	6.45	3.09	14.98	90.24	8.25	2.97	15.74	95.82

Fig. 3 Pictorial view of the peeled kinnow and sweet orange fruits

in the range of 80.72% (small fruits), 82.50% (medium fruits) and 84.09% (large fruits), respectively. The author also reported the pulp loss in the range of 1.29% (large fruits), 2.02% (medium fruits) and 2.20% (small fruits). The decrease in peeling efficiency and increase in the pulp loss was reported with the days of harvest. Ademoh and Akaba (2015) developed a domestic manual orange peeling device and reported 97% peeling efficiency along with 140 oranges/h peeling capacity which was substantially higher than that of manual peeling (32 oranges/h).

The average peel thickness obtained during the peeling operation was 2.50 to 2.69 mm. For sweet orange, the peeling and juicing operation requires 60–70 s/kg of fruit i.e. 50–60 kg/h capacity. Considering all the parameters, the optimum fruit rotation speed for sweet orange was 260 rpm. The variation of peeling time, peel remained on fruit, juice percentage and peeling efficiency at rotational speed was depicted graphically for kinnow (Fig. 4a) and sweet orange (Fig. 4b), respectively. The juice loss was higher in sweet orange (6.60–15.74%) as compared to kinnow (5.70–14.98%) may be because of the presence of a thick flavedo layer.

The freshness of the fruit affected peeling efficiency significantly. As the days after harvest increases, moisture loss from the fruit surface increases and the peel gets dried. This may definitely affect the contact area of the peel with the blade during peeling as also reported by Yadav (2006) for pomelo fruit. Singh and Reddy (2006) reported the decrease in peel cutting force of orange (*cv*. Nagpur Mandarin) with days of storage i.e. ambient (79.5–63.2 N) and refreigerated (79.5–66.3 N), respectively.

The overall extensive trials suggested that the corresponding fraction of peeled fruit weight (55–57%), peel obtained after peeling (35–37%) and juice loss (6–10%), for both kinnow and sweet orange. The average thickness of the unpeeled portion was 7.25 ± 1.60 mm (kinnow), 10.03 ± 3.04 mm (sweet orange), respectively. The respective quantity of material used for fabrication was recorded and the approximate cost was calculated to be around Rs. 34,000. However, the machine can be sold by the manufacturer at an higher price after considering the incurred expenses as well as profit margin.

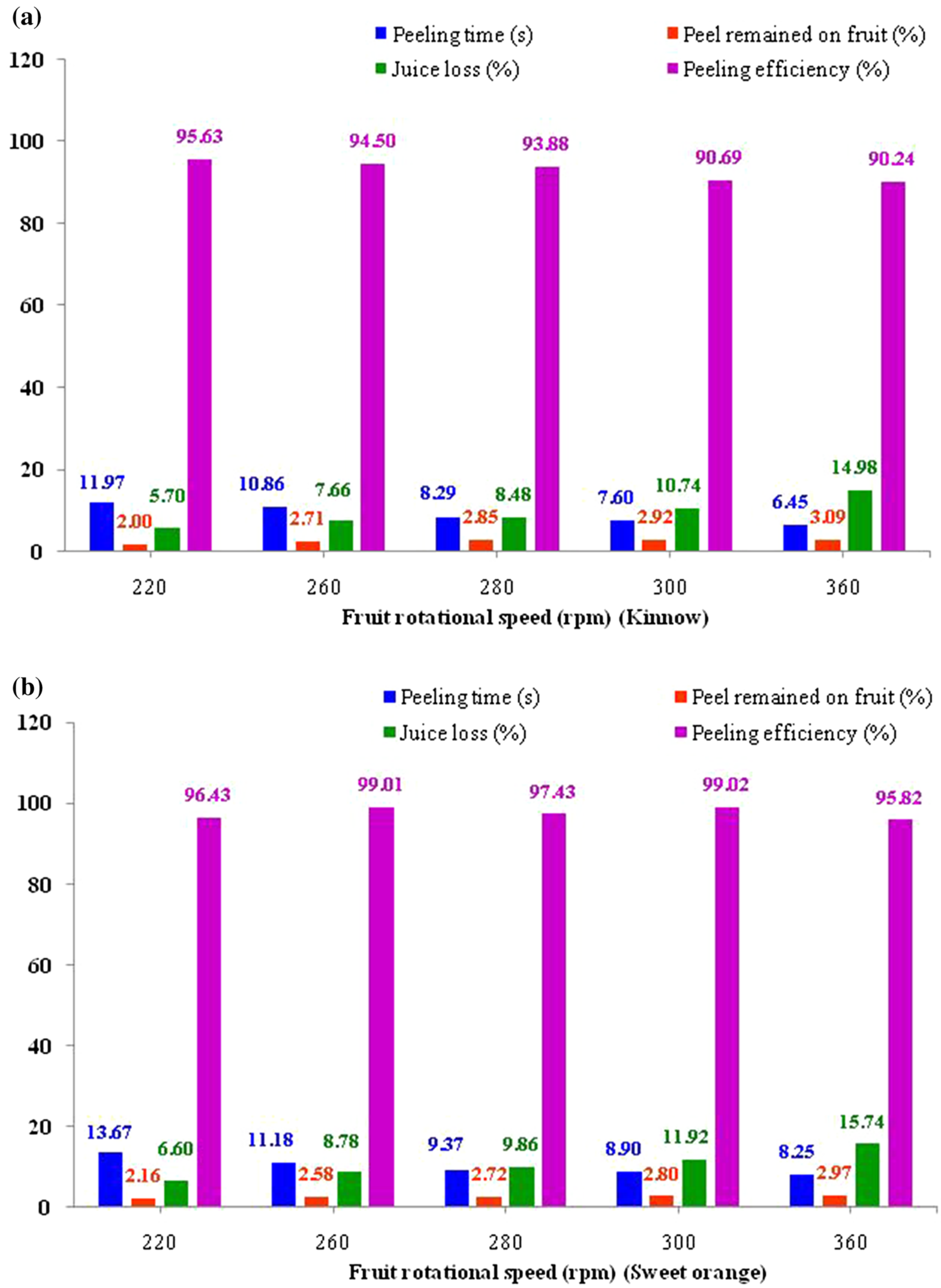


Fig. 4 Variation of peeling time, peel remained on fruit, juice loss and peeling efficiency at different rotational speed for **a** kinnow and **b** sweet orange

Conclusion

The developed composite peeler cum juice extractor resulted in the highest efficiency for peeling and juice extraction of both the fruits. The machine gave the best performance at fruit rotational speed of 220 rpm (kinnow) and 260 rpm (sweet orange), respectively with the respective capacity of 60–90 kg/h (kinnow) and 50–60 kg/h (sweet orange).This machine can be useful in time and cost saving for juice processing industries. The future research may be carried out to mechanize the feeding of fruit and to enhance the handling capacity of the machine for its better performance and wider applicability. Necessary modifications and improvements in the structural design shall certainly enhance the commercialization potential of this machine.

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