JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2022, VOL. 5(1), 35-52

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Investigation of different manual harvesting tools performance for harvesting output, mechanical injuries, storability and post-harvest physio-chemical attributes of mandarin fruit in Nepal

Shailendra Khatri[1*], Shreemat Shrestha[1], and Keshab Prasad Pokharel[1]

1, *National Agricultural Engineering Research Centre (NAERC), Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Bagmati, Nepal*

ARTICLE INFO

Original Article

Article history:
Received 11 July 2021
Revised 26 September 2021
Accepted 16 November 2021
Available online 1 February 2022

Keywords:
Harvesting tools
Mandarin
Manual picking
Physio-chemical attributes
Storability

DOI: 10.22077/jhpr.2021.4426.1220
P-ISSN: 2588-4883
E-ISSN: 2588-6169

***Corresponding author:**
National Agricultural Engineering Research Centre (NAERC), Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Bagmati, Nepal.

Email: shailenkhatri@yahoo.com

ABSTRACT

Purpose: With an increasing interest in closing the mechanized harvesting loop in citrus farming, harvesting tools could be reliable options for citrus harvesting. However, from performance investigation and post-harvest storability perspectives, not much has been reported in the area of manual harvesting tools for mandarin picking in Nepal. This study assessed the performance of different available models of manual fruit harvester based on harvesting output, operational features, post-harvest physio-chemical attributes and shelf life assessment of the mandarin fruits stored under ordinary room condition for 26 days. **Research method:** Six harvesting treatments were investigated as follows: a) Farmer practice-hand picking (FP_{ground}), b) Ladder climbing (FP_{ladder}), c) Secateur + ladder climb (SE_{ladder}), d) Cut and hold type picking shears (CH), e) Long reach finger type fruit picker (LRF), f) Fruit picker with basket and cushion (PHB). **Findings:** The harvesting capacity of FP_{ground}, FP_{ladder}, SE_{ladder}, LRF, CH and PHB treatments were 60.6±2.26, 33.43±3.13, 24.25±2.25, 43.85±6.34, 61.30±9.28 and 49.13±2.61 kg/hr, respectively. The harvesting output of CH, LRF and PHB type harvester was 39.15% (779 nos/hr), 15.78% (648 nos/hr) and 30.21% (729 nos/hr) higher than FP_{ladder} practice (560 nos/hr) and that of SE_{ladder} method was 15.62% (442 nos/hr) lower than FP_{ladder}. Based on storability characteristics, SE and CH found effective in prolonging the average shelf life and maintaining the quality of mandarin compared to FP and PHB. The short pedicle on the fruit in SE, CH and LRF treatment help to control and retard the sap oozing, weight loss and lateral infection that retain the fruit firmness, and minimize the fruit damage and decay loss. **Research limitations:** Further investigation on storability behavior in controlled storage condition is suggested. **Originality/Value:** Hand held secateur and cut and hold type harvester are suitable tools for picking fruit and abating post-harvest loss of mandarin fruit along the horticultural value chain.

INTRODUCTION

Mandarin (*Citrus reticulata* Blanco; particularly named as *Suntala* in Nepali), is one of the important and highly commercialized citrus fruit for the hill farmers of Nepal. Mandarin orange is playing vital role in augmented food availability, improved nutrition, employment opportunities and economy of nation. In Nepal, the total fruit productive area, production and productivity in the FY 2018/19 were 120,023 ha, 1,177,640 MT and 9.81 MT/ha, respectively (Khatri et al., 2021; MoALD, 2020). Citrus fruits have a total productive area of 28,406 ha with 9.57 MT/ha productivity and 271,908 MT production out of which mandarin contributing to productive area of 17,220 ha (60.62% acreage of the total citrus area) with 10.30 MT/ha productivity and 177,381 MT production during 2018/19 (MoALD, 2020). Currently, mid hills region having latitude: 26˚45'-29˚40'N and longitude 80º15'-88º12'E (Bhattarai et al., 2013; Timilsina & Tripathi, 2019) is becoming a mandarin production hub due to unique promising topography and agro-climatic condition.

Harvest and post-harvest loss of perishable commodities including fruits is one of the major horticultural value chain problems which negatively impacts food security, nutrition and economic stability of farmers, exporters, traders and consumers. Nearly 20-35% of losses (around 7-15% in harvesting) occurred along the value chain due to inappropriate harvesting, packaging, handling, storage, transportation and marketing practices (Bhattarai et al., 2013; Rokaya et al., 2016). In other words, the inception of postharvest decay in citrus fruit principally rely on farming practices such as the method and time of harvest, and pre and postharvest factors (Kassim et al., 2020). The post-harvest losses can be lessened by improving shelf life by proper pre-harvest and post-harvest steps such as use of proper harvesting tools and post-harvest treatments to minimize rate of transpiration, respiration, microbial infection & protect peels from disorganization (Joshi et al., 2020; Khatri et al., 2021).

In the context of citrus farming, harvesting is considered as one of the crucial and critical job in fruit production due to possible damage to the fruits and musculoskeletal stress on the worker (Li et al., 2011; Rokaya et al., 2020; Sabale et al., 2017). Generally, mandarins harvesting is done by hand pulling using ladder and collecting bag. Moreover, conventional methods such as tree climbing, tree shaking and hitting by sticks are also commonly applied by farmers. Mandarin is a thin skinned fruit having brittle rind and liable to quick mechanical injury. Pulling of the fruits can led to fruit injury by rupturing the peel of loose skin of the mandarin at the time of harvesting. Indeed, several studies have demonstrated that those conventional methods deteriorate the market quality, nutritive values and shelf-life of the fruit and earning of farmers (Khatri et al., 2021; Ogoe et al., 2020; Rokaya et al., 2020). There are number of studies pointing to the hazards and physical damage that occurs during manual harvest of fruits indicating the importance of harvesting tools. In a recent study, Khatri et al. (2021) evaluated the effect of harvesting methods on sweet orange storage behavior under room storage condition and highlighted that shelf-life of fruit picked from branch shaking is 7 days only compared to 13-21 days in harvester picked fruit. Likewise, a study by Rokaya et al. (2020) discovered that fruit harvested by clippers were superior in quality and shelf-life with minimum weight loss and decay loss during storage under Cellar condition as compared to hitting by stick. In a similar study, Vagadia et al. (2020) compared effect of harvesting method on storability of lime at storage condition. From their results, spoilage started from 2th day in pulling method and after 11 days it was 36.67%. While no spoilage was mentioned up to 8th day in harvester picking and after 11 days it was only 13.33%.

Around the world, mechanical harvesters like limb shaker, air blasting, canopy shaker and trunk shaker, particularly for citrus fruits have been investigated and practiced to improve profitability and efficiency of citrus farming. However, there are major issues such as the flexibility, the fruit selection ability, the damage to the fruit and trees, the layout of the grove design for mechanical harvester and topographical constraints (Kassim et al., 2020; Li et al., 2011) which still limits the investment capability and application of the mechanical harvesters in developing countries like Nepal. Based on the above discussions, appropriate manual harvest aid tools can be a valuable alternative to pick the mandarin from the tree for improving labor conditions in the field, increasing harvest yield and minimizing the damage. Thus, effective and farmer friendly small scale harvesting tools addressing issues of conventional methods is prime need of Nepalese mandarin farmers and entrepreneurs. Additionally, farmers usually put harvested mandarins in ordinary room condition for immediate fresh marketing. So, assessment on effect of different harvesting tools on post-harvest storability attributes of mandarin is a mandatory requirement to have clear understanding on harvester suitability. In other side, the lacking of proper performance investigation and dissemination on available promising fruit detachment alternatives such as manual fruit harvesting tools applicable for mandarin fruit would possibly limits their potential use in harvesting.

To fill the gaps, this study investigates different available models of fruit harvester (six harvesting treatments) in terms of harvesting output and operational features, farmer's feedback and limitation in mandarin harvesting. This study also appraises post-harvest physio-chemical storability attributes (physiological loss of weight, decay incidence, fruit firmness, total soluble solids and titratable acidity) and shelf life of the harvested mandarin under ordinary room storage condition. Finally, the study will ascertain and endorse appropriate manual harvesting tools for mandarin based on easiness of harvester handling, harvesting output, damage to mandarin and physiochemical attributes behaviour in stored condition.

MATERIALS AND METHODS

Experimental site

Field experimental work on harvesting using different treatments was performed in the farmer's mandarin field of Sharada Batase, Dhulikhel Municipality-10, Kavrepalanchok district during the month of January, 2021. Harvested mandarin shelf-life storage trials and rest of work was performed in National Agricultural Engineering Research Centre (NAERC), NARC, Khumaltar, Lalitpur. Geographically, Sharada Batase, Kavre is located in the central region, Bagmati Province of Nepal having latitude, longitude and average mean sea level of 27°81'N, 85°74' E and 1400-1550 masl., respectively (Timilsina & Tripathi, 2019). It is 30 km far from Kathmandu, the capital city of Nepal. Kavre, the mid-hill district of Nepal is one of the important hubs for mandarin production of the country. During 2018/19, Kavre occupied a mandarin productive area of 935 ha with 12.47 MT/ha productivity and 11,660 MT productions (MoALD, 2020).

Technical details and general characteristics of manual harvesters used in mandarin harvesting

The following experimental treatments were studied a) Farmer practice-hand picking (FP_{ground}), b) Farmer practice-ladder climbing (FP_{ladder}), c) Secateur + ladder climb (SE_{ladder}), d) Pole mounted cut and hold type picking shears (CH), e) Telescopic long reach finger type fruit picker (LRF) and f) Fruit picker harvester with basket and cushion (PHB). A further detailed description of the general characteristics of applied harvesting treatments is reported in Table 1. Treatment no. (c) to (f) are manual fruit harvesting tools investigated in our study.

Table 1. Technical details and general characteristics of experimental treatments.

Treatment	Harvesting method	Features and operation
a*	FP_{ground}	Farmers hand picking method for fruit reachable from the ground, pulling.
b	FP_{ladder}	Farmers hand picking method, fruit unreachable from the ground, pulling by climbing ladder. 'A' frame type aluminum ladder with 0.38 m wide and 6 m high.
c	SE_{ladder}	Use of handheld Secateur plus ladder for the higher parts of the tree canopy for fruit unreachable from the ground.
d	CH	It can cut and hold the pedicle of fruits until the handle is released. It will be easy to harvest fruit unreachable from ground without touching by hand or using ladder. The ergonomic spring-loaded handle will spring back to allow another cut and help reduce hand and wrist fatigue. Due to the sharp pruner blade, need to be careful when cleaning and need to put it in a locked position at the time of unused condition.
e	LRF	Twist, and turn the fruit and then hold the fruit inside the fingers of the picker. Allow easily pick and reach fruit which is unreachable from ground. Three soft rubber padded claws keep each piece of fruit safe from damage. Hold fruit from 5.5 to 13 cm in diameter. Adjustable pole ranging from 1m to 2m.
f	PHB	The fruit stem of the fruit which need to be picked is line up in between two of the long prongs and then gently pull down so that fruit will fall in picker basket. The fruit picker basket can hold multiple pieces of fruit, so that there's no need to retract the basket after each pick. The basket is 15 cm wide and 33 cm high.

* a) Farmer practice-hand picking (FP_{ground}), b) Farmer practice-ladder climbing (FP_{ladder}), c) Secateur + ladder climb (SE_{ladder}), d) Pole mounted cut and hold type picking shears (CH), e) Telescopic long reach finger type fruit picker (LRF), f) Fruit picker harvester with basket and cushion (PHB).

Experimental design and setup, methodology, data collection and analysis

Figure 1 shows a schematic view of the experimental set-up designed for mandarin harvesting and storage trials of this study. To conduct the harvesting trials, five mandarin trees (code A-E) were randomly selected and labelled with the code number for identification. The tree profile of each selected mandarin tree was recorded. Different models of harvester were provided to farmers one week before experimental and demonstration work to make them familiar with harvesting tools. All experiment was conducted systematically. Figure 2 shows the photographic view of mandarin harvesting experiments conducted in the farmer's field. An electronic weighing balance was used to record the weight (kg) of harvested samples. Similarly, harvesting time (min) was noted by using stop watch. Harvested samples of different treatments are collected carefully in each labelled crate for storage trials. Farmer's feedback on different types of harvester was noted down along with model prioritization. The harvesters were evaluated based on harvesting capacity, injury to mandarin, feedback from farmers and post-harvest physio-chemical attributes assessment of the fruit by performing storage trials under ordinary room storage condition.

Storage trial was accompanied in NAERC, Khumaltar, Lalitpur at room temperature in a well-ventilated room from January 28, 2021 to February 22, 2021 (26 days). Vernier caliper (accuracy of 0.01 mm) is used to measure the linear dimensions of mandarin (length, major diameter and minor diameter in cm) along three perpendicular axes. Five fruits for each replication of each treatment were labelled and used for determining physiological loss in weight (PLW), rot incidence, shrinkage and shelf-life during ordinary storage condition. The weight of samples was taken and recorded in grams by using a digital balance from the first day (day 1) at the interval of 1 day. Observations on PLW, shrinkage behavior and damage due to rotting were noted visually by assessing each fruit. The numbers of the rotted samples were noted to calculate the percentage of rotted mandarin. PLW (%) was obtained from the weight loss during storage and initial values as per following equation 1 (Khatri et al., 2021).

$$PLW\ (\%) = \frac{WI - WF}{WI} \times 100 \qquad (1)$$

Where, PLW: Physiological weight loss (%), WI: Initial weight at the start of storage (day first) in g, WF: Weight measured at the certain day interval of storage duration in g.

Likewise, ten samples for each treatment were allocated for quality assessment of the harvested fruit. Physio-chemical quality parameters such as shrinkage, fruit firmness, total soluble solids (TSS), titratable acidity (TA) and TSS/TA ratio were analyzed on day 1, day 9, day 17 and day 26 of storage. Fruit firmness (kg/cm^2) was measured by a handheld digital fruit hardness tester (Lutron FR-5120) using 8 mm penetrometer tip as per method described by Khatri et al. (2021). Briefly, the fruit is held against a hard surface and force is gently applied at a slow and uniform speed to make a puncture in the fruit with the selected tip. Each firmness value was an average of the three puncture point values in each fruit. Handheld refractometer (ATAGO N1 Brix 0-32%, Japan) was used to determine TSS values (°Brix). TA was determined by titrating aqueous solution (filtrate) of mandarin juice with 0.1N standard NaOH using phenolphthalein indicator and expressed as a percentage of citric acid (AOAC, 2005). TSS/TA ratio was obtained by dividing the TSS content by TA of each treatment. Damage number due to rot (cumulative decay loss) and the color change was determined by visual observations. Shelf-life was determined based on observation of color, brown patches on outer cover and rot incidence of fruit. Dry bulb temperature and wet bulb temperature were taken daily at 6:00 AM, 10:00 AM, 1.30 PM, 5:00 PM and 9:00 PM and was averaged for the daily temperature. Relative humidity was calculated based on recorded temperatures values. Experiments on each treatment were performed in triplicate (18 trials in total) and all analyses and measurements are displayed as average values of triplicate readings. Descriptive analysis was done to summarize data into means and standard deviations values by the statistical tool using MS Excel. Analysis of Variance (One-Way ANOVA) was used to investigate potential differences in harvesting output and mass of mandarin between the treatments. All inferential analysis was done within the 95% level of confidence ($p \leq 0.05$, statistically significant) using Sigma Plot software version 12.5 (SYSTAT Software Inc., USA).

Fig. 1. Schematic diagram of experimental set-up for mandarin harvesting and storage trials under ordinary storage condition

Fig. 2. Photographic view of mandarin harvesting experiment in farmer's field at Kavrepalanchok district, Nepal. 1. Farmer practice-hand picking (FP_{ground}), 2. Farmer practice-ladder climbing (FP_{ladder}), 3. Secateur + ladder climb (SE_{ladder}), 4. Pole mounted cut and hold type picking shears (CH), 5. Telescopic long reach finger type fruit picker (LRF), and 6. Fruit picker harvester with basket and cushion (PHB).

Table 2. Temperature and relative humidity of experimental period in storage site

	Average daily temp (°C)		Average relative humidity (%)	
Storage duration	Outside	Inside room	Outside	Inside room
Day 1-Day7	12.54±0.65	11.23±0.29	58.96±2.83	57.26±1.94
Day 8-Day 14	13.6±1.43	11.85±0.89	60.94±3.69	62.11±2.37
Day15-Day21	16.2±0.38	14.37±0.36	64.87±2.08	69.25±4.34
Day22-Day26	19.6±0.98	17.02±0.8	64.65±5.72	67.86±4.65

N=35 for each interval

Table 3. Average temperature and relative humidity in a day at certain hour interval

Parameters/time		6:00 AM	10:00 AM	1.30 PM	5:00 PM	9:00 PM
Avg. dry temp (°C)	outside	4.8±3.9	20.8±3.0	23.8±3.2	16.1±3.1	10.3±3.5
	storage room	11.8±2.3	12.5±2.6	14.7±2.3	14.7±2.3	13.1±2.4
Avg. relative humidity (%)	outside	86.5±4.2	51.5±7.6	41.3±7.0	52.0±12.5	79.6±7.9
	storage room	71.4±5.3	68.0±6.4	56.1±9.7	57.0±8.3	66.6±6.1

RESULTS AND DISCUSSION

Temperature and relative humidity of the storage trial site during experiment period weather was winter during the experimental period in NAERC, Lalitpur. For mandarin storage, ideal room temperatures and RH should be between 0-9 °C and 85-95% which can have a storage life up to 8 weeks (Liu, 2010; Paltrinieri, 2014). Temperatures and relative humidity (RH) of this trial were higher than the requirement of mandarin storage. The average daily outside dry temperature was 15.17 °C (average of 26 days, average reading, n=26) which varies from 0 to 31°C within a day while that of storage room was 13.36 °C which ranged from 9 °C to 19 °C during the experimental storage period (Table 2). Similarly, the average daily RH of storage room was 63.84% which ranged from 39.9% to 80.4% while that of the outside was 62.18% which ranged from 26.9% to 93.4%. Furthermore, the average temperature and RH variation within a day was obtained from the values of 6:00 AM, 10:00 AM, 1.30 PM, 5:00 PM and 9:00 PM for up to 26 days and shown in Table 3. From Table 3, it can be seen that room temperature increased from 11.8 °C at 6 AM to 14.7 °C at 1.30 PM and then decreased at 9 PM (13.1°C). Similarly, RH is high at 6:00 AM (71.4%) and lowest value (56.1%) at 1.30 PM.

Table 4. General profile of experimental tree

S.N	Parameters/Tree code no.	A	B	C	D	E
1	Height of tree (m)	7	6.5	5	5.5	6.4
2	Diameter of tree canopy (m)	5.2	5	2.9	3.5	4.5
3	Location of fruit from the ground (m)					
	a) Maximum	6.6	6.4	4.8	5.5	6.2
	b) Minimum	1.8	1.5	1.5	2	1.8
4	Colour and condition of fruit	Matured yellow color				
5	No of fruits around the periphery of tree height reachable from ground (nos.)	320	230	225	250	310
6	No of fruits around the periphery of tree height unreachable from ground (nos.)	600 (65.2%)	750 (76.5%)	470 (67.6%)	600 (70.5%)	500 (61.7%)
7	Spacing between tree (m)	3-6 (variable spacing)				
8	Tree age (year)	15-17				

Table 5. Physical characteristics of harvested mandarin

Harvesting treatments	Descriptive statistics	Length (cm)	Major Dia (cm)	Minor Dia. (cm)	Weight (g)
FP_{ground}	average	4.49±0.39	5.22±0.24	5.01±0.27	61.0±8.09
	max-min	5.45-4.0	5.6-4.85	5.40-4.45	72.0-46.0
FP_{ladder}	average	4.37±0.35	5.17±0.34	5.06±0.34	60.26±9.23
	max-min	4.78-3.95	5.75-4.65	5.55-4.5	75.0-46.0
SE_{ladder}	average	4.35±0.43	4.78±0.29	4.63±0.35	50.15±10.60
	max-min	5.0-3.6	5.30-4.30	5.30-4.10	71.0-34.0
CH	average	4.96±0.61	5.70±0.51	5.51±0.43	72.53±15.62
	max-min	6.3-4.0	6.41-4.75	6.2-4.65	96.0-42.0
PHB	average	4.55±0.39	5.20±0.29	5.06±0.26	63.33±9.42
	max-min	5.15-3.9	5.65-4.60	5.45-4.55	78.0-46.0
LRF	average	4.73±0.29	5.40±0.24	5.27±0.27	68.4±8.72
	max-min	5.40-4.10	5.8-4.95	5.7-4.65	78.0-51.0

N=15 for each treatment. All values are expressed as means ± standard deviation.

Table 6. Mandarin harvesting output of different harvesting treatments

Parameter	H.T. / Unit	FP_{ground}	FP_{ladder}	SE_{ladder}	LRF	CH	PHB
Harvesting output	kg/hr	60.6^{a}±2.26	33.43^{cd}±3.13	24.25^{d}±2.25	43.85^{bc}±6.34	61.30^{a}±9.28	49.13^{ab}±2.61
	Number/ hour	870^{a}±51.96	560.47^{d*}±52.22	442.11^{e}±13.67	648.95^{c}±46.40	779.9^{ab}±34.9	729.80^{bc}±8.48
Difference in harvesting output (%)				-15.62	15.78	39.15	30.21

*Represents harvesting output of farmer practice (FP_{ladder}) from which the percentage difference for the other treatment was calculated. All values are expressed as means ± standard deviation (n= 3). Means within a row followed by a common letter are not significantly different by the Holm-Sidak method at the 5% level of significance.

Table 7. One-way ANOVA depicting differences in harvesting output at different harvesting treatments

Source of Variation	DF	SS	MS	F	P
Between Groups	5	360001.9	72000.38	47.706	<0.001
Residual	12	18110.89	1509.241		
Total	17	378112.8			

Comparison	Diff of Means	t	P	P<0.050
Comparisons for factor:	harvesting treatment			
FP_{ground} vs. FP_{ladder}	309.524	9.758	<0.001	Yes
CH vs. FP_{ladder}	219.394	6.917	<0.001	Yes
PHB vs. FP_{ladder}	169.32	5.338	0.001	Yes
SE_{ladder} vs.FP_{ladder}	118.371	3.732	0.014	Yes
LRF vs. FP_{ladder}	88.475	2.789	0.048	Yes
PHB vs. LRF	80.845	2.549	0.05	No
CH vs. PHB	50.074	1.579	0.14	No
CH vs. LRF	130.919	4.127	0.008	Yes
CH vs. SE_{ladder}	337.765	10.648	<0.001	Yes
PHB vs. SE_{ladder}	287.691	9.07	<0.001	Yes
LRF vs. SE_{ladder}	206.846	6.521	<0.001	Yes

*All Pairwise Multiple Comparison Procedures (Holm-Sidak method), Overall significance level = 0.05

Tree profile and physical characteristics of mandarins harvested by different methods

The general profiles of mandarin trees used for harvesting trials were shown in Table 4. The age of mandarin trees ranged from 15-17 years old and the spacing between the two trees is 3-6 m. The height and canopy diameter of a tree is 5 to 7.5 m and 2.9 to 5.2 m, respectively. The minimum height of location of fruit from the ground is 1.5 m and maximum height of that is 6.6 m. Fruits located around the outer periphery/circumference of tree height unreachable from ground ranged from 61.7 to 76.5%. In the light of farmer view, tree climbing, stick biting, branch shaking or uses of local ladders are the commonly adopted farmer’s conventional harvesting practice till yet.

Regarding physical properties; the mean, standard deviation, maximum-minimum values of linear dimension (major diameter, minor diameter and length) and mass of harvested mandarin are summarized in Table 5. Considering overall treatments, it can be seen that maximum-minimum values of length, major diameter and minor diameter of the harvested mandarin were 6.30-3.60, 6.41-4.30 and 6.20-4.10 cm, respectively. Similarly, maximum-minimum values of mass for harvested mandarin ranged from 78-34 g. The average mass of harvested mandarin was lowest in SE_{ladder} treatment (50.15±10.60 g) and that was highest in CH treatment (72.53±15.62 g). There was statistically significant difference in mass of harvested mandarin of SE_{ladder} and other treatment i.e., CH, PHB and LRF ($p<0.05$), however, we find no significant difference among FP_{ladder} and SE_{ladder} ($p=0.055$).

Harvesting performance of different models of fruit harvester on mandarin picking

Harvesting output of different treatments was evaluated based on kg per hour and the number of fruit per hour and summarized in Table 6. Regarding weight basis, the harvesting output was higher in CH method (61.30±9.28 kg/hr) followed by FP_{ground} (60.6±2.26 kg/hr). The higher value of harvesting output in FP_{ground} treatment can be due to the easy accessibility of fruits to the person staying on the ground. The lowest harvesting capacity was obtained with SE_{ladder} (24.25±2.25 kg/hr). The operation of secateurs in climb position for SE_{ladder} treatment resulted low output. The difference in mass of each harvested mandarin during different harvesting treatments can affect the output based on kg. Thus, comparative evaluation of harvester output based on nos. of fruit per hour, was done to have more clear understanding on harvester performance. From Table 6, it can be seen that SE_{ladder}, CH, LRF and PHB method can harvest 442, 779, 648, and 729 mandarins per hour, respectively. The harvesting output of CH, LRF and PHB type harvester was 39.15%, 15.78% and 30.21% higher than FP_{ladder} practice and that of SE_{ladder} method was 15.62% lower than FP_{ladder}. The ANOVA results (Table 7) revealed that harvesting output from CH, LRF and PHB type harvester was significantly ($p< 0.05$) higher than from FP_{ladder} practice. Additionally, the harvesting output of SE_{ladder} was significantly lower than FP_{ladder}. However, there was no significant difference in harvesting output of PHB when compared to LRF and CH model. CH, LRF and PHB type fruit harvester can be used to harvest mandarins up to a height of 3.5 m, 3.6 m and 3.9-4.9 m, respectively from the ground.

Importantly, there would be variation in harvesting output from one harvesting work to another by the same model. Previous studies on the performance of different models of fruit harvester support our arguments. For instance, a recent study by Khatri et al. (2021) evaluated performance of different models of harvester on sweet orange and reported 29.03% and 15.93% higher harvesting output in cut and hold type, and long reach finger type fruit harvester than tree climbing farmer practice. However, fruit picker harvester with basket and cushion method has 20.96% lower output than farmer practice in that study which is in contrast with the result of present study. From the above discussions, it can be concluded that harvesting capacity depends on the fruit density, fruit accessibility, type and nature of fruits, physical strength and speed, operator's knowledge and skill level on handling and operation of fruit harvester and familiarity with the application of harvester.

Even though, PHB type fruit harvester has higher harvesting output than FP_{ladder} practice in our study, this model seems not appropriate for mandarin harvesting from the marketability, injuries and appearance point of view. The major demerits of PHB method is the damage of mandarin because it harvests the fruit by hooking and pulling principle which caused the peeling of the outer soft skin of mandarin. Pulling the fruit also results the button to be removed and even breaks the skin at the stem end. But, it can be used to pick mandarins for immediate fresh consumption purposes. In case of LRF model, catch-twist-turn-hold principle needs to follow during harvesting soft skin fruit like mandarin. It is strictly not recommended catch-pull-hold principle for this type of harvester as this will ultimately breaks the skin and removes the button. Operator need to be careful at the time of harvesting the fruit that the button remains attached to the fruit. Regarding SE and CH method, mandarin need to be clipped in such a way that the peduncle remains intact with the fruits. Especially in CH method, it is strictly suggested that longer pedicel left on the fruit should be cut off close to the fruit because it can puncture the rind of other fruit, causing injury and fruit spoilage by mold/bacteria during harvest and post-harvest activities.

Conclusively, Secateur (SE) and, cut and hold (CH) harvesters are the suggested models of fruit harvester for mandarin harvesting with reference to field performance and farmers' response. Moreover, long reach finger type fruit picker (LRF) model also seems one of the alternative for farmer to harvest mandarin but the correct harvesting principle need to be strictly followed.

Post-harvest storability characteristics behaviour of harvested mandarins under ordinary room storage condition

The physio-chemical attributes (PLW, rot incidence, color, fruit firmness, TSS and TA) of harvested mandarin during ordinary room storage condition were measured, analyzed and presented in this portion.

Physical quality parameters

Physiological loss in weight (PLW)

Weight loss is an important factor to analyze postharvest deterioration in mandarin fruit because fruits contain 65-95 percent of water. Water loss causes shrinking, desiccation, softening, wilting and influences the texture and visual appearance of the fruit. The results displayed in Table 8 shows that the initial PLW of fruit harvested by harvesters is not only lower than that of FP practice but also delay in the decrease of weight than that of FP. For instance, on day 9, the PLW in CH, SE and LRF harvested fruit were 7.55%, 8.79% and 9.37%, respectively compared to 11.35% in FP_{ladder} practice. However, the obtained PLW in PHB method (11.07%) was almost similar to FP method. Likewise, in 17 days, the loss was the lowest (15.14%) in SE_{ladder} treatment and the highest in FP_{ground} (23.15%). PLW of FP and PHB lies between 21.5-23.5% however that of SE, CH and LRF ranged from 15 to 19% on that day. Finally, in 26 days, CH had the lowest (21.78%) weight loss while it was the highest (28.19% and 29.50%) in PHB and FP method. Fruit injury during harvest increased quick water loss and stimulated rot incidence and ethylene production rates (Elshiekh & Abu-Goukh, 2008; Kitinoja & Kader, 2002; Ogoe et al., 2020) leading to rapid deterioration of fruit in FP (pulling) and PHB (hook and pull). Conversely, minimum and delayed weight loss in SE, CH and LRF method could be attributed to lack of bruises and less evapotranspiration from the fruit surfaces.

Previous studies on the effect of harvesting methods on the storage behavior of fruits corroborate our findings. In a recent study, Khatri et al. (2021) evaluated the effect of harvesting methods on sweet orange storage behaviour under room storage condition and highlighted that weight loss was minimum in fruit picked by secateur (6.56%) compared to tree branch shaking (13.14%). In a similar study, Rokaya et al. (2020) evaluated mandarin storability under cellar condition and reported less water loss in clipped fruits (3.15%) than that of fruit harvested by sticks (15.81%). As well, Waskar et al. (1997) reported that mango harvested by using harvesters have weight loss of 12.3-13% as against 17.20% of manual harvesting after 16 days of storage.

Table 8. Physiological loss in weight (PLW in %) of harvested mandarin during storage trial

Physiological loss in weight (PLW in %)												
Treatments	Days of storage											
	3	5	7	9	11	13	15	17	19	21	24	26
FP_{ground}	4.0^{a} ±1.2	6.0^{a} ±1.0	8.7^{a} ±1.4	11.2^{a} ±1.6	13.3^{a} ±1.76	16.5^{a} ±2.1	19.5^{a} ±3.5	23.1^{a} ±1.7	24.5^{a} ±2.4	26.1^{a} ±2.6	27.5^{a} ±2.5	29.5^{a} ±2.5
FP_{ladder}	3.5^{a} ±0.1	6.1^{a} ±0.5	8.8^{a} ±0.2	11.3^{a} ±0.3	13.8^{a} ±0.9	16.4^{a} ±1.3	18.8^{a} ^{b}±1.0	22.9^{a} ±1.4	26.1^{a} ±1.8	-	-	-
SE_{ladder}	1.6^{a} ±0.3	3.1^{b} ±0.4	6.1^{ab} ±0.5	8.7^{ab} ±0.1	9.9^{ab} ±0.1	12.3^{a} ^{b}±0.4	14.0^{a} ^{b}±0.9	15.1^{b} ±1.2	17.9^{bc} ±1.0	19.7^{ab} ±0.2	22.4^{ab} ±0.7	23.5^{bc} ±0.5
CH	2.1^{a} ±0.4	3.3^{b} ±0.5	5.5^{b} ±0.5	7.5^{b} ±1.1	9.0^{b} ±1.2	11.0^{b} ±1.7	12.4^{b} ±1.8	15.5^{b} ±1.4	17.5^{c} ±1.7	18.5^{b} ±2.4	20.8^{b} ±2.3	21.7^{c} ±2.0
PHB	3.8^{a} ±1.8	6.4^{a} ±1.9	8.9^{a} ±1.7	11.0^{a} ±1.7	13.1^{ab} ±2.4	15.8^{a} ±2.0	17.7^{a} ^{b}±2.0	21.7^{a} ±3.5	23.4^{ab} ±3.0	24.6^{ab} ±2.7	26.3^{ab} ±2.0	28.1^{ab} ±1.5
LRF	2.4^{a} ±0.1	3.9^{ab} ±0.1	7.1^{ab} ±0.4	9.3^{ab} ±1.0	11.8^{ab} ±0.8	13.9^{a} ^{b}±0.9	16.9^{a} ^{b}±2.5	18.8^{ab} ±1.8	20.7^{abc} ±1.8	22.9^{ab} ±3.0	24.8^{ab} ±2.5	25.8^{abc} ±1.7
P	0.047	0.002	0.003	0.009	0.007	0.004	0.012	0.001	0.001	0.013	0.018	0.002

*PLW measurement was stopped from day 21 in FP_{ladder} due to 100% sample got decay loss. Means within a column followed by a common letter are not significantly different by the Holm-Sidak method at the 5% level of significance.

Table 9. Rot incidence (%) of harvested mandarin stored for 26 days

Cumulative rot incidence (%)													Shelf life (day)*
Harvesting treatments	Days of storage (day)												
	3	5	7	9	11	13	15	17	19	21	24	26	
FP_{ground}	-	-	-	6.7	20.0	33.3	60.0	73.3	80.0	86.7	86.7	86.7	7
FP_{ladder}	-	-	-	-	26.7	46.7	53.3	60.0	60.0	60	100	100	9
SE_{ladder}	-	-	-	-	-	-	-	-	-	-	6.7	6.7	19
CH	-	-	-	-	-	-	-	-	-	6.7	6,7	6.7	19
PHB	-	-	-	-	-	13.3	26.7	33.3	53.3	66.7	86.7	86.7	11
LRF	-	-	-	-	-	-	6.7	6.7	13.3	13.3	20.0	20.0	13

* Shelf-life was estimated based on start of decay loss and daily visual observation of color, brown patches on outer cover and rot incidence of stored samples

Rot incidence (decay loss) and shrinkage behaviour

Table 9 summarizes the cumulative percentage of decayed fruits which were stored for 26 days under ordinary room condition. From the Table 9, mandarin harvested through farmers practice (pull method) had the highest rot incidence (100%) followed by PHB (86.7%) type harvester treatment during the 26 days of storage. Ten percent rot incidence occurred in the fruit harvested by CH (day 21) and SE_{ladder} treatment (day 24), respectively. Similarly, LRF treatment has 20% decay loss in total during the entire storage experimental period. Among the treatments, the earlier physiological disorder (brown patches or spot on the rind and fruit discolor) and decay loss (6.7%) started from 9 days of storage in FP method where 100% decay loss has occurred in 24 days of storage. Likewise, the decay loss (13.3%) started from 13 days and reached 86.7% on day 26 in PHB type treatment. This loss could be due to skin fracture, puncturing and injuries of fruit like bruises and other damages due to peeling or wound of outer skin nearby peduncle extremity in farmers pull method (FP). In the same way, hooking and pulling of fruit in PHB treatment caused peeling of the outer soft skin attached to peduncle of a mandarin.

From our daily visual observation, we found that the injured area of the damaged fruits begins to discolor with multiple brownish spots. Later softening and decay caused by molds was seen in FP practice. Decay of fresh produce during storage is mostly caused by the infection of mechanical injuries provoked by microorganisms, mostly mold, bacteria and fungi (Paltrinieri, 2014). Contrarily, lower decay incidence in SE and CH treatments is attributed to intact fruit with controlled sap oozing and lateral infection due to the presence of pedicel in fruit (Khatri et al., 2021; Kumargoud et al., 2017; Singh et al., 1993; Sonkar et al., 1999). Moreover, fruits with intact stalk were less prone to fungal infection during storage than those without fruit stalk (Purbiati & Supriyanto, 2013; Rokaya et al., 2020; Waskar et al., 1997). Correspondingly, twisting and turning action by the three soft rubber padded claws of LRF prevents peeling and damage of outer skin around peduncle extremity point. But, hardening of the skin and development of wrinkling/shrinkage appeared as a result of water loss in SE and CH method at day 26 of ordinary storage condition. The shrinkage of outer peel is attributed to weight loss due to the dehydration process after long term storage in ordinary room. Since the peel is a visible marketing feature, changes in the appearance of the peel will have an adverse effect on the marketability of the fruits.

Based on results of decay loss and visual appearance of mandarin (marketability), the shelf-life of FP practice and PHB type harvester was 7-9 days and 9-11 days, respectively. Use of LRF model harvester in mandarin picking prolonged shelf-life up to 13 days and that by SE and CH model ranged from 16-19 days, respectively. A previous study by Singh et al. (1993) and Waskar et al. (1997) in mango reported fruits with stalk had 2-4 days more shelf-life with minimum decay loss and higher marketability. Likewise, Sonkar et al. (1999) revealed that decay was considerably less in clipped Nagpur mandarin and further reduced by fungicidal wax treatment during storage up to 15 days under ambient condition and 45 days under refrigerated condition. Conclusively, it can be said that inappropriate harvesting leads to hastened physiological deterioration, which can manifest in the propagation of microbiological activity and accelerated decay.

Table 10. Fruit firmness of harvested mandarin stored for 26 days

Fruit firmness (kg/cm^2)				
Harvesting treatments	Days of storage			
	Day 1	Day 9	Day 17	Day 26
FP_{ground}	$8.3^{a}\pm0.7$	$7.6^{a}\pm1.1$	$7.3^{ab}\pm0.6$	$6.2^{bc}\pm0.2$
FP_{ladder}	$7.9^{a}\pm0.5$	$7.7^{a}\pm0.5$	$6.3^{b}\pm0.8$	$5.7^{c}\pm0.2$
SE_{ladder}	$7.8^{a}\pm0.7$	$7.7^{a}\pm0.8$	$8.2^{a}\pm0.2$	$9.5^{a}\pm0.5$
CH	$7.5^{a}\pm0.2$	$7.6^{a}\pm0.6$	$7.3^{ab}\pm0.4$	$9.0^{a}\pm0.5$
PHB	$8.4^{a}\pm0.7$	$8.3^{a}\pm0.3$	$7.4^{ab}\pm0.1$	$6.6^{bc}\pm0.4$
LRF	$7.4^{a}\pm1.8$	$7.6^{a}\pm0.2$	$7.0^{ab}\pm0.7$	$6.9^{b}\pm0.3$
P	0.71	0.84	0.024	<0.001

Means within a column followed by a common letter are not significantly different by the Holm-Sidak method at the 5% level of significance.

Fruit firmness

Fruit firmness is a mechanical property that can be described as the resistance to puncture or deformation (Kassim et al., 2020). It is one of the critical post-harvest quality factor to investigate the storability behaviour and shelf life of fruit as consumers select a firm rather than a soft one (Mahajan et al., 2016). Table 10 shows the firmness values of stored mandarins harvested by different methods. The fruit firmness of the mandarin showed a decreasing trend with an increase in storage period for the FP and PHB treatment. For example, the fruit firmness was 8.3 and 8.4 kg/cm^2 for FP and PHB treatment on day 1, but decreased to 6.2 and 6.9 kg/cm^2, respectively in 26 days (Table 10). Conversely, SE and CH method harvested mandarin has maintained fruit firmness values of day 1 (7.5-7.8 kg/cm^2) till 17 days. Later, we find increased values of firmness in SE (9.5) and CH (9.0) while the lowest was recorded in FP_{ladder} treatment (5.7 kg/cm^2) at day 26.

The decrease in fruit firmness is related to loss of pectic substances (degradation of protopectin by pectinatase) in the middle lamella of the cell wall that leads to the loss of cell wall integrity, that in turn results softening and shriveling of fruit (Faasema et al., 2011; Khatri et al., 2021; Mahajan et al., 2016). The decrease in the firmness could also be attributed to fruit senescence due to prolonged storage in ordinary storage condition that will reduce fruit quality and poor visual appearance to consumers (Alhassan et al., 2014). In other hand, firmness basically depends on cell turgidity, which is associated with the moisture content (Kassim et al., 2020). SE and CH methods mandarins resulted in superior fruit firmness, compared to FP and PHB method samples. The steadiness of fruit firmness could be lesser mechanical damage that lowers the respiration rate and slowdown in moisture loss and breakdown of starch to glucose and fructose (Mahajan et al., 2016; Rokaya et al., 2020). The presence of peduncle improves clipped fruit firmness by preventing enzyme activity involved in fruit softening or by cell wall lignification. But, the high value of firmness in those methods on day 26 could be due to hardening of the skin (tough and leathery peel) as a result of water loss and the development of wrinkling after long term storage in ordinary room condition (Faasema et al., 2011). Based on fruit firmness, we recommend 10-15 days storage under ordinary room or unmodified condition of storage for fruit harvested by manual harvesting tools (SE_{ladder}, CH, and LRF).

Table 11. Total soluble solids (TSS), Titrable acidity (TA) and TSS/TA ratio of harvested mandarin stored for 26 days

Harvesting treatments	TSS (ºBrix)				TA (%)				TSS/TA			
	Days of storage				Days of storage				Days of storage			
	1	9	17	26	1	9	17	26	1	9	17	26
FP_{ground}	14^{a}	15^{a}	15^{a}	17^{a}	1.99^{ab}	1.67^{bc}	1.43^{a}	1.23^{a}	7.04^{ab}	8.98^{ab}	10.49^{ab}	13.82^{a}
FP_{ladder}	13^{a}	14^{a}	16^{a}	15^{ab}	2.02^{ab}	1.79^{b}	1.53^{a}	1.3^{a}	6.44^{ab}	7.82^{ab}	10.46^{ab}	11.54^{b}
SE_{ladder}	14^{a}	14^{a}	14^{a}	14^{b}	2.4^{a}	2.23^{a}	1.90^{a}	1.55^{a}	5.83^{b}	6.28^{cd}	7.37^{c}	9.03^{c}
CH	14^{a}	13^{a}	14^{a}	15^{ab}	1.75^{b}	1.73^{bc}	1.60^{a}	1.46^{a}	8.00^{a}	7.51^{bc}	8.75^{bc}	10.27^{bc}
LRF	13^{a}	13^{a}	14^{a}	15^{a}	2.23^{ab}	2.4^{a}	1.88^{a}	1.52^{a}	5.83^{b}	5.42^{d}	7.45^{c}	9.87^{bc}
PHB	13^{a}	14^{a}	16^{a}	14^{b}	1.85^{ab}	1.51^{c}	1.42^{a}	1.31^{a}	7.03^{ab}	9.27^{a}	11.27^{a}	10.69^{bc}
P	0.11	0.11	0.1	0.01	0.07	0.001	0.012	0.013	0.020	0.001	<0.001	<0.001

Means within a column followed by a common letter are not significantly different by the Kruskal-Wallis One Way Analysis of Variance on Ranks and Tukey test method at the 5% level of significance.

Chemical quality parameters

Total soluble solids (TSS)

The TSS of citrus fruit constitutes carbohydrate (70-80%) and other minor constituents such as proteins, organic acids, minerals and lipids. It contributes nearly 10–20% of the fresh weight (Kassim et al., 2020). The TSS content was increased with advancement of storage duration regardless of the harvesting methods except SE treatment (Table 11). In the light of all treatments, on day 1, initial TSS lies within 13-14 °Brix, but at the end of the storage period (day 26), TSS values lies within 14-17 °Brix. Maximum value for TSS (17 °Brix) was obtained in FP treatment and the minimum (14 °Brix) was recorded in SE_{ladder} on 26th day of storage. The higher value of TSS occurred in FP_{ground} (17) on day 26, FP_{ladder} (16) and PHB (16) on day 17 while that for CH (15) was obtained on day 26. Surprisingly, the achieved TSS values of SE_{ladder} treatment was constant (14) during the whole storage period. The increase in TSS values was seen earlier in the fruit harvested by FP (pull method) and PHB (hook and pull) treatment than those by CH method (Table 11). The minimum and delayed increase in TSS of fruit would be advantageous for the preservation of post-harvest fruit quality under storage condition (Pippal et al., 2016). The increase in TSS with advancement of storage could be accounted to hydrolysis of polysaccharides (starch, pectin and other insoluble carbohydrates) to simpler sugars like glucose and fructose as well as increase in the solute concentration by moisture loss (Alhassan et al., 2014; Faasema et al., 2011; Jafarpour & Fatemi, 2012; Kassim et al., 2014; Pippal et al., 2016; Purbiati & Supriyanto, 2013; Rokaya et al., 2020). The delayed increase in TSS of CH harvested fruit might be attributed to delayed moisture loss and ripening, lower metabolic activities due to intact fruit rind and slower senescence processes. Consequently, the decrease in TSS is attributed to the consumption of sugars and organic acids to other organic products as a substrate for respiration and metabolism process in mandarins during storage (Faasema et al., 2011; Kassim et al., 2020). Studies by Purbiati and Supriyanto (2013) and Rokaya et al. (2020) reported that fruit harvested by hitting with a stick has high respiration rate and quick increase of TSS than that by clipper. Likewise, Elshiekh and Abu-Goukh (2008) found an increase in TSS during storage of grapefruits, and they attributed this to the loss in moisture content which led to the concentration of TSS.

Titratable Acidity (TA)

Organic acids have a key role in the organoleptic characteristics of citrus fruit. Citric acid accounts for approximately 80–95% of the total titratable acids in citrus fruit (Kassim et al., 2020). The acidity of fruits has a decreasing trend in all groups of harvesting treatments with the advancement of storage duration (Table 11). However, the FP and PHB fruits showed a faster decreasement than the harvester (SE_{ladder} and CH) harvested fruits during storage. For instance, on day 1 of storage, TA of FP, SE, CH, PHB and LRF was 1.99, 2.4, 1.75, 1.85 and 2.23%, respectively. On the day 26, it was decreased to 1.23, 1.55, 1.46, 1.31 and 1.52 % for FP, SE, CH, PHB and LRF, respectively. The minimum acidity (1.23%) was recorded in FP treatment and the maximum (1.55%) was recorded in SE_{ladder} after twenty-six days of storage. The decrease in titratable acids may be ascribed to catabolism and utilization of citric acid in pyruvate decarboxylation reaction in the aerobic respiration process during storage (Kassim et al., 2020; Mahajan et al., 2016; Rokaya et al., 2016). In other words, the breakdown of pectin substances into pectic acid during post-harvest metabolic activities could decrease the acidity of fruits stored in ordinary condition (Ullah et al., 2018). Previous studies such as Sonkar et al. (1999) reported that the TSS did not change much while TA dropped more in manually harvested fruit as compared to clipped fruit. Thus, the presence of peduncle in SE and CH method might have helped in better retention of acidity, delayed the post-harvest metabolic activities (respiratory process) and low degree of oxidation of organic acids as compared to other treatment. Conclusively, with the increase in storage duration, acidity was decreased in all treatments but the use of proper harvesting tool like SE and CH delayed the postharvest decrease in acidity of the mandarin.

TSS/TA

TSS/TA ratio increased in all the treatments over the advancement of storage period (Table 11). Considering overall treatments, TSS/TA ratio ranged from 5.83 to 8.0 on day 1 however, it ranged from 9.03 to 13.82 on day 26 of storage. SE, LRF and CH treatment has lower TSS/TA values (9.03-10.27) than FP (11.54-13.82) and PHB (10.69) at day 26. Fruits having TSS/TA ratio higher than 19 are regarded as sweet and less acidic in taste (Mavis et al., 2014). Although the values are below 19, the increase in TSS /TA ratio could be due to a reduction in TA and an increase of TSS in our study. A high TSS/TA has generally been regarded as a quality index for orange fruits. However, the increase in TSS/TA during our storage trials can also be accompanied by the development of off-flavors due to the formation of ethanol in the fruit, an indication of spoilage (Davis et al., 1974; Mavis et al., 2014) which was supported by rot incidence phenomena of our study. Thus, we recommended controlled storage condition trials to have more articulate picture on TSS/TA behaviour.

CONCLUSION

Based on the number per hr, the harvesting output of CH, LRF and PHB type harvester was 39.15%, 15.78% and 30.21% higher than FPladder practice and that of SEladder method was 15.62% lower than FPladder.

CH and SE treatment found effective in prolonging the average shelf-life and maintaining the quality of mandarin up to 17 days under ordinary room condition as opposed to 7-9 days only in the case of FP. The button or pedicle of fruit has synergistic effect on maintaining the fruit quality by minimizing the rot incidence and moisture loss during ordinary storage.

The storage trials on fruit physiochemical attributes exhibited that use of appropriate harvesting tools are effective in delaying the decrease of PLW and TA, and also decelerating the TSS accumulation, which in turn results in improved storability and extended shelf-life of fruits in stored condition.

Overall, based on our findings, we suggest that hand held secateur and cut and hold type harvester are suitable harvesting tools for soft skinned fruit like mandarin picking. Moreover, long reach finger type fruit picker (LRF) model also seems one of the alternative for farmer to harvest mandarin however the correct harvesting principle (catch-twist-turn-hold) need to be strictly followed. Importantly, our findings on storability physiochemical characteristics are primarily based on ordinary room storage condition. Controlled storage condition (85-90% RH and 3-9°C) and different post-harvest treatments such as hot water, surface coatings, ultra-violet irradiation, chlorine, salt treatments and microbial antagonists were reported to be beneficial in reducing the prevalence of postharvest decay, maintaining the citrus quality and further enhancing the shelf life of harvested fruit. In light of this, further investigations on the post-harvest storability behaviour of harvesters picked and pretreated mandarin in controlled storage condition is recommended.

Acknowledgments

This work was supported by grants from Korea International Cooperation Agency (KOICA) and United Nations Development Program (UNDP) under the Value Chain Development Project (VCDP) in NARC, Nepal. This study was an activity of a project named 'Adoption of appropriate engineering technologies for reducing harvest and post-harvest losses of fruits and vegetables, and profit enhancement of farmers' lead by NAERC. The authors are grateful to the entire family of NAERC, NFRC, NHRC (especially Dr. Ishwori Prasad Gautam and Mrs. Suprabha Pandey) and Mr. Purushottam Khatiwada (Horticulture Specialist, VCDP project) for their valuable assistance in this work. The authors likewise greatly appreciate the critical and constructive comments from the anonymous reviewers, which have helped improve this manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

REFERENCES

Alhassan, A.F., Adjei, M., & Sadick, M. (2014). Effect of maturity stage and storage duration on physico-chemical properties of citrus (*Citrus sinensis* var. Late valencia). *European Scientific Journal*, *10*(36), 148-162.

AOAC. (2005). Official methods of analysis (16th edition). *Association of official analytical chemists. Washington D.C. USA.*

Bhattarai, R.R., Rijal, R., & Mishra, P. (2013). Post-harvest losses in mandarin orange: A case study of Dhankuta District, Nepal. *African Journal of Agricultural Research*, *8*(9), 763-767.

Davis, P., Hoffman, R.C., & Thatton, T. (1974). Temperature and duration of storage on ethanol content of citrus fruits. *Horticultural Science*, *9*, 376-377.

Elshiekh, F., & Abu-Goukh, A. A. (2008). Effect of harvesting method on quality and storability of grapefruits. *University of Khartoum Journal of Agricultural Sciences*, *16*(1), 1-14.

Faasema, J., Abu, J.O., & Alakali, J.S. (2011). Effect of packaging and storage condition on the quality of sweet orange (*Citrus sinensis*). *Journal of Agricultural Technology*, *7*(3), 797-804.

Jafarpour, M., & Fatemi, S. (2012). Post harvest treatments on shelf life of sweet orange Valencia. *Journal of Medicinal Plants Research*, *6*(11), 2117-2124.

Joshi, P., Ojha, B. R., & Kafle, A. (2020). Effect of different postharvest treatments on prolonging shelf life of Citrus reticulata Blanco. *Nepalese Horticulture*, *14*(1), 1-8. https://doi.org/10.3126/nh.v14i1.30603

Kassim, A., Workneh, T.S., Mark D., & Laing, M.D. (2020). A review of the postharvest characteristics and pre-packaging treatments of citrus fruit. *AIMS Agriculture and Food*, *5*(3), 337-364. https://doi.org/10.3934/AGRFOOD.2020.3.337

Khatri, S., Shrestha, S., & Pokharel, K. P. (2021). Evaluation of manual fruit harvesters and storability characteristics of harvested sweet orange under ordinary room storage condition. *Sustainability in Food and Agriculture (SFNA), 2*(2), 84-91. http://doi.org/10.26480/sfna.02.2021.84.91

Kitinoja, L., & Kader, A. (2002). Small-scale postharvest handling practices: a manual for horticultural crops (4th edition). *Postharvest Horticulture Series No. 8E. University of California, Davis Postharvest Technology Research and Information Center.* http://ucce.ucdavis.edu/files/datastore/234-1450.pdf

Kumargoud, V., Gowda, S. J., Karthik, S.K., & Mohithkumar, G.V. (2017). Performance evaluation of mango harvesting techniques. *Agriculture Update*, *12*(TECHSEAR-4), 1135-1137. http://researchjournal.co.in/upload/assignments/12_1135-1137.pdf

Li, P., Lee, S. H., & Hsu, H. Y. (2011). Review on fruit harvesting method for potential use of automatic fruit harvesting systems. *Procedia Engineering*, *23*, 351-366. https://doi.org/10.1016/j.proeng.2011.11.2514

Liu, F.W. (2010). Development and application of citrus storage technologies with concurrent consideration of fruit quality preservation, energy use, and costs. Paper presented at the 2010 AARDO workshop on technology on reducing post harvest losses and maintaining quality of fruits and vegetables, 26-47. https://scholars.tari.gov.tw/bitstream/123456789/2624/1/publication_no147_07.pdf

Mahajan, B. V. C., Singh, R., & Kumar, M. (2016). Quality assurance and shelf-life extension of kinnow mandarin fruit under supermarket conditions. *International Journal of Fruit Science, 16*(1), 94-102. https://doi.org/10.1080/15538362.2015.1061959

Mavis, O.A., Firibu, K.S., & Samuel, S.D. (2014). Effect of storage time and storage conditions on physicochemical quality of sweet orange (*Citrus sinensis* L). *Journal of Agriculture and Food Technology*, *4*(5), 36-41.

MoALD. (2020). Statistical information of Nepalese agriculture (2018/19). *Government of Nepal, Ministry of Agricultural and Livestock Development, Planning & Development Cooperation Coordination Division, Statistics and Analysis Section, Singha Durbar, Kathmandu, Nepal*

Ogoe, P. B., Appiah, C., & Ofori, E. (2020). Effects of harvesting methods on the quality characteristics of citrus fruits in the central region of Ghana. *Science Development*, *1*(1), 1-7. https://www.sciencepublishinggroup.com/journal/paperinfo?journalid=630&doi=10.11648/j.scidev.20200101.11

Paltrinieri, G. (2014). Handling of fresh fruits, vegetables and root crops, a training manual for Grenada, TCP/GRN/2901. *Food and Agriculture Organization of the United Nations: Rome, Italy, 2014.* http://www.fao.org/3/a-au186e.pdf (Accessed on 2020/11/03).

Pippal, R., Gupta, R., Kuchi, S.V., & Rana, S. (2016). Quality characterization of mandarin (*Citrus reticulata* Blanco) during storage. *International Journal of Agriculture Sciences*, *8*(33), 1697-1701.

Purbiati, T., & Supriyanto, A. (2013). Effects of harvesting method and storage temperature on shelf life of mandarin fruit cultivar 'SoE' from East Nusa Tenggara, Indonesia. *Acta Horticulturae, International Society for Horticultural Science (ISHS)*, *989*, 149-152. https://doi.org/10.17660/ActaHortic.2013.989.18

Rokaya, P., Baral, D., Gautam, D. M., Shrestha, A., & Paudyal, K. (2016). Effect of postharvest treatments on quality and shelf life of mandarin (*Citrus reticulata* Blanco). *American Journal of Plant Sciences*, *7*, 1098-1105. http://dx.doi.org/10.4236/ajps.2016.77105

Rokaya, P., Baral, D., Gautam, D. M., Shrestha, A., & Paudyal, K. (2020). Effect of harvesting methods on storage behaviour of mandarin (*Citrus reticulata* Blanco) under cellar condition. *International Journal of Science and Qualitative Analysis*, *6*(1), 8-12. https://doi.org/10.11648/J.IJSQA.20200601.12

Sabale, P.R., Nalawade, R.D., Bhosale, T.B., & Menu, S.S. (2017). Development of manual orange (*Citrus sinensis*) fruit harvesting system. *International Journal of Current Microbiology and Applied Sciences*, *6*(11), 3427-3433.

Singh, B. P., Parla, S. K., & Tonden, D. K. (1993). Effect of methods of harvesting on storage behaviour of mango. *Indian Journal of Horticulture*, *50*(1), 5-9.

Sonkar, P., Ladaniya, M., & Singh, S. (1999). Effect of harvesting methods and post-harvest treatments on storage behaviour of Nagpur mandarin (*Citrus reticulata*) fruit. *Indian Journal of Agricultural Sciences*, *69*(6), 434-437.

Timilsina, K., & Tripathi, K. (2019). Chemical quality attributes of mandarin (Citrus reticulata Blanco) as affected by altitude and fruit bearing position in Kavre, Nepal. *Archives of Agriculture and Environmental Science*, *4*(3), 319-325. https://doi.org/10.26832/24566632.2019.0403010

Ullah, F., Sajid, M., Gul, S. L., Zainub, B., & Khan, M. (2018). Influence of hot water treatments on the storage life of sweet orange cv. sherkhana-i. *Sarhad Journal of Agriculture*, *34*(1), 220-224. https://doi.org/10.17582/journal.sja/2018/34.1.220.224

Vagadia, V. R., Mashru, H.H, Rank, H.D., Prajapati, G.V., Satasiya, R.M., & Subbaiah, R. (2020). Development and performance evaluation of lime harvesting device. *International Journal of Economic Plants*, *7*(2), 80-85. http://dx.doi.org/10.23910/2/2020.0362

Waskar, D.P., Masalkar, S.D., Gaikwad, R.S., & Damame, S.V. (1997). Effect of method of harvesting on post harvest loss reduction and extension of shelf life of mango. *Acta Horticulturae*, *455*, 662-668.