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Ergonomic assessment of manual maize stalk harvesting

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Abstract
Manual harvesting of maize stalks by sickle involves repeated bending, stretching and standing postures while operation. The subject has to harvest the crop from the bottom of stalks which involve repeated bending posture and harvested stalk should be leaves as swaths in the field which involve repeated standing and stretching postures. Harvesting of maize by sickle is very drudgery prone and causes pain in different region of subject body. The aim of study is to conduct the ergonomical assesment of different subjects during the harvesting of stalk. The parameters Heart rate (HR), Oxygen consumption rate (OCR), Overall discomfort rate (ODR), Body part discomfort score (BPDS) and Postural assessment (REBA) are considered during the ergonomical assessment of subjects. Physiological responses (HR and OCR) values are falls under "moderate heavy" category. Average ODR score is 4.1 which comes into moderately painful category. BPDS score showed a range of 18.4 to 46.0 with mean value of 35.7. The majority of discomfort experienced by the workers was in the right elbow, right arm, lower back, right shoulder, knee and leg of subjects. The average REBA score obtained was 11.6 harvesting which results in very high risk levels. It was suggested that the manual harvesting of maize stalk was drudgery prone and change must be needed.

Keywords: Oxygen consumption rate, overall discomfort rate, body part discomfort score, postural assessment

1. Introduction
Maize is native of America. It was introduced to India by Portuguese during 17th century. Its cultivation in India dates back to the Maratha Empire. India has 5 percent of corn acreage and contributes 2 per cent of world production. Maize is the third most important food grain in India after wheat and rice. It is also an important cereal crop of India with around 9.43 million ha area under this crop in the year 2013-14 and 24.35 million tonnes annual production and 2583 kg/ha productivity (Anonymous, 2014) [2]. The most suitable temperature for germination is 21 °C and for growth 32 °C (Anonymous, 2007) [1]. Maize requires fertile, pH of the soil range 7.5 to 8.5, sown in rows 60-75 cm apart, plants in the row are spaced at 20 to 25 cm.
Cobs which are to be utilized as grain should be harvested when the grains are almost dry or containing less than 20 percent moisture. For sweet corn harvesting, harvest when tassels begin to turn brown and cobs start to swell. For the Baby corn, harvested young cobs, especially when the silks have either not emerged or just emerged, and no fertilization has taken place. Maize grown for fodder should be harvested at the milk to early dough stage.
In India generally maize stalk harvesting is done by manual labours resulting in physical, physiological and postural discomfort to the labours.

2. Materials and Methods
Ergonomical evaluation of manual maize stalk harvesting by sickle
Parameters measured during the ergonomic evaluation of manual maize stalk harvesting are

- Physiological parameters like heart rate (HR) and oxygen consumption rate (OCR) are measure with the help of Computerized Ambulatory Metabolic System (K4b^2).
- 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) [4] technique.
- Body Part Discomfort Score (BPDS) was calculated using Corlett and Bishop's (1976) [4] technique.

- The postural musculoskeletal disorder (MSD) risk was calculated by using the REBA worksheet which takes into account body postures, forceful exertions, type of movement or action, repetition and couplings.

Subject selection

Selection of subjects plays an important role in conducting the ergonomic investigations. According to Gite and Singh (1997) [6] the maximum strength/ power can be expected from the age group of 25 to 35 yrs. Similarly, Grandjean (1982) [7] reported that the maximum percentage of work could be expected during 20 to 35 years. Considering this a healthy age group ranging 20-35 years free from any physical abnormalities and were under sound health condition, at the time of experiments was selected for maize stalk harvesting operations. Ten male agricultural subjects of the age group were randomly selecting for the study.

Measurement of basic physical characteristics of the subjects

Basic physical characteristics of the subjects namely age, weight and stature were measured in the laboratory. Personal weighing scale (100 kg capacity) was used for the measurement of weight. Stature was measured using stadiometer.

Fig 1: Measurement of weight of different subjects

2.1 Physiological parameters

Heart rate

Heart rate is the primary indicator of circulatory function. It is determined by the number of heart beats per unit time, typically expressed as beats per minute (beats/min). In this study the heart was measured by Computerized Ambulatory Metabolic Measurement System ($K4b^2$). A chest belt transmitter sense the heart beat and transmit to the $K4b^2$ unit which is recording the heart rate and can be downloaded at the end of experiment.

Fig 2: Heart rate transmitter

Oxygen consumption rate (OCR)

Oxygen consumption is the pertinent parameter for assessing the human energy required for performing various types of operations (Curteon, 1947) [5]. Oxygen consumption is the amount of oxygen taken up and utilized by the body of subject per minute. OCR is used to determine how much energy a subject is expending. OCR is reported in absolute term ml/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 $K4b^2$ system which records oxygen consumed in every breath which can be downloaded at the end of experiment.

2.2 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 (1976) [4] technique. A scale of 70 cm 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 was asked to indicate their overall discomfort rating on the scale. The overall discomfort ratings given by each of the ten subjects were added and averaged to get the mean rating.

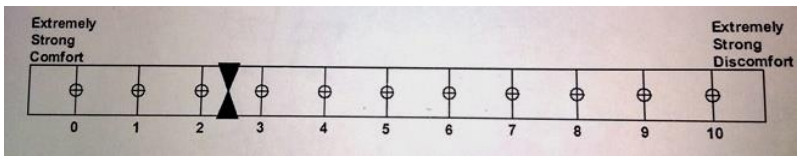

Fig 3: ODR scale

Body part discomfort score (BPDS)

To measure localized discomfort, Corlett and Bishop (1976) [4] technique was used. In this technique the subject's body was divided into 27 regions shown in the Fig.4. A body mapping similar to that of body mapping was made with thermocoal to have a real and meaningful rating of the perceived exertion of the subject. 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 (Lusted *et al*., 1994) [10]. 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) [9]. 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 were categorized and rating

were assigned to these categories in an arithmetic order as explained below:-

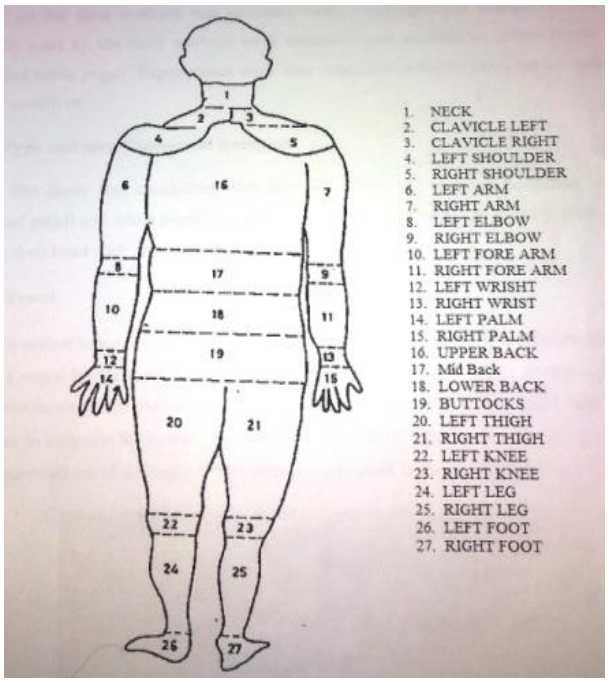

Fig 4: Regions for evaluating body part discomfort score

The body parts experiencing pain are counted say 'X'. As mentioned above, the pain intensity levels are also counted say 'N'. The discomfort/pain rating was calculated as X/N. The group of body parts experiencing maximum pain was allotted rating as 'X', The next maximum pain rating was 'X-X/N', so on with last pain rating as 'X/N'. The body part discomfort score of each subject will be the rating multiplied by the number of body parts corresponding to each category. The total body part score for a subject will be the sum of all individual scores of the body parts assigned by the subject. The body discomfort score of all the subjects is to be added and averaged to get mean score. The same procedure was repeated for all the selected subjects.

Fig 5: Body regions experienced pain

2.3 Postural assessment

A good posture is one, which requires minimum of static muscular effort hence the work performed will be better and the body discomfort will be less. Postural discomfort is the discomfort experienced by the subject because of muscular pain to maintain the body posture during the operation.

Postural analysis can be done by using ergonomical tools like RULA and REBA. In the present study, REBA was used to assess posture of entire body while performing a harvesting operation.

This ergonomic assessment tool uses a systematic process to evaluate whole body postural MSD and risks associated with job tasks. A single page worksheet is used to evaluate required or selected body posture, forceful exertions, type of movement or action, repetition, and coupling. Using the REBA worksheet, a particular score is assigned for each of the following body regions: wrists, forearms, elbows, shoulders, neck, trunk, back, legs and knees. The REBA worksheet is divided into two body segments labeled as Group A and Group B.

Group A (Left side) covers the neck, trunk, and leg. Group B (Right side) covers the arm and wrist as shown in the Fig 6. This segmenting of the worksheet ensures that any awkward or constrained postures of the neck, trunk or legs which might influence the postures of the arms and wrist are included in the assessment. For each region, there is a posture scoring scale plus the additional adjustments which are considered and accounted for in the score. Then score the Load/Force and Coupling factors. Finally, score the Activity.

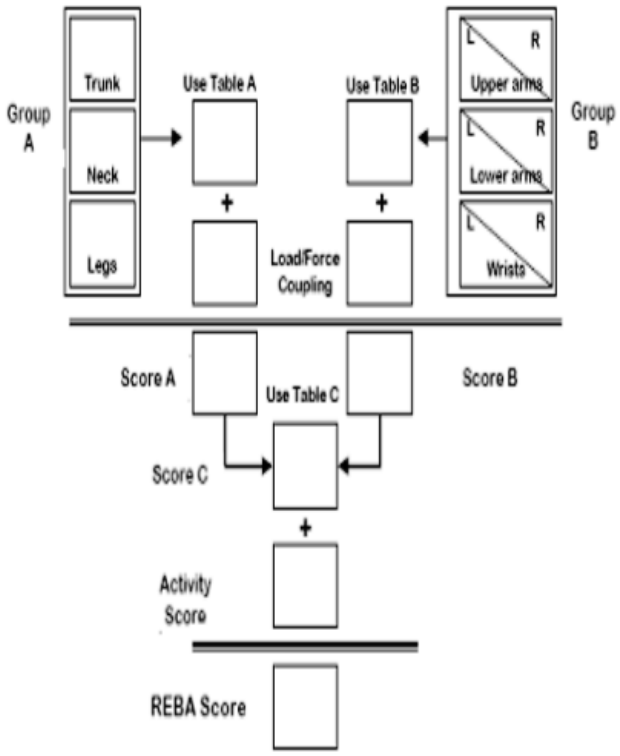

Fig 6: REBA scoring sheet

Working postures involved during manual harvesting of maize stalk

Manual harvesting of maize stalks by sickle involves repeated bending, stretching and standing postures while operation. The subject has to harvest the crop from the bottom of stalks which involve repeated bending posture and harvested stalk should be leaves as swaths in the field which involve repeated standing and stretching postures. Harvesting of maize by sickle is very drudgery prone and causes pain in different region of subject body.

Fig 7: Working postures involves during manual harvesting of maize stalk

3. Results and Discussion

3.1 Physiological responses of subjects for harvesting operation

Experiments were carried out to assess the physiological responses as explained in the section 2.4 of the subjects namely heart rate (beats/min) and oxygen consumption rate (l/min).

Heart rate

The mean values of heart rate for all the subjects are furnished in Table 1. It was observed that there was a difference in the heart rate among the subjects performing the same operation under the same conditions due to difference in subject's age, weight and stature.

Table 1: Working heart rate during harvesting operation

Subject	Resting HR	Working HR	$\Delta HR = HR_{working} - HR_{resting}$
S_1	79.3	104.4	25.1
S_2	81.4	111.7	30.3
S_3	78.3	112.4	34.1
S_4	81.2	102.7	21.5
S_5	80.8	104.6	23.8
S_6	79.8	111.2	31.4
S_7	80.2	107.4	27.2
S_8	78.7	110.7	32.0
S_9	79.0	101.8	22.8
S_{10}	76.2	109.1	32.9
average	79.4	107.6	28.1

From Table 1 the heart rate values during resting and working time in manual harvesting by sickle varied from 76.2 to 81.4 beats/min and 101.8 beats/min to 112.4 beats/min, with average value of heart rate for ten subjects were 79.49 and 107.6 beats/min, respectively. The difference in working heart rate and resting heart rate i.e. ΔHR by manual harvesting was 28.1 beats/min.

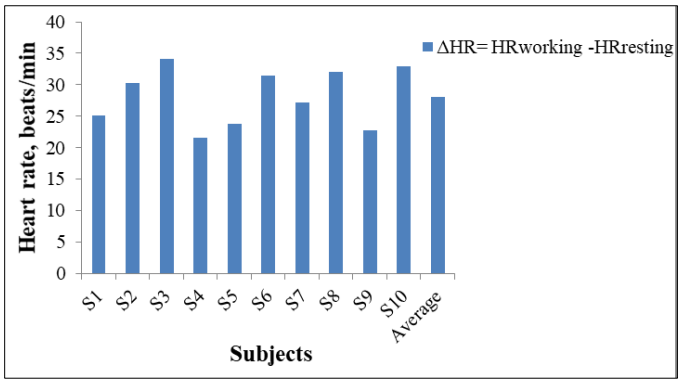

Fig 8: Difference in heart rate of subjects

Oxygen consumption rate

The mean values of heart rate for all the subjects are furnished in Table 2.

Table 2: Oxygen consumption rate during harvesting operation

Subjects	Resting OCR	Working OCR	$\Delta OCR = OCR_{working} - OCR_{resting}$
S_1	0.362	0.819	0.457
S_2	0.382	0.848	0.466
S_3	0.457	0.991	0.534
S_4	0.387	0.850	0.463
S_5	0.432	0.870	0.438
S_6	0.358	0.747	0.389
S_7	0.325	0.967	0.642
S_8	0.331	0.746	0.415
S_9	0.319	0.822	0.503
S_{10}	0.368	0.954	0.586
Average	0.372	0.861	0.489

From Table 2 the oxygen consumption rate values during resting and working time in manual harvesting by sickle varied from 0.319 to 0.457 l/min and 0.746 to 0.991 l/min, with average value of oxygen consumption rate for ten subjects were 0.372 and 0.861 l/min, respectively. The difference in working oxygen consumption rate and resting oxygen consumption rate i.e. ΔOCR by manual harvesting was 0.489 l/min.

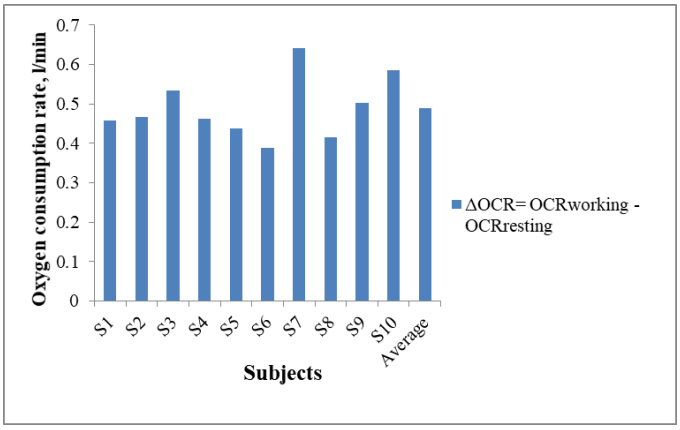

Fig 9: Difference in Oxygen consumption rate of subjects

The work load was classified as the values obtained for harvesting operations from Table 1 and 2 on the basis of Sen (1969) as shown in Table 3 considering Heart rate (beats/min) and Oxygen consumption rate (l/min).

Table 3: Classification of work load

Mode of work	HR (beats/min)	OCR (l/min)
Very light	< 75	< 0.35
Light	75-100	0.35-0.70
Moderate heavy	100-125	0.70-1.05
Heavy	125-150	1.05-1.40
Very heavy	150-175	1.40-1.75
Extremely heavy	>175	>1.75

From Table 3 it can be stated that average working heart rate and oxygen consumption rate for harvesting of maize stalk by sickle could be scaled in "moderate heavy" category.

3.2 Physical responses of subjects for harvesting operation of maize stalk Experiments were carried out to assess overall discomfort rating (ODR) and body part discomfort score (BPDS) experienced by the subjects.

Overall discomfort rating (ODR)

The subjects were allowed to perform maize stalk harvesting operation by sickle. The Overall Discomfort Rating (ODR) of each of the ten subjects was measured as explained in the section 2.5 and the values are presented in Table 4.

Table 4: ODR experienced by the subjects during harvesting operation

Subjects	By sickle	
	Subject feelings	Score
S_1	Moderately painful	4
S_2	Moderately painful	4
S_3	Highly painful	5
S_4	Slightly painful	3
S_5	Highly painful	5
S_6	Moderately painful	4
S_7	Moderately painful	4
S_8	Slightly painful	3
S_9	Highly painful	5
S_{10}	Moderately painful	4
Average	Moderately painful	4.1

According to ODR values suggested by Corlett and Bishop (1976) [4] shown in Fig.3 the ODR value ranged from 4 to 5 i.e. from moderately painful to highly painful but the average ODR value is 4.1 which come into moderately painful category when harvesting was done by sickle.

Body part discomfort score (BPDS)

The subjects were allowed to perform harvesting operation of maize stalk by sickle. Based on the Corlett and Bishop (1976) [4] regional discomfort technique, body part discomfort score for the harvesting of maize stalk were calculated. The values of Body Part Discomfort Score (BPDS) of the ten subjects are presented in Table 5.

Table 5: BPDS experienced by the subjects during harvesting operation

Subjects	BPDS score
S_1	31.5
S_2	46.0
S_3	35.1
S_4	25.5
S_5	46.0
S_6	36.8
S_7	44.0
S_8	18.4
S_9	40.0
S_{10}	33.3
Average	35.7

From Table 5 when harvesting of maize stalk was done by sickle the BPDS score showed a range of 18.4 to 46.0 with mean value of 35.7. The maximum numbers of intensity levels of pain experienced were of 4 categories. The majority of discomfort experienced by the workers was in the right elbow, right arm, lower back, right shoulder, knee and leg of subjects during the maize stalk harvesting by sickle.

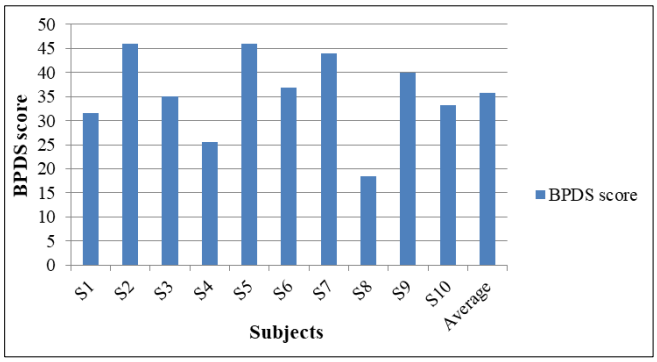

Fig 10: BPDS score of subjects

3.3 Evaluation of working postures

For postural risk assessment, limb and body movements were analyzed for maize stalk harvesting operation. For harvesting operation, the angles obtained in different working postures and the risk level associated with the posture was measured as explained in the section 2.6 and the values are given in the following Table 6.

Table 6: Measurement of working postures of the subjects during operation

Subjects	Group A parameters			Group B parameters		
	Trunk angle	Neck angle	Leg angle	Upper arm angle	Lower arm angle	Wrist angle
S_1	87	19	40	58	62	13
S_2	83	18	43	66	48	17
S_3	78	15	65	50	35	15
S_4	84	17	55	55	45	13
S_5	88	21	45	63	42	19
S_6	76	19	63	57	56	20
S_7	82	18	52	58	38	18
S_8	94	21	62	71	53	13
S_9	87	16	45	60	58	17
S_{10}	85	17	65	65	62	19
Average	84.4	18.1	53.5	60.3	49.9	16.4

In harvesting operation, the REBA Score is calculated based on the angles obtained by assessing the different working postures. The obtained REBA Score and risk level of subjects for both harvesting methods is given in Table 7 the respectively.

Table 7: REBA score obtained in harvesting operation

Subject	Manual harvesting by sickle	
	REBA Score	Risk level
S_1	13	Very high
S_2	12	Very high
S_3	11	Very high
S_4	10	High risk
S_5	13	Very high
S_6	12	Very high
S_7	12	Very high
S_8	10	High risk
S_9	11	Very high
S_{10}	12	Very high
Average	11.6	Very high

From Table 7 the average REBA Scores obtained in harvesting by sickle was 11.6 which fall in high risk level category, implement change. The posture should be omitted in order to reduce the risk level and to eliminate the MSDs on subjects in manual harvesting operation.

4. Conclusion

1. Physiological responses (HR and OCR) values are falls under "moderate heavy" category.
2. Average ODR score is 4.1 which comes into moderately painful category during the manual maize stalk harvesting.
3. BPDS score showed a range of 18.4 to 46.0 with mean value of 35.7. The majority of discomfort experienced by the workers was in the right elbow, right arm, lower back, right shoulder, knee and leg of subjects during the manual maize stalk harvesting by sickle.
4. The average REBA score obtained for manual maize stalk harvesting by sickle results in very high and high risk levels. It was concluded that the harvesting operation was drudgery prone and change must be needed.

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