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Ergonomic Evaluation of a Walking Type Power Operated Maize Stalk Harvester

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ABSTRACT

Background: Ergonomics is a science that focuses its study on improved design as a remedial measure to fatigue and discomfort in humans. Its objective is to optimize health, safety and productivity.

Methods: In the current study, an ergonomic evaluation of walking type power operated maize stalk harvester was done with traditional system.

Result: It was observed that the average working heart rate, working oxygen consumption rate, ODR, BPDS and, REBA score was 93.3 beats/min, 0.582 litre/min, 1.1 (uncomfortable), 23.5, 5.3 (medium risk) respectively. The working angles of different body parts like trunk, neck, leg, upper arm, lower arm and wrist were studied and are 9.1°, 7.3°, 41.8°, 23.6°, 48.2° and 7.9° for developed prototype respectively.

Key words: Body part discomfort score, Ergonomic, Heart rate, Maize stalk harvester, Overall discomfort rate, Rapid entire body assessment.

INTRODUCTION

Maize is a native crop of America. It was introduced to India by the Portuguese during the 17th century. It is grown in many parts of the country throughout the year. *Kharif* (monsoon) season is the main growing season in northern India. Maize is the third most important food grain in India after wheat and rice, with around 9.86 million ha area under this crop in the year 2020-21and 31.51 million tonnes annual production and 3195 kg/ha productivity (Agricultural Statistics at a Glance 2021). In India, about 28 per cent of produced maize is used for food purposes, about 11 per cent as livestock feed, 48 per cent as poultry feed, 12 per cent in the wet milling industry (for example starch and oil production) and 1 per cent as seed (Anonymous, 2007).

Maize extensive use is for livestock feeds: cattle poultry and piggery both in the form of seed and fodder. In most of the developing countries maize is consumed directly as food. In India, over 85 per cent of the maize production is used as food. The green fodder can be fed to milch cattle to boost the milk production of a considerable extent. The maize has to be harvested when the grains are in milky stage and is supposed to have lactogenic effect hence, especially suited for milch cattle. The digestability of maize fodder is higher than sorghum, bajra and other non-leguminous forage crops. Livestock production is the backbone of Indian agriculture contributing 7 per cent to National GDP and a source of employment and ultimate livelihood for 70 per cent of the population in rural areas.

In India, to cut and chop the fodder crop different types of self-propelled and tractor-mountedforage harvesters are available in the market which is fully mechanized. The major issue regarding the self-propelled machines is the very high cost. Their design is limited to a specific task. Hence these machines being so costly cannot be used for any other productive work. The high degree of automation in such machines makes it unpopular among the farmers. Proper training has to be given to the operator for precise work. The self-propelled machines thus are sophisticated considering the current scenario of a typical Indian farmer.

Tractor-mounted harvesters are popular among a handful of rich farmers. However, due to their overall size and the requirement of tractors, they are not used on small farms. The power requirement is high and a tractor above 40 HP is needed. Tractors are available for rent and a skilled

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operator is also available but our Indian farmers cannot even afford that, leading to their dependency on the traditional method of fodder harvesting by sickle resulting in the drudgery of labour, time-consuming, low work capacity and high labour cost. There is no appropriate small harvester to cut the stalk of maize after the cob is removed from the plant. Therefore, a small-size stalk harvester is an essential machine to reduce the cost of harvesting and reduce drudgery. To overcome these drawbacks a manually pushing type power operated small size maize stalk harvester was developed and its ergonomic evaluation was compared with the manual maize stalk harvesting.

MATERIALS AND METHODS

Detail of device

The equipment was developed to cut the stalks by a circular serrated blade with the principle of shear or impact. The power was transmitted from the engine to the blade through the flexible shaft. The manually pushing type maize stalk harvester was comprises of engine, handle, blade and shaft, crop support and wheels (Fig 1). The harvester for maize crop is operated by 1.8 kW two stroke petrol engine having 3600 idle ratedrpm and the engine is mounted on the main frame. The power is transmitted from the engine to the blade through the flexible shaft. The harvester is developed for single row harvesting of maize stalk and worked between rows of maize crop. Due to forward pushing of harvester by operator the rows are divided by row crop divider and guided to the cutting unit and after harvesting of maize stalk the harvested stalks are conveyed to the field by the windrowing attachment.

In order to carry out the ergonomic evaluation of the developed maize stalk harvester and traditional method of harvesting through sickle were examined based on the Physiological parameters (heart rate and oxygen consumption rate), Physical parameters **(**overall discomfort rating and body part discomfort Score) and postural musculoskeletal disorder (MSD) risk were calculated by REBA worksheet which takes into account body postures, forceful exertions, type of movement or action, repetition and couplings.

Physiological parameters

Heart rate (HR)

Heart rate is the primary indicator of circulatory function. It is determined by the number of heartbeats per unit time, typically expressed as beats per minute (beats/min). In this study, the heart rate was measured by computerized ambulatory metabolic measurement system ($K4b^2$). A chest belt transmitter senses the heartbeat and transmitsit to the $K4b^2$ unit which records the heart rate and was downloaded at the end of the experiment (Fig 2).

Oxygen consumption rate (OCR)

Oxygen consumption is the pertinent parameter for assessing the human energy required for performing various types of operations (Curteon,1947). Oxygen consumption is the amount of oxygen taken up and utilized by the body of a subject per minute. OCR is reported in absolute terms, l/min. Oxygen consumption is dependent on the ability of the heart to pump our blood, the ability of the tissues to extract oxygen from the blood, the ability to ventilate and the ability of the alveoli to extract oxygen from the air. OCR of ten subjects was measured with the help of the $K4b^2$ system which records oxygen consumed in every breath and results were downloaded at the endof the experiment (Fig 3).

Physical parameters

Overall discomfort rating (ODR)

For the assessment of overall discomfort rating, a 10-point psychophysical rating scale (0-no discomfort, 10-extreme discomfort) was used which is an adoption of Corlett and Bishop's (1976) technique. A scale of 70 cm in length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their overall discomfort rating on the scale. The values were tabulated. The overall discomfort ratings given by each of

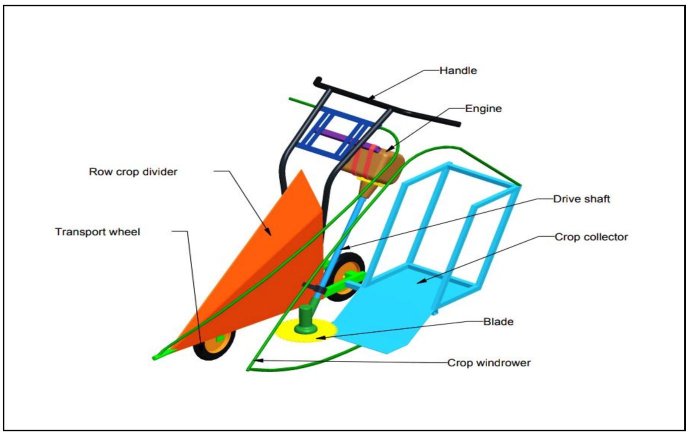

Fig 1: CAD view of developed prototype.

the ten subjects were added and averaged to get the mean rating (Fig 4).

Body part discomfort score (BPDS)

To measure localized discomfort, Corlett and Bishop's (1976) technique was used. In this technique, the subject's body was divided into 27 regions. The subject was asked to mention all body parts with discomfort, starting with the worst, the second worst and so on until all parts have been mentioned (Fig 5) (Lusted *et al*., 1994). The subject was asked to fix the pin on the body part in the order of one pin for maximum pain, two pins for next maximum pain and so on (Legg and Mohanty, 1985). The number of different groups of body parts, which were identified from extreme discomfort to no discomfort, represented the number of intensity levels of pain experienced. The number of intensity levels of pain experienced for the operation was categorized and ratings were assigned to these categories in an arithmetic order.

Postural assessment

Posture assessment tool was selected to compare the ergonomic performance of traditional maize stalk harvesting tool (sickle) by developed prototype. The posture assessment tool namely REBA was used to assess postural discomfort of the entire body.

REBA was proposed by Hignett and McAtamney (2000) as a means to assess posture to identify the risk of work related musculoskeletal disorders (WMSDs). Single page worksheet (Fig 6) was used to evaluate required body posture, force and repetition. Based on the evaluations, scores are entered for each body region in Group A for the trunk, Neck and Legs similarly in Group B for the Upper arm, Lower arm and Wrists. After the data for each region was collected and scored. Table 1 was used to compile the risk factor variables, generating a single score that represents the level of MSD risk.Force/Load required for harvesting by the manual method was measured by texture analyzer and force required to the developed harvester was measured by using load cell apparatus as shown in Fig 7.

Experimental procedure for measurement of physical and physiological parameter

The experiments were conducted in the maize field between 9:00 a.m. to 5:00 p.m. during the month of June 2019 which was planted in the month of December 2018. The ten subjects (male) were asked to harvest maize stalk with traditional and developed prototype. 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.

RESULTS AND DISCUSSION

The comparative ergonomic evaluation of developed prototype and traditional harvesting method was conducted by using heart rate (HR) oxygen consumption rate (OCR), overall discomfort rate (ODR), body part discomfort score (BPDS) and postural movements using the postural assessment tool REBA of the selected subjects.

Fig 2: Heart rate transmitter.

Fig 3: Installation of K4b^2 on the subject.

Fig 4: Overall discomfort rating.

Fig 5: Different body regions experiencing pain by subjects.

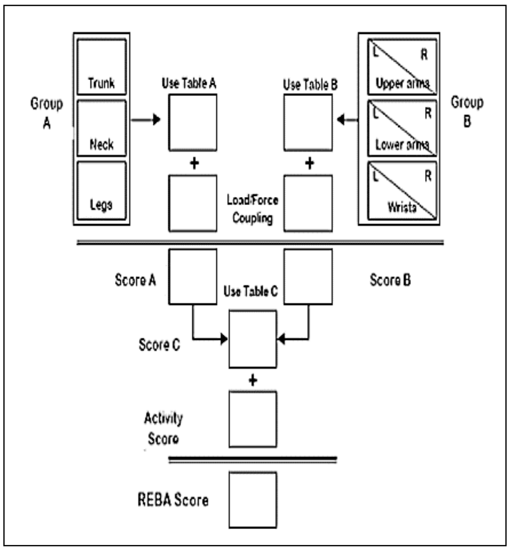

Fig 6: REBA scoring sheet.

Heart rate (HR)

The mean values of heart rate for all the subjects are furnished in Table 2. It was observed that there was a difference in the heart rate among the subjects performing the same operation under the same conditions with different harvesting technique.

From Table 2 the heart rate values during working time in manual harvesting by sickle varied from 101.8 beats/min to 112.4 beats/min with an average value 107.6 beats/min respectively. The heart rate values during working time with developed prototype varied from 85.7 beats/min to 99.6 beats/min with an average value of heart rate for ten subjects 93.3 beats/min respectively. The difference in working heart rate and resting heart rate *i.e.*, ΔHR by manual harvesting was 28.1 and by developed harvester was 13.6 respectively. The average data about the heart rate (beats/min) has been presented in Fig 8 and it can be stated that the mean heart rate for all subjects was higher in the case of manual harvesting operation of maize stalk by sickle in comparisons to the harvesting performed by the developed harvester.

Oxygen consumption rate (OCR)

The mean values of oxygen consumption rate for all the subjects are furnished in Table 2. Oxygen consumption rate values during working time in manual harvesting by sickle varied from 0.746 to 0.991 l/min, with an average value of 0.861 l/min, respectively. The oxygen consumption rate during working time harvesting by developed harvester varied from 0.467 to 0.654 l/min with average values of 0.582 l/min respectively. ΔOCR by manual harvesting was 0.489 and by developed harvester was 0.203 respectively. The average data about the oxygen consumption rate (l/min) has been presented in Fig 9.

From Fig 9 it can be concluded that the mean oxygen consumption rate for all subjects was higher in the case of manual harvesting operation of maize stalk by sickle in comparison to the harvesting performed by the developed harvester.

Overall discomfort rating (ODR)

According to ODR values suggested by Corlett and Bishop (1976), the ODR value ranged from 4 to 5 *i.e.*, from moderately painful to highly painful but the average ODR value is 4.1 as shown in Table 2 which comes into the moderately painful category when harvesting was done by sickle. The ODR value varied from 0 to 2 *i.e.*, from comfortable to pain starts but the average ODR value is 1.1 which comes into uncomfortable when harvesting was done by a developed harvester. The variation in mean ODR in different harvesting method is shown in Fig 10.

Body part discomfort score (BPDS)

The BPDS score showed a range of 18.4 to 46.0 with a mean value of 35.7 when harvesting of maize stalk was done by sickle. The maximum number of intensity levels of pain experienced by the subject was categorized into 4 categories. The majority of discomfort experienced by the workers was in the right elbow, right arm, lower back, right shoulder, knee and leg subjects during the maize stalk harvesting by sickle.

When harvesting of maize stalk was done by a developed harvester the BPDS score showed a range of

Table 1: REBA score and Risk level.

REBA score	Risk level
1	Negligible risk
2-3	Low risk, change may be needed
4-7	Medium risk, further investigation, change soon
8-10	High risk, investigate and implement change
11-15	Very high risk, implement change

17.5 to 36.8 with a mean value of 23.5. The majority of discomfort experienced by the workers was in the right arm, left arm, right shoulder and wrist of subjects during the maize stalk harvesting by the developed harvester. From Fig 11 it can be stated that the subjects feel more pain when harvesting was done by sickle compared to harvesting done by the developed harvester.

Evaluation of working postures

Fig 7: Texture analyzer and Setup for push force measurement

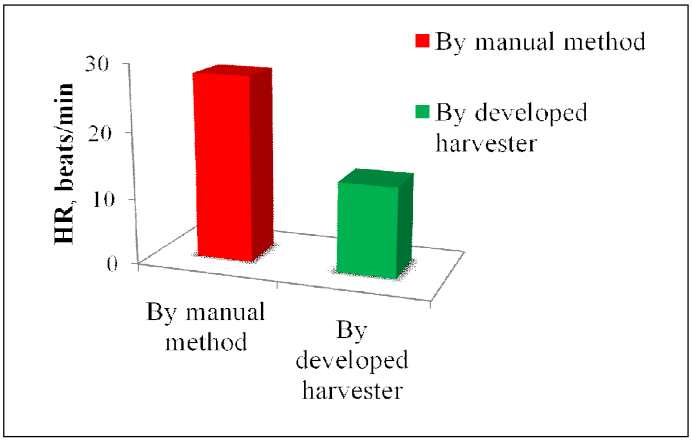

Fig 8: Heart rate during the harvesting operation.

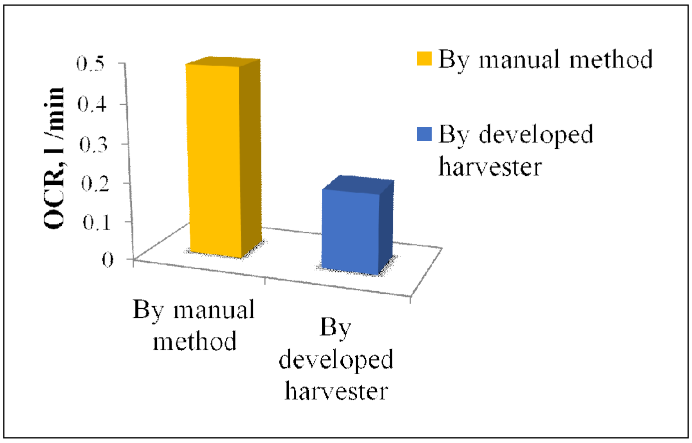

Fig 9: Effect of harvesting operation on oxygen consumption rate (l/min).

The average REBA score for traditional method was found to be 11.6 which shows that the working postures of the workers for traditional harvesting operation with the developed prototype was found in very high risk zone. On the other hand, the average REBA score for developed method was found to be 5.3 which shows that the working postures of the workers for maize stalk harvesting operation with developed method was found in medium risk zone (Table 3). In the developed method, the trunk, neck and leg angle was 9.1°, 7.3° and 41.8° respectivelybut in traditional

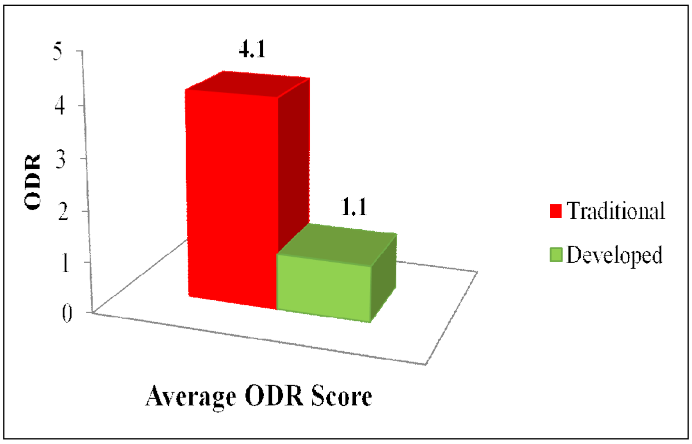

Fig 10: Average ODR Score.

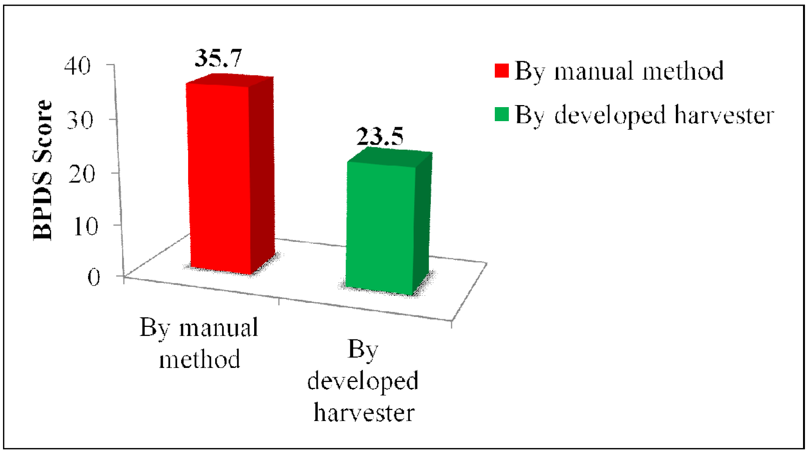

Fig 11: Effect of harvesting operation on BPDS score.

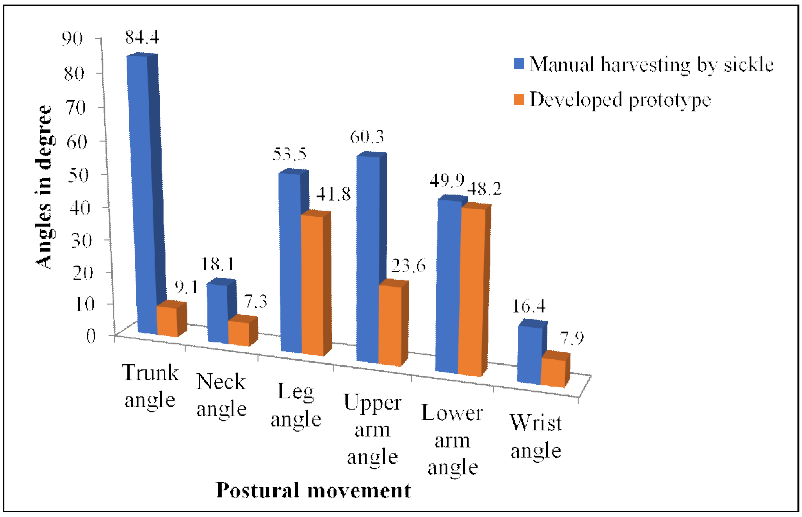

Fig 12: Average postural movement of subject with different angles.

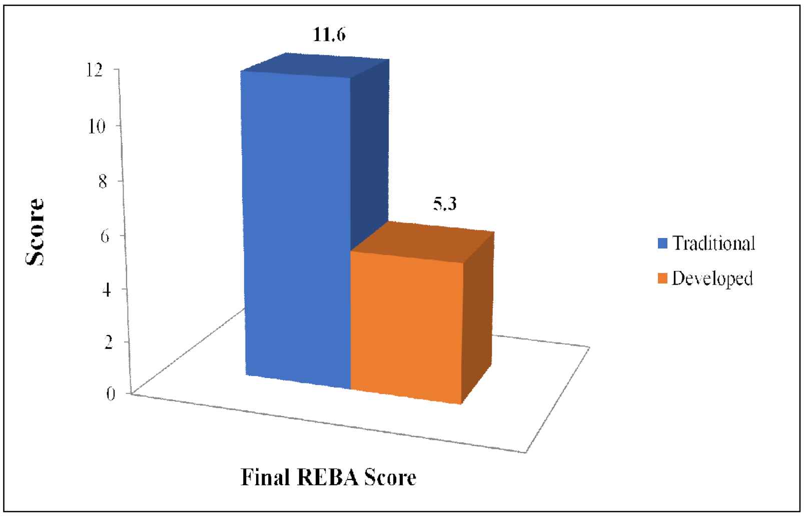

Fig 13: REBA Score.

(A) (B)

Fig 14: Walking type power operated maize stalk harvester.

Table 2: Heart rate (beats/min), OCR and ODR of the subjects in traditional and developed method.

Subjects	T_m		D_m		T_m		D_m		T_m		D_m	
	Working HR	ΔHR	Working HR	ΔHR	Working OCR	ΔOCR	Working OCR	ΔOCR	ODR	Score	ODR	Score
S_1	104.4	25.1	98.3	17.2	0.819	0.457	0.591	0.223	MP	4	C	0
S_2	111.7	30.3	92.9	12.9	0.848	0.466	0.498	0.122	MP	4	PS	2
S_3	112.4	34.1	89.2	10.6	0.991	0.534	0.621	0.154	HP	5	PS	2
S_4	102.7	21.5	85.7	10.1	0.850	0.463	0.611	0.224	SP	3	UC	1
S_5	104.6	23.8	93.1	12.7	0.870	0.438	0.570	0.149	HP	5	UC	1
S_6	111.2	31.4	88.4	12.1	0.747	0.389	0.647	0.289	MP	4	C	0
S_7	107.4	27.2	99.6	18.6	0.967	0.642	0.467	0.172	MP	4	PS	2
S_8	110.7	32.0	95.5	14.6	0.746	0.415	0.546	0.215	SP	3	UC	1
S_9	101.8	22.8	91.7	10.1	0.822	0.503	0.622	0.227	HP	5	UC	1
S_{10}	109.1	32.9	99.2	17.9	0.954	0.586	0.654	0.256	MP	4	UC	1
Average	107.6	28.1	93.3	13.6	0.861	0.489	0.582	0.203	MP	4.1	UC	1.1

*Tm= Traditional method, **Dm= Developed method, MP= Moderately painful, HP= Highly painful, SP= Slightly painful, PS= Pain start, C= Comfortable, UC= Uncomfortable, HR= Heart rate, OCR= Oxygen consumption rate.

Table 3: BPDS score and REBA of the subjects in traditional and developed method.

Subjects	BPDS Score		REBA			
	T_m	D_m	T_m		D_m	
S_1	31.5	36.8	13	VH	4	MR
S_2	46.0	22.5	12	VH	5	MR
S_3	35.1	21.0	11	VH	5	MR
S_4	25.5	17.5	10	HR	5	MR
S_5	46.0	20.0	13	VH	6	MR
S_6	36.8	24.0	12	VH	5	MR
S_7	44.0	22.5	12	VH	6	MR
S_8	18.4	27.0	10	HR	5	MR
S_9	40.0	21.0	11	VH	7	MR
S_{10}	33.3	22.5	12	VH	5	MR
Average	35.7	23.5	11.6	VH	5.3	MR

*Tm= Traditional method, Dm= Developed method, VH= Very high, HR= High risk, MR= Medium risk.

method it was very high *i.e*. 84.4° for trunk, 18.1° for neck and 53.5° for leg respectively. Also, the upper arm, lower arm and wrist angle of 23.6°, 48.2° and 7.9° respectively for the developed prototype were comparatively low with the traditional method *i.e*. 60.3°, 49.9° and 16.4° respectively (Fig 12). There is a significant difference in both the methods. The improved method Fig 14. Causes less fatigue to perform themaize stalk harvesting operation than traditional harvesting method, which shows that the developed method is betterthan the traditional method.

REBA Scores obtained in harvesting by sickle and developed harvester are 11.6 and 5.3 respectively which fall in the high-risk level category, implement change and medium-risk categories respectively. Fig 13 clearly depicts that the score of REBA for developed prototype is significantly lower than the traditional method of harvesting. The posture should be omitted to reduce the risk level and to eliminate the MSDs on subjects in manual harvesting operations. It is also revealed that using the developed harvester for operations falls in the medium risk category with an average REBA score of 5.3 which states that further investigation is required.

CONCLUSION

In the study of ergonomic evaluation of walking type power operated maize stalk harvester (Fig 14 A, B) the physiological responses (HR_{work} and OCR_{work}) values were observed to be 107.6 beats/min and 93.3 beats/min and 0.861 l/min and 0.582 l/min respectively, when harvesting was done by sickle and developed harvester respectively. Physical responses (ODR and BPDS) scores were minimum and the operator feels more comfortable when harvesting was done by a developed harvester than with the sickle. The average REBA score obtained for manual maize stalk harvesting by sickle was 11.6 resulting in a very high-risk level. REBA score by the developed harvester was 5.3 which results in a medium risk levelhence developed harvester was feasible and can be recommended for maize stalk harvesting operation as it reduces drudgery to the operator and can also be easily operated by farm women.

Conflict of interest: None.

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