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Ergonomic Evaluation of Developed Manual Fruit Harvesting Device

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ABSTRACT

Background: Ergonomics in agriculture assumes pronounced importance as it is a multidisciplinary science that endeavors to make a better fit between the job and the worker to ensure their health and safety.

Methods: In the current study, a evaluation of developed manual fruit harvester was done suitable for selective harvesting and comparison was done with traditional system on ergonomic grounds.

Result: The mean working heart rate (HR) during kinnow harvesting operation was 102.09 beats per min, and 108.53 beats per min for traditional and developed method respectively. The ODR (overall discomfort rating) value ranged from 4 to 5 and 0 to 4 and the BPDS value ranged from 40.66 to 59.58 and 30.91 to 51.33 in harvesting operation by traditional and developed system respectively The average RULA score for traditional method was found 7 and action level 4 which fall in the range of very high risk level and changes are required immediately. The average RULA score for developed method was found 4 and action level 2 which fall in the range of low risk level and changes may be required.

Key words: Body part discomfort, Ergonomics, Heart rate, Overall discomfort rate, Rapid upper limb assessment.

INTRODUCTION

Harvesting of fruit is a labour-intensive operation, worldwide, which accounts in many cases for about 50 per cent of total production costs (Sanders, 2005). In addition, it is a tedious, stoop type job, which is needed to be performed on a seasonal basis during a relatively short time. These combined factors, in addition to the costly operation may contribute detrimentally to the issues of safety, health and quality of picking (Mlotek, 2015). In India harvesting of fruits is mostly done manually plucking or by means of bamboo sticks having hook. These method results high labour, high energy requirements, drudgery and damage to fruits and branches etc Ghadge *et al*. (2001).

The various researchers developed different fruit harvesting devices and conducted the ergonomic feasibility study of devices. Wade (2010) studied the ergo-friendly harvesting system for guava (Psidium Guajava) fruit. He observed that the ODR (overall discomfort rating) value ranged from 4.8 to 6.4 and 3.1 to 4.3 in harvesting operation by traditional and improved system respectively. The mean working heart rate (HR) during guava fruits harvesting operation ranged from 98.70 to 102.02 beats/min and 89.49 to 91.39 beats/min and the mean Ä HR value ranged from 21.00 to 26.35 beats/min and 14.27 to 18.69 beats/min for traditional and improved guava harvesting methods, respectively. Sabale *et al*. (2017) carried out study to develop the ergonomically feasible manual orange fruit harvesting system. The developed system consists of the aluminum tripod adjustable as per the operator’s height and the whole harvester assembly mounted on the tripod. The micro camera and display arrangement reduce musculoskeletal stress on the operator. The performance of the improved system evaluated in terms of fruit selection, harvest rate, fruit damage and field performance by field tests and compared with traditional harvesting methods. The maximum harvest rate ranged from 49.26 to 64.12 kg/h and 37.12 to 45.70 kg/h for the harvesting of orange fruits by the traditional and improved method, respectively. The average damage to fruits in traditional method observed 14 per cent and it was almost no fruit damage in improved method. The

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improved harvesting system found better than traditional methods and reduces musculoskeletal stress on the operator. Conlan *et al*. (1995) implemented occupational biomechanics to evaluate lower back stress in the citrus harvesting operation. The objective of this investigation was to identify activities which induce excessive lower back stresses on citrus harvesting workers. Lower back stress was evaluated under static conditions in three commonly occurring citrus harvesting positions. Three commonly occurring positions were analyzed-descending the citrus ladder, walking with a full citrus bag and bending over to pick citrus from the ground. Sensitivity analysis was performed and found for that the citrus bag weight, abdominal pressure, height, weight and physical size of the worker affects the lower back stress. Some of these activities caused lower back force to exceed established industrial limits.

During field operations, there is increase in the value of physiological as well as physical parameters depending upon workload on the individual agricultural worker. Further undesirable posture, which cannot sustain a minimum of static muscular effort, does not allow the worker to perform the given task more effectively Chaudhary *et al*. (2019). To overcome the human drudgery involved in fruit harvesting Chaudhary *et al*. (2019) developed a manual fruit harvesting device and evaluated it under field conditions for kinnow (*Citrus nobilis* X *citrus deliciosa*). An ergonomic study of developed manual fruit harvesting device was needed. In this regard ergonomic evaluation of the developed fruit harvesting device and its comparison with the traditional system was conducted in the present study.

MATERIAL AND METHODS

Detail of device

A long hollow aluminium telescopic pipe of 3530 mm length was designed and developed in the Department of Farm Machinery and Power Engineering, College of Technology and Engineering, (M.P.U.A.T.) Udaipur, Rajasthan as shown in Fig.1 to provide a combination of long reach and high cutting power of multiple fruits. The aluminium rod has support system of stands for battery and display, one hand grip and two butterfly locking mechanism for mounting camera and attaching fruit collecting net. Furthermore, this entire apparatus is mounted on the body of operator through a clamp and nut bolt mechanism which is attached to ergonomically designed and fully supported belts because of which it can be rotated at 360° to easily harvest the fruit at any height and angle.

In order to carry out the ergonomic evaluation of the developed manual fruit harvesting device a physiological parameter i.e. heart rate (HR), physical parameter i.e. body part discomfort score (BPDS) and overall discomfort ratings (ODR) experienced by the subjects were estimated. The posture assessment tool rapid upper limb assessment (RULA) developed by Atamney and Corlett (1993) was also used to assess postural discomfort.

Heart rate (HR)

Since heart rate is an effective indication of physiological response since 1970 (Mc Cormick) and easier to measure therefore, heart rate was selected as indicator for the physiological response. Field experiments were carried out to assess the HR response during manual kinnow harvesting operations (traditional as well as for developed system). The heart rates for all the subjects were assessed during kinnow harvesting operations.

Protocol adopted to measure the heart rate (HR) of the subjects:

1. The selected subjects were asked to report to the field in the morning. It was ensured that they are in good health condition, had sound sleep in the previous night and had taken a normal breakfast. They were ensured to be free from stimulated beverages, smoking and recent exercise.
2. The subjects were explained about the objectives of the experiment and made familiar with the operation to ensure their full cooperation.
3. Before the start of the operation subject was allowed to take rest for 10 minutes and their resting heart rate was noted using polar heart rate monitor.
4. Observation was taken for 30 minutes work and thereafter recovery period.
5. The heart rate was averaged for 3 minute and that was the mean steady state heart rate.
6. Increase in heart rate (“HR) was computed from the difference between working heart rate and resting heart rate.
7. The observations were taken for both traditional and developed harvesting system.

Body part discomfort score (BDPS)

The body part discomfort score suggested by Corlett and Bishop (1976) is the body pain arising because of the working posture and for an excessive stress on muscles due to the effort involved in the activities. Drudgery caused due to bad posture is reflected in terms of postural discomfort experienced by the worker.

Protocol adopted to measure the body discomfort

The first three protocols adopted for measuring the BPDS were not only similar but same, which were followed for the heart rate with minor amendments which were necessary such as;

1. After continuously working for 30 minutes the subject was asked to indicate his discomfort on BPDS chart of (Corlett and Bishop, 1976) method as shown in Table 1.
2. The subject was asked to indicate the regions, which is most painful. Having noted these, the next more painful areas was asked and so on until no further areas was reported, Based on the reporting the body part discomfort score (BPDS)was calculated.

Overall discomfort rating (ODR)

The ODR suggested by Borg (1990) is a method used to assess the overall body discomfort**.** This is a scale of 70 cm length having 0 to 10 digit marked on it at equidistant as shown in Fig 2. A movable pointer is provided to indicate the rating of discomfort felt by the subject during operation. The steps involved in the measurement of ODR were similar as above however, the worker was assumed to indicate his discomfort level on physical scale rather on BPDS chart of body region.

Rapid upper limb assessment (RULA)

Posture assessment tool was selected to compare the ergonomic performance of kinnow harvesting by developed fruit harvesting device with the traditional method. The posture assessment tool namely RULA was used to assess postural discomfort. The different body angles and movement were measured by using the goniometer as shown in Fig 3.

The RULA was developed by Atamney and Corlett (1993) to evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity musculoskeletal disorder (MSD). A single page worksheet was used to evaluate required body posture, force and repetition. Based on the evaluations, scores are entered for each body region in section A for the arm and wrist and section B for the neck and trunk. After the data for each region was collected and scored. The Table 2 was used to compile the risk factor variables, generating a single score that represents the level of MSD risk.

Experimental procedure for measurement of physical and physiological parameter

The experiments were conducted in the kinnow orchard between 9:00 a.m. to 5:00 p.m. during the month of February 2019. The ten subjects (male) were asked to harvest Kinnow with traditional and developed methods. Every subject was instructed to do harvesting by both the methods thrice a day i.e. in morning from 9:00 a.m. to 11:00 a.m. in afternoon from 12:00 p.m. to 2:00 p.m. and in evening from 3:00 p.m. to 5:00 p.m for two consecutive days. OPSTAT software was used to analyze the data statistically.

RESULTS AND DISCUSSION

The comparative ergonomic evaluation of developed and traditional fruit harvesting method was conducted by using heart rate (HR), overall discomfort rating(ODR),body part discomfort score (BPDS) and rapid upper limb assessment (RULA) are described as below.

Measurement of heart rate (HR)

The mean working heart rate (HR) during kinnow harvesting operation ranged from 92.7 to 111.6 beats per min and average working heart rate was 102.09 where as mean

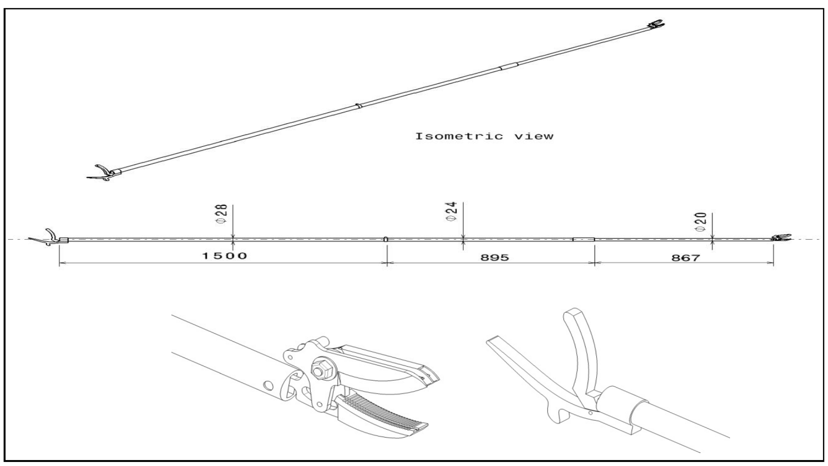


Fig 1: Drawing of different parts of developed fruit harvesting device.

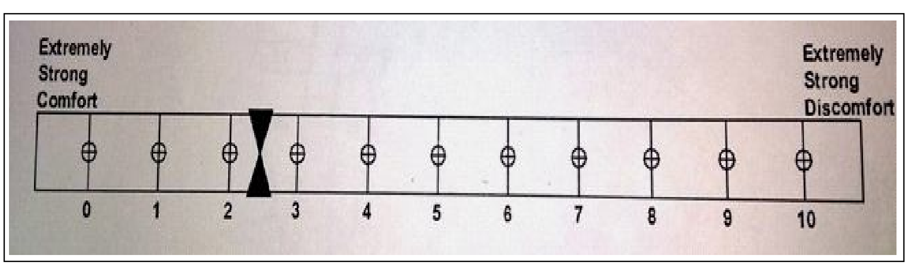
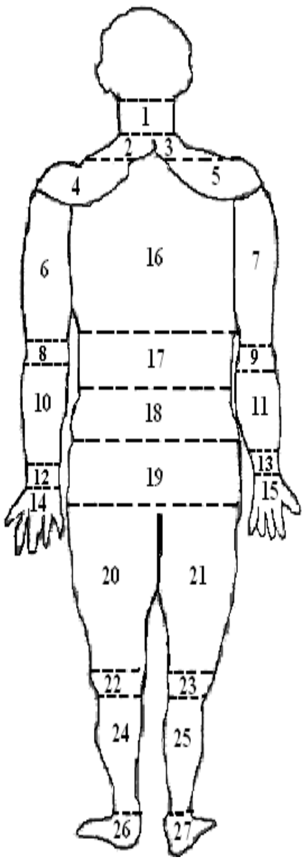


Fig 2: ODR Scale.

Table 1: Body divided in 27 parts.



1.	NECK
2.	CLAVICLE L.BFT
3.	CLAVICLE RIGHT
4.	LEFT SHOULDER
5.	RIGHT SHOULDER
6.	LPTF ARM
7.	RIGHT ARM
8.	LERFT ELBOW
9.	RIGHT ELBOW
10.	LEFT FORARM
11.	RIGHT
12.	LEFT WRIST
13.	LEFT PALM
14.	RIGHT WRIST
15.	RIGHT PALM
16.	UPPER BACK
17.	MID BACK
18.	LOWER BACK
19.	BUTTOCKS
20.	LEFT THIGH
21.	RIGHT THIGH
22.	LEFT KNEE
23.	RIGHT KNEE
24.	LEFT LEG
25.	RIGHT LEG
26.	LEFT FOOT
27.	RIGHT FOOT

Fig 3: Digital Goniometer.

Table 2: Level of MSD Risk.

Score	Level of msd risk
1-2	Negligible risk, no action required
3-4	Low risk, change may be needed
5-6	Medium risk , further investigation, change soon
6+	Very high risk, implement change now

ÄHR value was found to vary in the range of 20.7 to 26.3 and average ÄHR was 22.49 for all subjects for traditional method respectively (Table 3). According to classification suggested by Christensen (1953) mean working heart rate for harvesting of kinnow by traditional method could be scaled in "light" as well as "heavy" category in some of the cases but the average working heart rate scaled in "moderate heavy" category. On the other hand the average working heart rate for developed method *i.e*. 108.53 and average ÄHR *i.e*. 28.53 for all subjects scaled in "moderate heavy" category. There is no significant difference between both as both the methods comes in "moderate heavy" category.

In order to observe the significance of heart rate for different kinnow harvesting methods, the data were analyzed statistically and it was that the time and method was significant at 1 per cent level of significance and interaction between time and method at 5 per cent level of significance in both the methods of harvesting. There is a significant difference of heart rate between the time and method, the highest heart rate of 108.348 beats/min was obtained in afternoon (A2) and the lowest of 103.006 in the morning (A1) in both the methods. Average working heart rate of 102.09 was observed in the traditional system of kinnow fruits harvesting whereas it was 108.53 for developed fruits harvesting method. The variation in mean working heart rate in different kinnow harvesting method is shown in Fig 4.

Measurement of ODR

According to classification suggested by Borg (1990), the ODR value ranged from 4 to 5 *i.e*. from moderately painful to highly painful but the average ODR value is 4.3 which comes into moderately painful category in traditional method. The average ODR value for all subjects is 2.1 which comes into "Pain start" category in developed method (Table 3). The improved method as shown in Fig 5 requires less fatigue to perform the fruit harvesting operations than traditional harvesting method. The statistical analysis indicated that the time and method was significant at 1 per cent level of significance and interaction between time and method also at 1 per cent level of significance in both the methods of harvesting.

There is a significant difference of ODR between the time and method, the highest ODR was obtained in afternoon (A2) and the lowest in the evening (A3) in both the methods and there is a significant difference of ODR between traditional and developed method. Average ODR of 4.3 was observed in the traditional system of kinnow harvesting whereas it was 2.1 for developed fruits harvesting method which means using developed technique is more comfortable as compared to the traditional method. The variation in mean ODR in different kinnow harvesting method is shown in Fig 6.

Measurement of BPDS

The average BPDS value of 50.45 and 38.99 was observed in traditional and developed method of kinnow harvesting

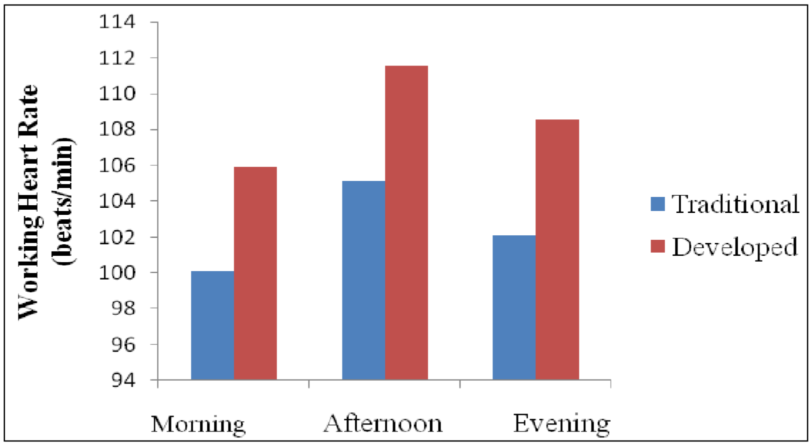


Fig 4: The variation in mean working heart rate in different kinnow harvesting method.

Table 3: Heart rate (beats/min), ODR and BPDS of the subjects in traditional and developed method.

Subjects	*T_m		**D_m		T_m		D_m		T_m	D_m
	HR	ÄHR	HR	ÄHR	ODR	Score	ODR	Score	BPDS	
S_1	111.6	22.6	115.06	29.06	MP	4	C	0	40.66	30.91
S_2	107.6	21.6	113.23	28.23	MP	4	U	1	54.00	41.33
S_3	108.3	26.3	107.6	29.60	MP	4	PS	2	53.25	36.80
S_4	104.8	21.8	113.5	28.50	MP	4	PS	2	47.33	36.25
S_5	100.7	21.7	104.26	28.26	HP	5	U	1	48.33	36.66
S_6	99.2	23.2	110.2	28.20	MP	4	PS	2	42.66	30.91
S_7	102.1	22.1	108.7	29.70	HP	5	SP	3	50.58	39.58
S_8	97.4	22.4	102.16	27.16	MP	4	SP	3	47.66	36.25
S_9	92.7	20.7	104.73	28.73	MP	4	SP	3	60.50	49.90
S_{10}	96.5	22.5	105.9	27.90	HP	5	MP	4	59.58	51.33
Average	102.09	22.49	108.53	28.53	MP	4.3	U	2.1	50.45	38.99

*T_m = Traditional method, **D_m = Developed method, MP = Moderately painful, HP = Highly painful, SP = Slightly painful, PS = Pain start, C = Comfortable, U = Uncomfortable

respectively (Table 3). In case of traditional method, the subjects experienced discomfort at neck, left and right shoulder, clavicle right, upper back, lower back, palm, right wrist and right elbow because of the standing posture and application of force by raising the stick over his head to apply force to branch to detach fruits from plants. On the other hand, in case of developed method the subjects experienced discomfort at clavicle right, right shoulder, right elbow and lower back due to wearing of harvesting machine on body and motion of right palm to cut the fruits. There was a significant difference in both the methods, using the improved method causes less fatigue to perform the fruit harvesting operations than traditional harvesting method.

The Fig 5 clearly depicted that the value of BPDS was significantly lower in developed method (38.99) for kinnow harvesting as compared to traditional method (50.45) of harvesting which means using developed technique is more comfortable in kinnow harvesting as compared to the traditional method. The BPDS was observed during kinnow harvesting operation was analyzed statistically and interaction between time and method was found non-significant because the pain in different parts of body and quantum of pain whilst harvesting through traditional method is same during various parts of day and the pain in various portions of body of subject and it's degree remained equivalent irrespective of time of day fruit was being harvested via developed equipment. The variation in mean BPDS in different kinnow harvesting method is shown in Fig 7.

Measurement of RULA

The average RULA score for traditional method was found to be 7 which shows that the working postures of the workers for kinnow harvesting operation with traditional method was found in very high risk zone. On the other hand, the average RULA score for developed method was found to be 4 and the action level was 2 which shows that the working postures of the workers for kinnow harvesting operation with developed method was found in medium risk zone (Table 2).

In the developed method, the neck and trunk angle was negligible *i.e.* 0° but in traditional method it was very high *i.e.* 19.72° for neck and 14° for trunk. Also, the upper arm angles were very small *i.e.* on an average of 46.83° in developed method as compare to traditional method *i.e.* 112.11°. There is a significant difference in both the methods. The improved method causes less fatigue to perform the fruit harvesting operations than traditional harvesting method, which shows that the developed method is better than the traditional method. The Fig 8 shows that the average postural movement of subject with different angles. In developed method the trunk angle was negligible but in traditional method it was very high. Also, the neck angle and upper arm angle were very high in traditional method as compare to developed method.

The figure 9 clearly depicted that the score of RULA is significantly lower in developed method (4) for kinnow harvesting from traditional method (7) of harvesting which makes the developed method ergonomically suitable. The rapid upper limb assessment (RULA) was analyzed statistically and interaction between time and method was found non-significant because the angles with the traditional and developed method was constant at all times of the day

Fig 5: Harvesting of fruits by developed device.

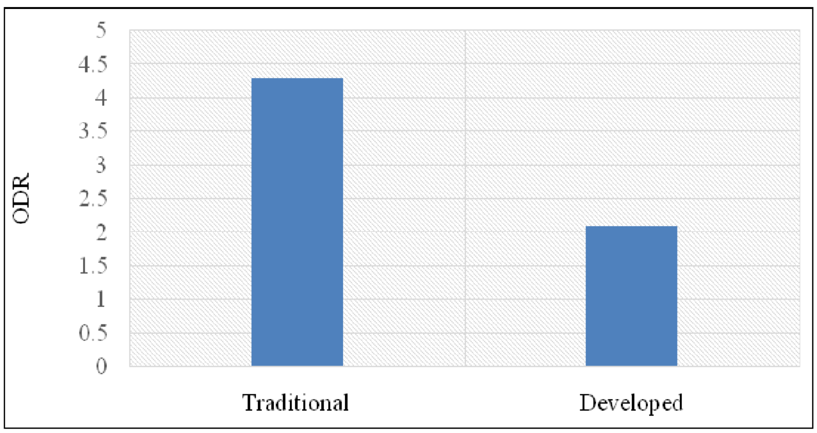


Fig 6: Mean ODR in different kinnow harvesting method.

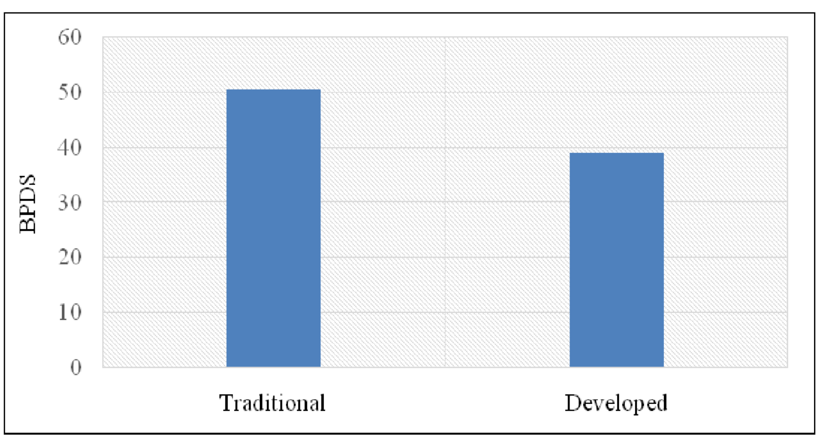


Fig 7: Mean BPDS in different kinnow harvesting methods.

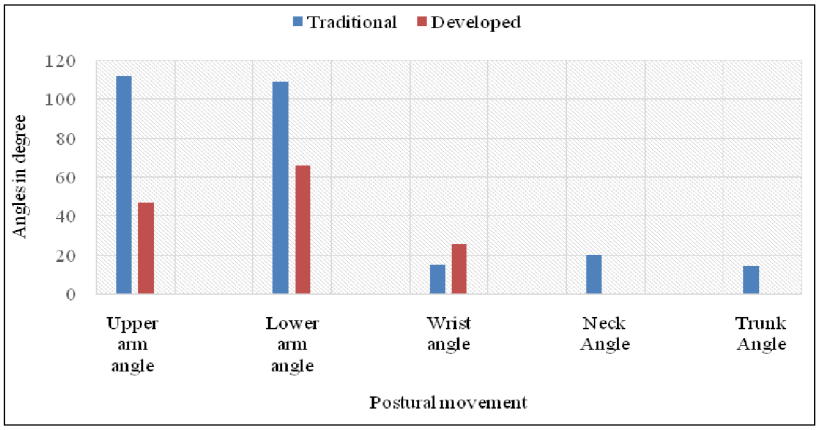


Fig 8: Average postural movement of subject in different methods.

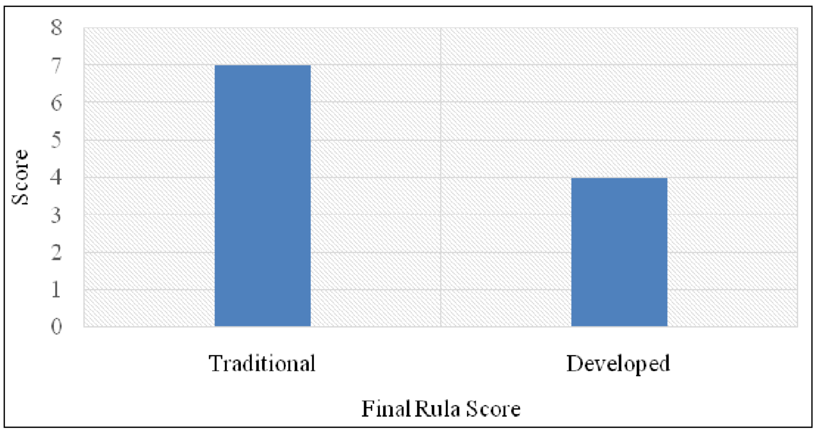


Fig 9: Final RULA score of traditional and developed method.

CONCLUSIONS

In this study, an ergonomic evaluation of developed manual fruit harvesting device was conducted with the comparison of traditional system. The mean working heart rate during kinnow harvesting operation was 102.09 and 108.53 beats per min for traditional and developed device respectively. In case of traditional and developed fruit harvesting device the overall discomfort rating ranged from 4 to 5 and 0 to 4 whereas the body part discomfort score ranged from 40.66 to 59.58 and 30.91 to 51.33 respectively The average RULA score for traditional and developed device was found to be 7 and 4 indicated high and low risk to labour/human being while performing harvesting operation in case of traditional method and developed device. The developed device was found ergonomically more feasible than the traditional system of fruit harvesting.

Conflict of interest: None.

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