



Comparative Evaluation of a Nutmeg Picking Tool with Conventional Methods using REBA and Physiological Metrics

P. Athira¹, Sanchu Sukumaran¹, Edwin Benjamin¹, D. Dhalin¹

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ABSTRACT

Background: The work-related musculoskeletal disorders (WMSDs) associated with agricultural workers had detrimental effects on productivity. Consequently, researchers have led to the development of various ergonomic evaluation and risk assessment tools. The present study aimed to ergonomically assess the nutmeg picking operation with the developed tool and compare with the conventional methods.

Methods: The physiological parameters and postural discomfort encountered by the subjects were determined for three operations: hand picking by bending posture (stooping), hand picking by sitting posture (crouching) and picking by a developed tool in standing posture. The postural analysis tool, Rapid Entire Body Assessment (REBA), was used for ergonomic risk assessment in the work.

Result: The average $\dot{V}O_2$ values for manual methods in stooping and crouching were found to be 38.4 beats.min⁻¹ and 49.2 beats.min⁻¹ respectively and 27.6 beats.min⁻¹ using the tool. Similarly, the oxygen consumption rate values were obtained as 0.82, 0.98 and 0.69 l.min⁻¹ for all operations respectively. Furthermore, the average overall discomfort rate (ODR) value for all subjects was 4.7, 5.9 and 1.4 for stooping, crouching and using the developed tool respectively. The average REBA score of 2 was obtained for the developed tool, which was lesser than that of conventional picking methods. The developed tool results in less fatigue than the conventional methods, which confirms that the developed tool is best, suited for nutmeg collection. Thus, new ergonomic interventions are vital in the field of agriculture to safeguard farmer's health and increase productivity.

Key words: Heart rate, MSDs, Oxygen consumption rate, Postural discomfort, REBA.

INTRODUCTION

Nutmeg (*Myristica fragrans*) is an important tree spice popular all over the world, which produces nutmeg seed (kernel) and mace (outer red arils covering the seed). India stands third position in nutmeg production across the globe with an area of production 24250 ha and output of 18.43 metric tonnes (Indiastat, 2024a). In India, regions of Kanyakumari and Tirunelveli in Tamil Nadu as well as Thrissur, Ernakulam and Kottayam districts of Kerala, are the primary areas under nutmeg cultivation (Anonymous, 2024). Kerala contributes the lion's share to India's nutmeg production, boasting the highest output compared to other regions in the country with a figure of 17.44 metric tonnes (Indiastat, 2024b).

Agriculture continues to evolve with increasing mechanization aimed at improving productivity and reducing labor-intensive practices. In crops like nutmeg, harvesting remains one of the most important and labor-intensive operations, since the crop at proper maturity stage will maintain their nutrients level as well as desirable quality. Marginal farmers in Kerala typically grow 100 to 200 nutmeg plants, with an average of 15 to 20 nuts maturing and dropping from the plants each day. Traditionally, nutmeg harvesting relies heavily on manual techniques like hand picking, by shaking the tree branches or by using long poles or climbing trees to collect the fruits. Yamagar and Dhande (2019) devised a nutmeg harvesting system, which was more efficient and economical than conventional harvesting techniques, comprising of a telescopic pole, a fruit harvester, a harvesting platform and

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a collecting net. During the peak season, it is difficult for farmers to harvest their entire field with harvesting tools as mature nutmeg plants can grow up to 18 meters tall with a wider canopy and thereby results in fruit abscission. The frequency of harvesting depends on the location of the field, the labour availability, productivity and the market price. Majority of the farmers are collecting the fallen nutmeg daily by hand picking in order to avoid its spoilage and thereby to maintain the quality of nutmeg mace and seed. This practice not only slows down the harvesting process but also exposes workers to significant ergonomic risks, including musculoskeletal disorders, fatigue and accidents related to prolonged overhead work and awkward postures (Nag *et al.*, 2013). In addition to the health and safety issues, these methods may also result in high labor, high energy

requirements, reduced productivity, time consumption, labor drudgery, etc. With the growing awareness of occupational health and safety in agriculture, there is an urgent need to adopt some alternative methods for nutmeg picking that may help to reduce labor discomfort and thereby improve productivity.

Ergonomics in agriculture plays a vital role by enhancing productivity, minimizing work-related strain and improving overall worker well-being (Salokhe and Gee-Clough, 2007; Benos *et al.*, 2020). Therefore, efforts should be made to assess the ergonomics involved in various postures taken by farmers while carrying out agricultural operations. There are numerous methods and techniques for the assessment of postural risk factors on labor (Ogedengbe *et al.*, 2023). The most common postural risk assessment tools include Rapid Upper Limb Assessment (RULA) (Chandra *et al.*, 2021), Rapid Entire Body Assessment (REBA) (Kamendra, 2025) (Das, 2023), Ovako Working Posture Analysis System (OWAS) (Kee 2021), Agricultural Lower Limb Assessment (ALLA) (Kong *et al.*, 2017), Agricultural Upper Limb Assessment (AULA) (Choi *et al.*, 2020) etc.

Agricultural workers suffer from MSDs over different body parts during the operation. This study aims to examine the hazardous elements of MSDs for each nutmeg picking method, viz. hand-picking and using a picking tool, with respect to workers' postural loads and self-reported discomfort through ergonomic intercession methods. The study was also intended to compare the ergonomic evaluation results of the different picking methods already mentioned.

MATERIALS AND METHODS

The picking device developed at the Department of Farm Machinery and Power Engineering, Kelappaji College of Agricultural Engineering and Food Technology (KCAEFT), Kerala Agricultural University, Thrissur, Kerala was ergonomically evaluated for nutmeg picking and it was compared with the manual hand picking methods by crouching and stooping. The picking tool used for this study is shown in Fig 1. The developed tool is a handheld device designed for picking nutmeg fruit or similar fruit from the ground. It consists of a hand-grip to hold the tool, a frame, an actuating lever connected internally to an actuating spring, a movable jaw, a fixed jaw and holding pads. While pressing the actuating lever, the movable jaw which was held away from the fixed jaw by the spring gets actuated and moves towards the fixed jaw to grasp the fruit in between holding pads. The collected fruit can be placed inside a carrier box by releasing the lever without any effort.

The experiments were conducted at Instructional Farm, KCAEFT, Tavanur, Malappuram, Kerala. The matured nutmeg plants in the orchard with 8 m × 8 m spacing were selected and experiments were carried out during the peak period of harvest with an average of 12-15 nuts fallen per plant per day. Ten subjects (male) were chosen and each one was instructed to carry out the nutmeg picking operation by conventional hand picking in stooping and crouching

posture as well as by using the picking tool. The subjects used for the experiment are aged between 25-50 years so that they represent the highest population of the farm workers. Prior to the experiment, it was confirmed that the selected subjects were in good health, had adequate sleep the previous night, had eaten meals and abstained from consuming beverages, tobacco, or engaging in recent physical activities. In order to achieve complete cooperation, the subjects were briefed the experimental procedure and acquainted with the operation. The physiological parameters and postural discomfort on the subject were noted during each trial. To perform the ergonomic evaluation of nutmeg picking operation, the physiological parameters, namely heart rate (HR) and oxygen consumption rate (OCR) and physical parameters like body part discomfort score (BPDS) and overall discomfort ratings (ODR) encountered by the subjects were determined for three operations: hand picking by bending (stooping), hand picking by sitting (crouching) and using picking device, as shown in Fig 2. The postural discomfort was assessed using Rapid Entire Body Assessment (REBA). Similarly, performance evaluation of the developed tool was conducted with respect to the number of nuts collected per unit time and was compared with conventional methods. The results obtained for both the conventional methods and the developed tool were then analyzed and compared for better interpretation and thus the ergonomically feasible methodology for nutmeg picking was suggested. Three replications of the data were collected and analyzed statistically.

Heart rate (HR) and Oxygen consumption rate (OCR)

Heart rate and oxygen consumption rate are commonly used as the parameters to measure physiological cost of work (Mehta *et al.*, 2022). HR is considered as an index of total stress on the body during work. The physical workload and the subject's physical work capability are closely

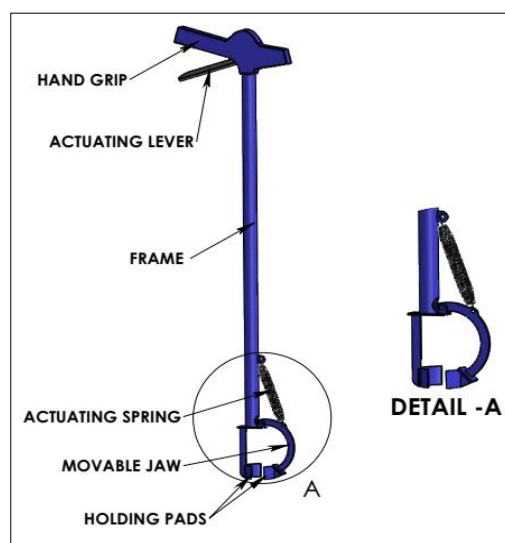


Fig 1: Nutmeg picking tool developed at KCAEFT.

correlated with the amount of strain indicated by their heart rate per minute. HR measurements can be used to compute the oxygen consumption during an operation. There exists a linear relationship between the HR and OCR. The quantity of oxygen intake used by the body per minute is represented by OCR.

In this study, the HR was monitored using a heart rate monitor (Model: - Polar H10) and the corresponding OCR was estimated using the equation 1 reported by Gite (2017) for male agricultural workers.

$$Y = 0.014 \text{ HR} - 0.80 \quad \dots(1)$$

Where,

Y= The oxygen consumption rate ($\text{l} \cdot \text{min}^{-1}$).

HR= The heart rate ($\text{beats} \cdot \text{min}^{-1}$).

A resting period of 15 minutes was provided for each subject before the commencement of the experiment and the corresponding resting heart rate was recorded. Thereafter observations were noted as the working heart rate, during the operation of 30 min. The difference in heart rate during work and rest period will indicate the increase in heart rate (ΔHR) of the subject and based on this ΔHR , work rest cycle can be recommended, if required (Chaudhary *et al.*, 2022).

Energy cost of operation

The physiological cost of any operation is determined by the cardio-respiratory response of subjects during work,

with the primary parameters measured *viz*; HR and OCR. The energy expenditure rate or energy cost of operation for each work (manual picking and picking using tools) can be calculated by multiplying the oxygen consumption rate and the calorific value of oxygen ($20.88 \text{ kJ} \cdot \text{l}^{-1}$) for all the subjects (Nag *et al.*, 1980; Aware *et al.*, 2017; Kumari *et al.*, 2022).

Postural discomfort

Discomfort in the body is mainly due to the improper working posture and thus causes excessive strain on muscles because of the effort involved in the activities. Body part discomfort score (BDPS) and overall discomfort rating (ODR) are the two methods used to assess body discomforts.

A ten-point physiological rating scale technique namely visual analogue discomfort scale, suggested by Borg, can be adopted to determine the overall discomfort rating (Chaudhary *et al.*, 2022). It is a 70 cm scale with 10 divisions separated by equal distance for representing the digits from 0 to 10 (0 being no discomfort, 10 being extreme discomfort). The rating was indicated using a movable pointer. The subjects were asked to rate their discomfort rating on the scale after performing the operation. The ODR of each subject was then added and averaged to obtain the mean value of discomfort rating in a particular operation.

BPDS, suggested by Corlett and Bishop (1976), provides a rating scale for the postural discomfort experienced by the worker with the help of a body map marked with 27 regions (Premkumari *et al.*, 2018;

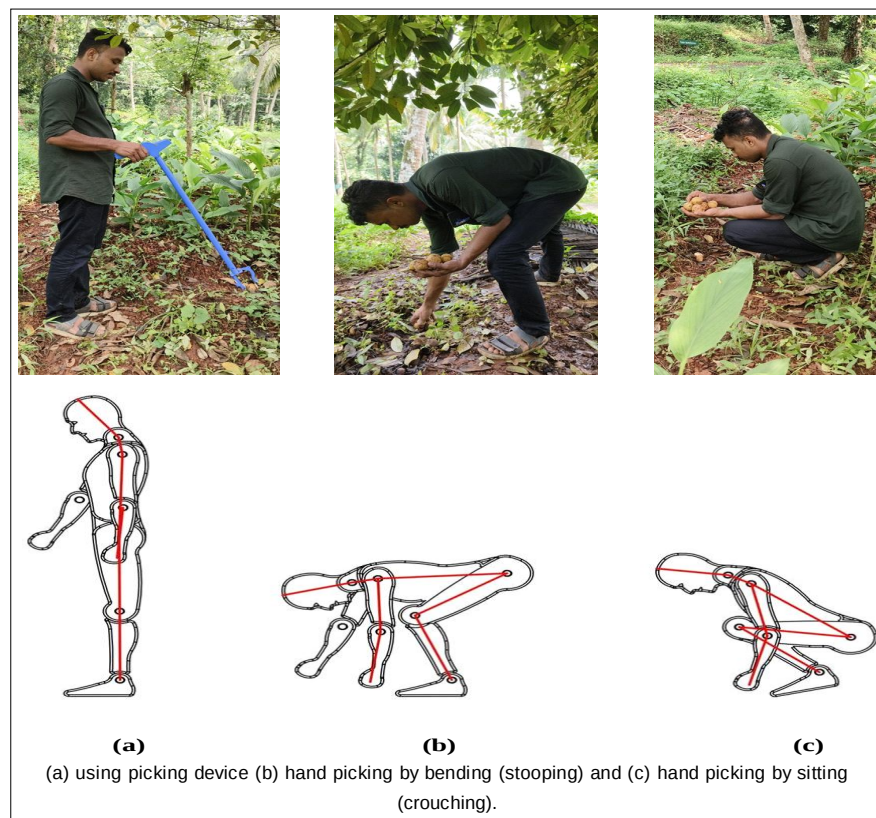


Fig 2: Different postures of nutmeg picking.

Chaudhary *et al.*, 2022). This BPDS value indicates the intensity of pain or discomfort experienced by the subject. After each operation, the subject has to mark the body parts experiencing discomfort, beginning with the extreme painful region, followed by the next most painful region and continuing in this order until no additional regions are identified. Different colored pins were used to categorize the body parts based on intensity levels of pain experienced, with the help of a body map. The body parts identified with extreme discomfort were pointed with red coloured pin while no discomfort with green coloured pin. Other colors were used to represent varying levels of pain intensity. These categories were given ratings in an arithmetic order. For example, if the experiment's maximum number of pain intensity categories was ten, the first category of body parts with the most pain were rated as "10," the second category of body parts with the next-highest pain were rated as "9," the third category's body parts with moderate pain were rated as "5," and so on, with the final category with no or little pain being rated as "1". Different subjects may experience pain in different categories. Each subject's body part discomfort score was calculated by multiplying the rating and the number of body parts associated with each category. The total body part score for a subject was determined by summing up the individual scores for all body parts assigned by that subject. In order to obtain the mean body discomfort score, the scores of all subjects were summed and averaged.

Postural analysis

Postural analysis can be a powerful technique for assessing work activities. Rapid Entire Body Assessment (REBA) is a postural assessment tool used to evaluate the work-related postural discomfort of individual workers by analyzing different working postures (Hignett and McAtamney, 2000; McOjha and Kwatra, 2014; Borah and Borah, 2020; Kee, 2021; Das, 2023). The photographs of various working posture were taken from the sagittal plane and different body angles inscribed in the posture were measured for further assessment. This assessment tool provides a rapid posture evaluation of upper arms, lower arms, wrist, trunk, neck and legs along with the impact of extraneous loads/force applied, muscle activity induced by static, dynamic or unstable postures and the interaction effect (Mehta *et al.*, 2022). A one page worksheet was utilized to determine the body posture, force and repetition. After complete posture analysis, the ranking of each posture was given by a score. Scores were entered for neck, trunk

and leg analysis along with force/load score in section A and arm and wrist analysis added with coupling score in section B. Based on the Score A and Score B, Score C will be obtained from a table which was added together with activity score to get the final REBA score. According to the final score, five action levels were provided to indicate the necessary actions required to ease the risks of injury due to physical loading on the worker. Table 1 indicates the various action levels of REBA representing the level of MSD risk and level of corrective action.

RESULTS AND DISCUSSION

Measurement of physiological parameters

Heart rate and oxygen consumption rate

The working heart rate (WHR) and ΔHR values of all subjects under various operating conditions are presented in Table 2. The WHR of subjects varied from 110 to 123 beats.min⁻¹ with an average WHR of 115.5 beats.min⁻¹ and 120 to 136 beats.min⁻¹ with an average WHR of 127.1 beats.min⁻¹ during manual hand picking of nutmeg in stooping and crouching posture respectively. According to the classification of work based on HR by Varghese *et al.* (1964), the manual method falls under the 'heavy' category. The average $\dot{A}HR$ values for both manual methods in stooping and crouching posture were determined as 38.4 beats.min⁻¹ and 49.2 beats.min⁻¹ respectively. On the other hand, the average WHR and ΔHR using the developed tool was 106.6 beats.min⁻¹ and 27.6 beats.min⁻¹ respectively which classify the work under 'moderate' category. From the Fig 3, it is evident that ΔHR of all the subjects is higher in manual picking methods than the developed tool. Among the two manual methods, $\dot{A}HR$ for crouching is higher than the stooping which might be because the operator has to sit for picking the nut, instead of stooping, after reaching the location and this process is repeated throughout the collection period. However, the efforts of operators are well reduced with the usage of developed picking tool. Within the same operation, significant differences in $\dot{A}HR$ can be observed within subjects. This may be due to the variation in age and physical conditions of different subjects.

The statistical analysis, in Table 3, indicates that the picking methods have a significant effect on the heart rate difference of each subject at 1% level of significance. The study also highlights that the significant variability in heart rate difference response between individuals at 5% level of significance might be due to the difference in the fitness level or experience. However, the interaction between

Table 1: REBA action levels (Hignett and McAtamney, 2000).

Action level	Score	Level of risk	Corrective action
Action level 0	1	Negligible risk	No action required
Action level 1	2-3	Low risk	Change may be needed
Action level 2	4-7	Medium risk	Further investigation required and change
Action level 3	8-10	High risk	Investigate and implement changes soon
Action level 4	11+	Very high risk	Investigate and implement changes immediately

replication, picking method and subjects has no relevance at 5% level of significance which indicates the combined effect of factors does not significantly impact heart rate difference.

The amount of OCR was calculated based on the WHR using equation 1. The average OCR of the selected subjects for stooping, crouching and using the developed tool were obtained as 0.82, 0.98 and 0.69 $\text{l}\cdot\text{min}^{-1}$, respectively. From the Fig 4, it is evident that OCR is less for the picking operation with the developed tool than the manual methods and follows the same trend as that of heart rate.

Energy expenditure rate (EER)

The average energy expenditure rate of the subjects for manual picking with stooping condition, crouching condition and using the developed tool were calculated as 17.06, 20.45 and 14.46 $\text{kJ}\cdot\text{min}^{-1}$, respectively. EER was higher for manual picking operations, especially under crouching, than the picking operation using the tool (as shown in Fig 5).

Postural discomfort

Overall discomfort rating (ODR)

The ODR of all the subjects for the different operations are presented in Fig 6. The ODR value ranged from 4 to 6 for the

subjects in manual picking operation under stooping, with an average ODR value of 4.7 which belongs to 'moderately discomfort' level. Similarly, the ODR for all the subjects ranges from 5 to 7 for manual picking operation under crouching and its average ODR was 5.9 which falls between 'moderately discomfort and more than moderate discomfort' category. However, the ODR for the nutmeg picking using the developed tool ranges from 1 to 2 for all subjects with an average ODR value of 1.4 which lies between 'no discomfort' and 'light discomfort' category. This improved method could reduce the fatigue caused during nutmeg picking operation than the conventional methods.

Body part discomfort score

The body map of musculoskeletal regions for analyzing BPDS under various operating conditions is shown in Fig 7. Maximum pain was experienced at the lower back, knee and thighs of subjects in the conventional methods. The BPDS for all the subjects ranges from 9 to 17 and 11 to 19 for manual picking under stooping and crouching conditions, respectively. Whereas, using the developed tool, the BPDS could be reduced to 4 to 6 and very light pain was felt only in the right hand palm, wrist and shoulder of the subjects due to continuous operation. This pain may be

Table 2: WHR and ΔHR (beats/min) values of all subjects for different operating conditions.

Subjects	Stooping		Crouching		Using picking tool	
	WHR (Beats/min)	ΔHR (Beats/min)	WHR (Beats/min)	ΔHR (Beats/min)	WHR (Beats/min)	ΔHR (Beats/min)
S1	110	36	120	44	105	25
S2	123	41	135	51	116	27
S3	121	41	134	49	106	23
S4	115	39	123	48	104	28
S5	113	40	122	48	104	31
S6	117	39	128	52	104	28
S7	110	31	124	47	104	28
S8	122	42	136	54	114	32
S9	112	37	125	51	103	27
S10	112	38	124	48	106	27
Avg	115.5	38.4	127.1	49.2	106.6	27.6

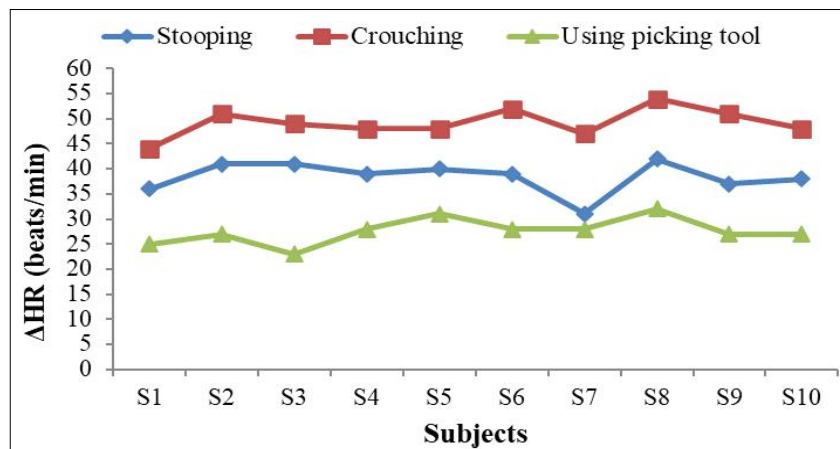


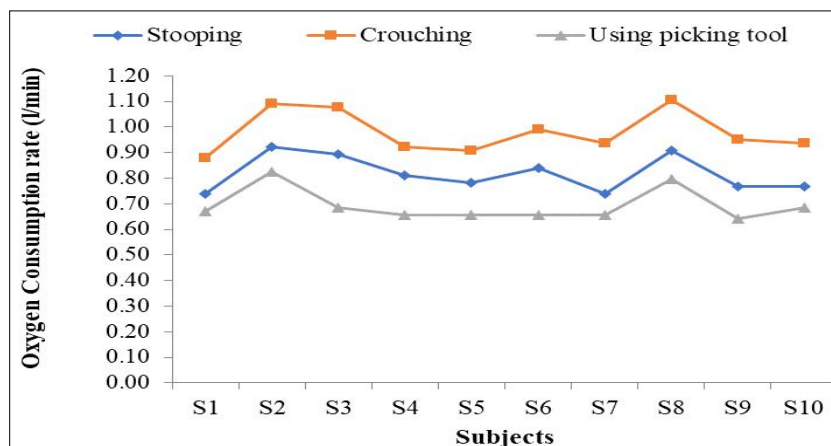
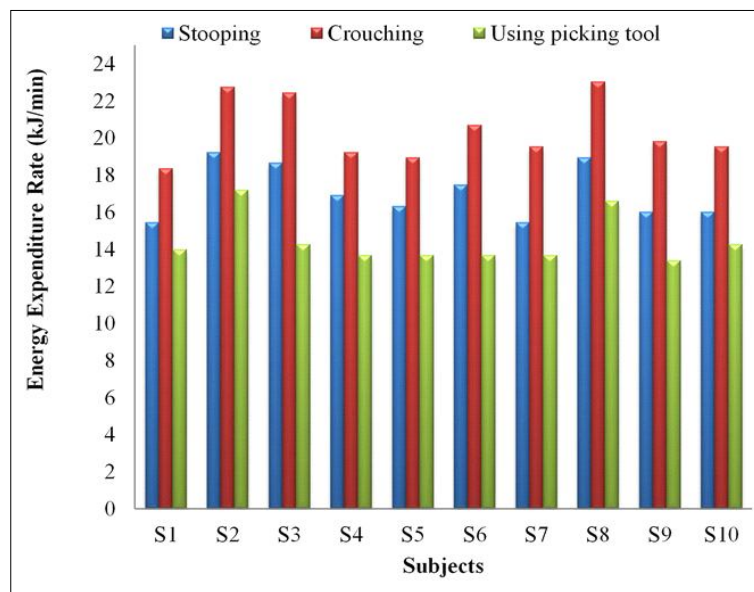
Fig 3: ΔHR values of all the subjects under different operating conditions.

Table 3: Statistical analysis results.

Source	Type III sum of squares	df	Mean square	F	Sig
Corrected model	8186.600 ^a	84	97.460	10.829	.007
Intercept	122885.770	1	122885.770	13653.974	<.001
Replication	70.044	2	35.022	3.891	.096
Picking method	6254.501	2	3127.251	347.472	<.001
Subjects	395.306	9	43.923	4.880	.048
Replication * Picking method	78.390	4	19.598	2.178	.208
Replication * Subjects	129.505	18	7.195	.799	.673
Picking method * Subjects	239.854	17	14.109	1.568	.326
Replication * Picking method * Subjects	273.588	32	8.550	.950	.596
Error	45.000	5	9.000		
Total	140942.000	90			
Corrected total	8231.600	89			

^aR Squared = .995 (Adjusted R squared = .903).

Dependent variable: Heart rate difference.

**Fig 4:** OCR values of all the subjects under different operating conditions.**Fig 5:** EER values of all the subjects under different operating conditions.

due to the tool weight and can also be eliminated by changing the material into a lighter weight.

Postural analysis using REBA

The average REBA scores of manual picking of nutmeg under stooping and crouching for all the subjects were 9 and 10 respectively. These scores indicate that both manual methods of nutmeg collection were at 'high risk' level and changes have to be implemented soon. Conversely, the average REBA score for nutmeg collection using the developed tool was 2 which appear to be 'low' risk level.

While using the developed tool, a negligible trunk and leg angle was observed but it was very high for both the manual methods. There was no significant difference found in neck angle for all the operations. After analyzing group A, the score A was obtained as 6, 7 and 1 for the operations under stooping, crouching and using the developed tool, respectively. Similarly, the analysis of group B which

consisted of arm and wrist analysis gives the value of score B as 4, 4 and 2 for the three operations respectively. Subsequently, the table C score was tabulated using Score A and B and thus the final REBA scores were obtained as 9 (stooping), 10 (crouching) and 2 (developed tool) as shown in Fig 8. The scores indicate that there was not much significant difference found between the manual methods but a commendable difference was found with respect to the developed method. The developed tool results in less fatigue than the other traditional manual picking methods, which confirms that the developed method is better than the traditional methods for nutmeg collection.

Performance evaluation of the developed tool

The number of nuts fallen differs from plant to plant and also in its maturity stages. The average number of nuts collected per unit time by conventional manual methods was 11 and 9 respectively (Fig 9). Though the collection

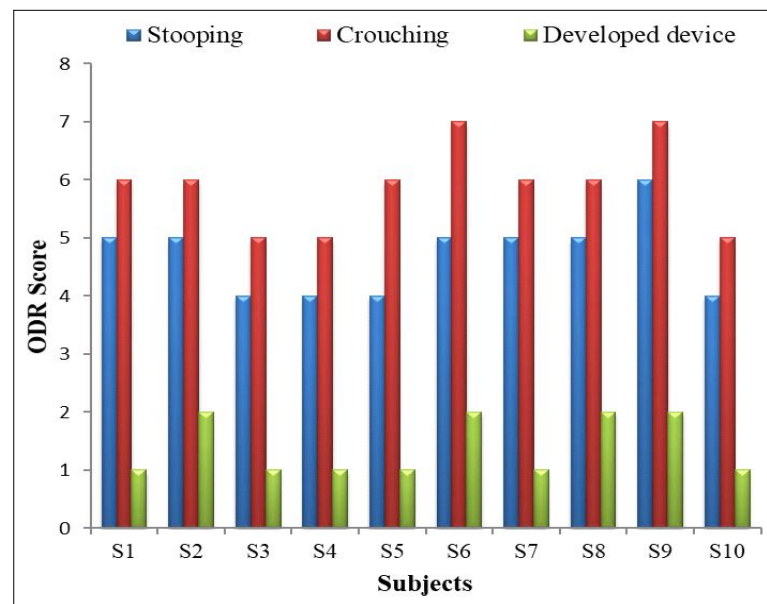


Fig 6: Overall discomfort rating (ODR).

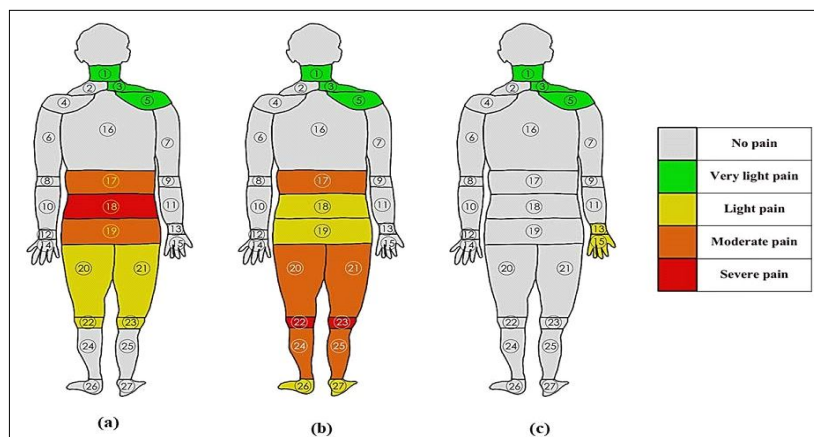


Fig 7: Body map of musculoskeletal regions for analyzing BPDS under (a) stooping; (b) crouching and (c) using developed tool.

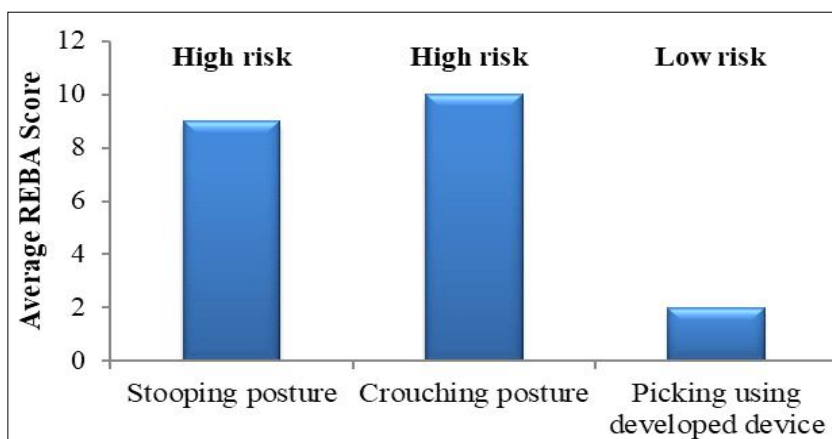


Fig 8: Final REBA score of all operations.

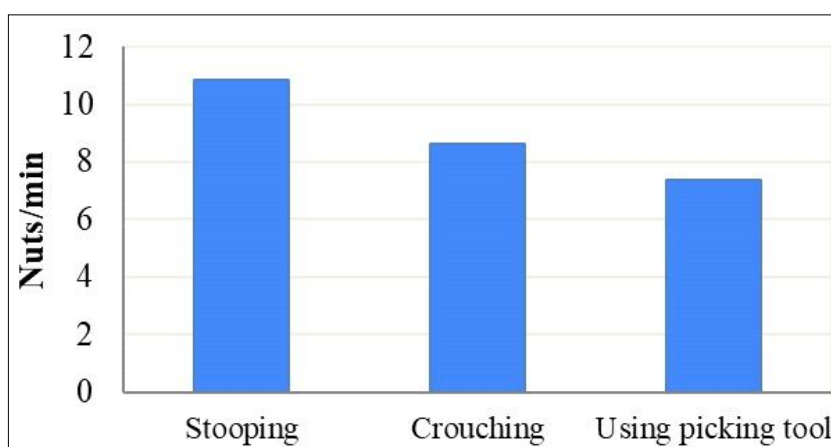


Fig 9: Nuts collection rate.

rate was comparatively lesser using the developed tool, *i.e.* 7, it is highly accepted by the operator in consideration with the ergonomic advantages incurred.

CONCLUSION

In this study, an ergonomic evaluation of a nutmeg picking tool was carried out and compared with the traditional collection methods. The results indicate that $\dot{A}HR$ of all the subjects is higher in manual picking operations than the developed tool. The average $\dot{A}HR$ values for manual methods in stooping and crouching were found to be 38.4 beats.min⁻¹ and 49.2 beats.min⁻¹ respectively and 27.6 beats.min⁻¹ using the developed tool. Similarly, the OCR values were obtained as 0.82, 0.98 and 0.69 l.min⁻¹ for all operations respectively. The average ODR value for all subjects was 4.7, 5.9 and 1.4 for picking operation under stooping, crouching and using the developed tool respectively. The maximum pain was experienced at the lower back, knee and thighs of subjects in the conventional methods whereas very light pain was felt in the right hand palm, wrist and shoulder with the developed tool while performing long trials. The average REBA score of 2 was obtained for the developed tool, which was lesser than that

of other manual picking methods. The developed tool results in less fatigue than the manual methods, which confirms that the developed tool is best suited for nutmeg collection. Even though the nut collection rate is lesser using the developed tool, it was found to be ergonomically more feasible than the manual nutmeg collection methods.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All procedures performed in studies involving human participants were in accordance with the ethical standards

of the institutional and/or national research committee. Informed consent was obtained from all individual participants included in the study.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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