Ergonomic evaluation of electric hedge trimmer using digital human modeling

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Abstract: Maintenance of gardens in public and owned premises is becoming costlier. The traditional ways of garden trimming requiring manual labor are becoming obsolete and electric trimmers are extensively being used in maintenance of gardens. While carrying out trimming activity with electric hedge trimmer, operator undergoes various awkward posture(s) resulting into musculoskeletal disorders. The present study is undertaken to evaluate existing electric hedge trimmer workstation and suggest suitable modifications in order to reduce drudgery. The study uses anthropometric data from the literature for the user population for modeling of manikin. The concept of digital human manikin (DHM) is used for modeling and simulation purpose. Here DHM tools in CATIA software such as Rapid Upper Limb Assessment (RULA), carry analysis and biomechanics analysis are used for the analysis. Study presents ergonomic evaluation of farm worker(s) in Maharashtra state of India operating electric hedge trimmer. RULA score of 6-7 showed that existing electric hedge trimmer workstation is not safe for workers and must be changed soon or immediately. However, carry analysis depicted that existing weight of trimmer is acceptable. Biomechanics single action analysis showed considerable values of moments and forces coming on the various joints and body parts. The study suggested new improved workstation for the electric hedge trimming operation on the basis of the RULA and biomechanics analysis. The improved workstation not only reduced RULA score to acceptable limit but also significantly reduced values of moments and forces coming on the body of worker. Thus, the study explored the potential of DHM technique in the product design, especially in ergonomic design of new workstations or to improve existing workstations.

Keywords: CATIA, digital human modeling (DHM), ergonomics, hedge trimming

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1 Introduction

In India, most of the homes and public places are decorated by gardens (Figure 1a). One of the important components of maintenance cost is trimming or cutting of shrubs in the garden to give them attractive shape or to restrict their unwanted growth. This shrub trimming tasks are mostly performed by agricultural and other workers. In India, day by day workers have been decreasing due to people's mindset, government policies, occupational change and reforms. Various equipments and machineries are required in the maintenance of the gardens. Hedge trimmer is ideal for work on small bushes and shrubs. A hedge trimmer, shrub trimmer, or bush trimmer, is a gardening tool or machine used for trimming shrubs to give them an attractive look and restrict unwanted growth. It is desirable that this trimming activity should be economical, quicker and trouble free.

There are different hedge trimmers in the market today depending upon the power source such as human power, gasoline, or electricity. Manual hedge trimmers (hedge shears or hedge clippers) are designed as large scissors or large pruning shears (Figure 1b). They are cheap and most environmentally friendly but involve heavy labor and operation is time consuming

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(Kuijt-Eversa et al., 2004; Singh and Arora, 2010). Gasoline-powered trimmers are powerful but are bulky and harder to start (Figure 1c). Electrical trimmers are light weight and less polluting/noisy (Figure 1d). Source of power to these trimmers is either electricity or rechargeable batteries. Batteries are generally mounted on operator body to reduce load coming on hands. Thus, electrical trimmers are light in weight, save time and labor, quieter in operation and pollution free and hence mostly preferred. Due to employee retention problem, today's industries are forced to pay attention to the physical comfort of the worker in working environment which in turn leads to increased efficiency of the industry. In such situations, ergonomics plays a major role (Singh and Singh, 2014; Vyavahare and Kallurkar, 2012; Yadav and Pund, 2007; Gilad and Byran, 2007).

Figure 1 (a) – Workplace; (b) – Hedge trimming by hedge clipper; (c) – Hedge trimming by gasoline-powered hedge trimmer; (d) – Hedge trimming by electric hedge trimmer

2 Materials and methods

The study is divided into four phases of work. The first phase involved selection of anthropometric data of the user population from the literature (Vyavahare and Kallurkar, 2015). The second phase involved visiting premises to understand hedge trimming operation by electric hedge trimmers and knowing the trimming process. This involved video recording of the working environment in the garden. The third phase of this study aimed at designing the existing workplace for various postures taken by operator in trimming process using CATIA software. In this phase, DHM and hedge trimmer model were developed. The fourth and final phase involved ergonomic analysis of the existing workplace for awkward postures attained by operator during trimming activity and provided inputs for improvement of the workstation of the hedge trimming activity (Dooley, 2012; Sanjog et al., 2012; Somasundaram and Srinivasan, 2010).

2.1 Anthropometric dimensions

For the analysis of trimmer male operators ranging 5^{th} to 95^{th} percentile are considered. The brief description of the anthropometric dimensions considered in this study is given in Table 1. These dimensions are demonstrated in Figure 2. Values of anthropometric parameters (mean and standard deviation) of male agricultural worker(s) for Maharashtra which are required for trimming operation are shown in Table 2 (Vyavahare and Kallurkar, 2015).

Table 1 Anthropometric dimensions selected for the study

Sr. No.	Name of Body Dimension	Description
1.	Stature	Vertical distance from a standing surface to the top of the head.
2.	Acromial Height, Standing	Vertical distance between the standing surface and the acromion landmark at the tip of the shoulder.
3.	Axilla Height	The vertical distance between the standing surface and the axillary fold at the anterior scye landmark on the torso.
4.	Waist height (Omphalion)	Vertical distance between the standing surface and the center of the navel (omphalion).
5.	Crotch height standing	Vertical distance between the standing surface and the crotch.
6.	Acromion radiale length	Distance between the acromion landmark at the tip of the shoulder and radial landmark on the elbow.
7.	Biacromial Breadth	Posterior distance between the right and the left acromion landmarks on the tips of the shoulders
8.	Radiale stylion length	Distance between the radiale landmark on the elbow and the stylion landmark on the wrist
9.	Sleeve length outseam	The straight line distance between the acromion landmark on the tip of the shoulder and the stylion landmark on the wrist, measured with the arm is straight at the side and the palm facing forward
10.	Chest Breadth	Maximum horizontal breadth of chest at the level of the bust point.
11.	Waist breadth	Horizontal breadth of the waist at the level of the center of the navel (omphalion).
12.	Hip breadth standing	Horizontal distance between the hips at the level of the lateral buttock landmarks.
13.	Knee Height, Midpatella	Vertical distance between the standing surface and the center of the knee at the midpatella landmark.
14.	Shoulder-Elbow Length	The distance between the acromion landmark at the tip of the shoulder and the olecranon landmark at the bottom of the elbow flexed to 90 degrees.
15.	Forearm Hand Length	Horizontal distance between the back of the tip of the elbow to the tip of the middle finger.
16.	Hand Length	Length of the hand between the stylion landmark on the wrist and the tip of the middle finger
17.	Wrist-Index Finger Length	Distance between the stylion on the wrist and the tip of the index finger
18.	Hand Breadth at metacarpal-III	Maximum breadth of the hand between the metacarpal II and the metacarpal V

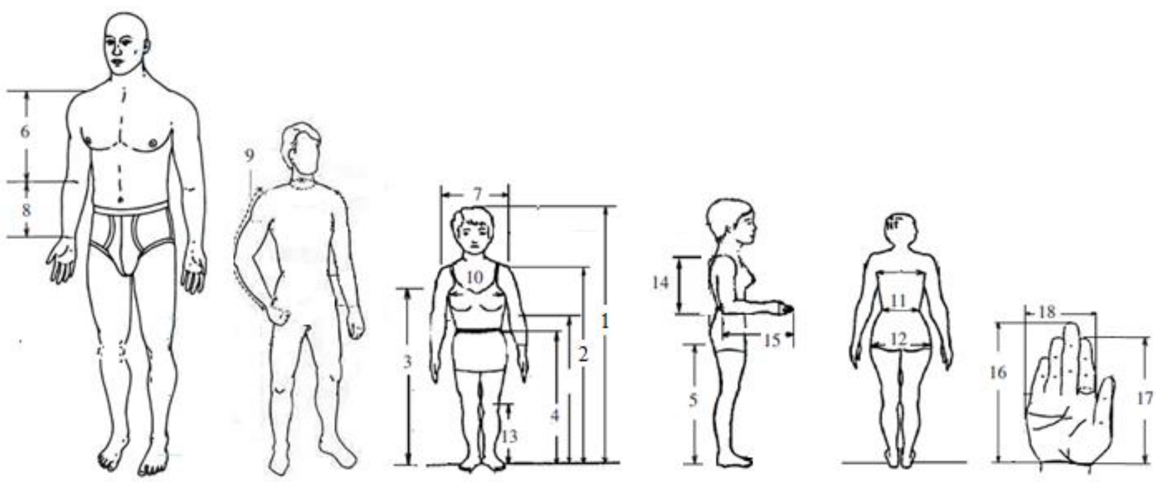

Figure 2 Anthropometric dimensions used in the study

Table 2 Anthropometric dimensions of male agricultural workers of Maharashtra state

Sr. No.	Description	CATIA ref. no.	Values (cm)	
			Mean Value	SD
1.	Stature	us100	164.7	6.0
2.	Acromial Height, Standing	us3	137.6	5.5
3.	Axilla Height	us7	125.2	5.2
4.	Waist height (Omphalion)	us120	99.6	4.9
5.	Crotch height standing	us39	76.6	4.8
6.	Acromion radiale length	us5	31.6	2.6
7.	Biacromial Breadth	us11	32.9	1.9
8.	Radiale stylion length	us88	26.5	2.3
9.	Sleeve length outseam	us98	59.5	3.3
10.	Chest Breadth	us33	26.2	2.1
11.	Waist breadth	us113	25.1	2.2
12.	Hip breadth standing	us66	29.3	1.7
13.	Knee Height, Midpatella	us73	48.5	2.7
14.	Shoulder-Elbow Length	us92	37.0	2.6
15.	Forearm Hand Length	us55	45.4	2.9
16.	Hand Length	us60	18.0	0.9
17.	Wrist-Index Finger Length	us130	16.7	0.9
18.	Hand Breadth at metacarpal-III	us58	8.1	0.4
19.	Weight (kg)	us125	57.9	7.2

2.2 Hedge trimmer and manikin modeling

There are various electric hedge trimmers available in the market. The commonly used hedge trimmer was modeled in CATIA V5R17 (Figure 3). First, all the parts of trimmer are modeled and then assembled in assembly workbench. Manikin was modeled using CATIA's human builder module using various anthropometric dimensions. Using human measurements editor workbench, dimensions of Maharashtra workers as shown in Table 2 are updated.

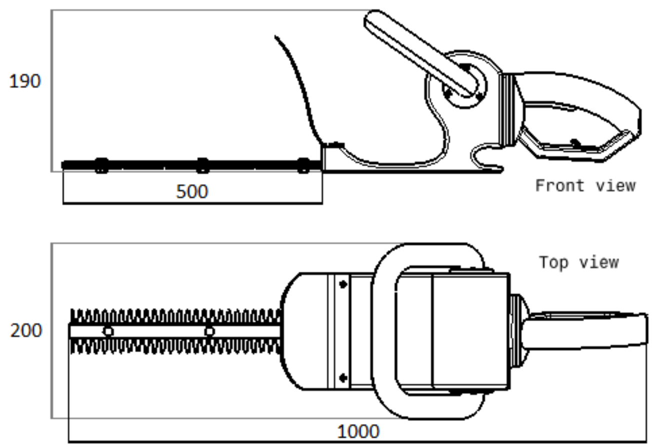

Figure 3 Drawing of electric hedge trimmer (all dimensions in mm)

2.3 Ergonomic analysis

In the traditional ergonomic analysis, product or workstation should be physically available for the analysis whereas DHM tools can be used virtually and simulation can be performed on the virtual models. The various ergonomic analysis tools such as Rapid Upper Limb Assessment (RULA), carry analysis and biomechanics analysis are used for the analysis.

2.4 Interpretation of results of RULA analysis

The RULA analysis examines the risk factors like the number of movements, working posture, static muscle work force and working time without a break to provide a final score ranging from 1 to 7. The final score is accompanied by a colored zone changing from green to red on the basis of final score. The score report consists of two modes namely basic mode and advanced or detailed mode. The scores, colors and their meaning in the basic mode are shown in Table 3.

Table 3 Interpretation of RULA score in basic mode

Score	Color	Meaning
1 and 2	Green	The posture is acceptable if it is not retained or repeated for longer period
3 and 4	Yellow	Further investigation is required and changes may also be required.
5 and 6	Orange	Investigation and changes are needed soon.
7	Red	Investigation and changes are needed immediately.

3 Results and discussion

3.1 RULA analysis

RULA allows manikin's upper limbs analysis based on parameters such as distance, weight and frequency. It is used to canvas many aspects of manikin posture based on various variables and user data such as lifting distance, lowering distance, action duration, object weight and task frequency. It takes care of work specific variables such as external support to the manikin, balance of the manikin and orientation of arms of the manikin with reference to body and feet. RULA score depicts acceptability of the task and posture and gives suggestions whether tasks or postures are acceptable or should be investigated further or should be changed soon or immediately. Hence, the RULA analysis helps to optimize manikin posture resulting in better designed and widely accepted products and workplaces (Ren and Xiao, 2009; Sanjog et al., 2012).

RULA analysis was performed for two commonly attained postures (posture 1 and 2) by operator (Figure 4a and 4b). Improved workstation was designed with a provision for the handle height adjustment and hedge trimmer placement (Figure 5a and 5b). RULA score for posture 1, 2 and modified workstation were presented in Table 4 for 5th and 95th percentile male worker. Detailed RULA analysis dialog box is shown in Figure 6a and Figure 6b.

Figure 4 Modeled existing workstations (a) posture 1 (Horizontal Cutting); (b) posture 2 (Vertical Cutting)

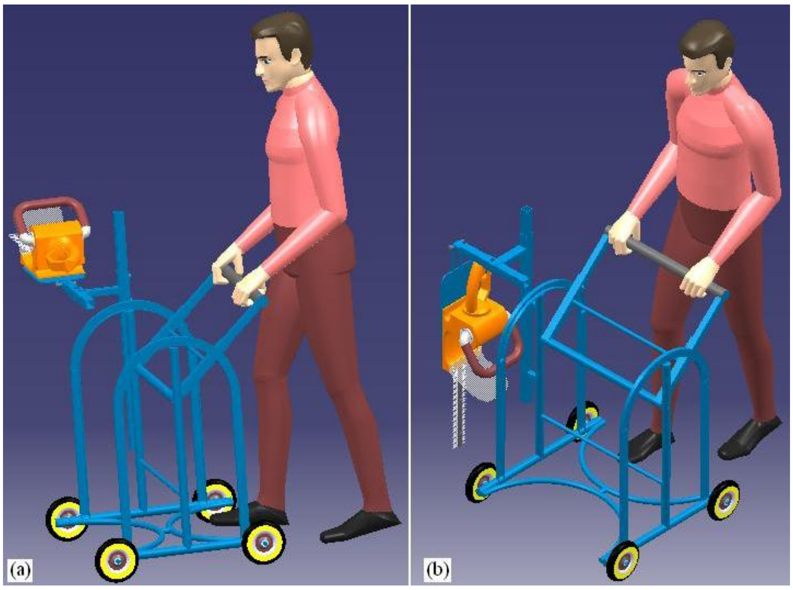

Figure 5 Modified workstations (a) for posture 1 (Horizontal Cutting); b) for posture 2 (Vertical Cutting)

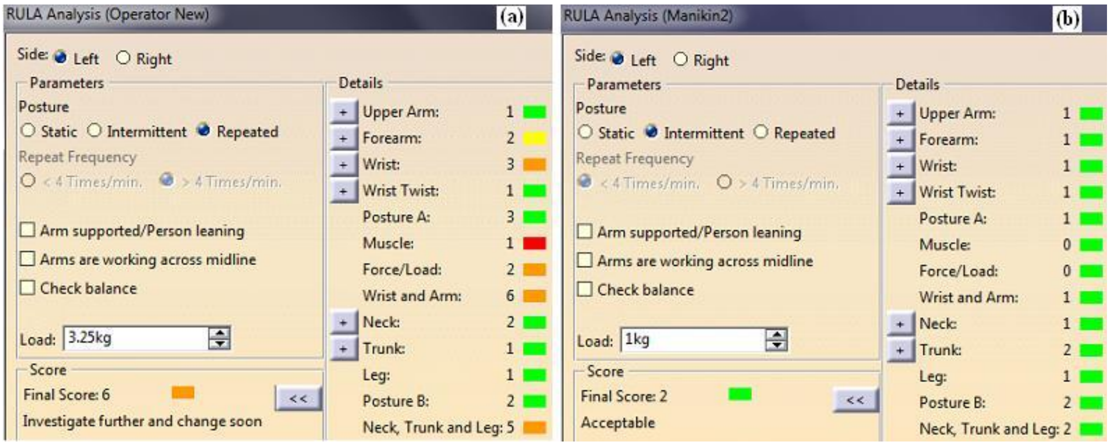

Figure 6 RULA score windows (a) for existing workstation (5th percentile manikin, left side, posture 1); (b) for modified workstation (5th percentile manikin, left side, posture 1)

The RULA analysis (Table 4) shows that existing working postures 1 and 2 of the hedge trimmer workers are highly dangerous (score 6 and 7) and must be changed by in-depth investigation of workstation in order to keep away the worker from musculoskeletal disorders. This high RULA score is due to awkward postures attained by the workers while working with electric hedge trimmer. An improved workstation is developed to carry hedge trimmer during shrub cutting which maintains safe acceptable posture of the operator resulting into reduced RULA score up to 2. This new workstation can be used to trim shrubs in horizontal, vertical or inclined fashion by adjusting the orientation of hedge trimmer. Using new workstation, load transferred from repeated to intermittent type.

Table 4 RULA analysis for key postures of operator while trimming process

Cutting Plane	Hand(Right/Left)	Posture	Population percentile	Score for existing workstation	Score for modified workstation
Horizontal	Right	1	5th	07	02
	left			06	02
	Right	2		07	02
	left			07	02
Vertical	Right	1	95th	07	02
	Left			06	02
	Right	2		07	02
	Left			06	02

3.2 Carry Analysis

Carry analysis was completed by using CATIA's carry analysis tool which uses general manual materials handling guidelines (Snook and Ciriello, 1991). The input for this analysis was:

- The frequency of the carry task
- The distance of carry
- The population sample

The output of carry analysis is the maximum allowed load under these conditions. Carry analysis dialog box is shown in Figure 7.

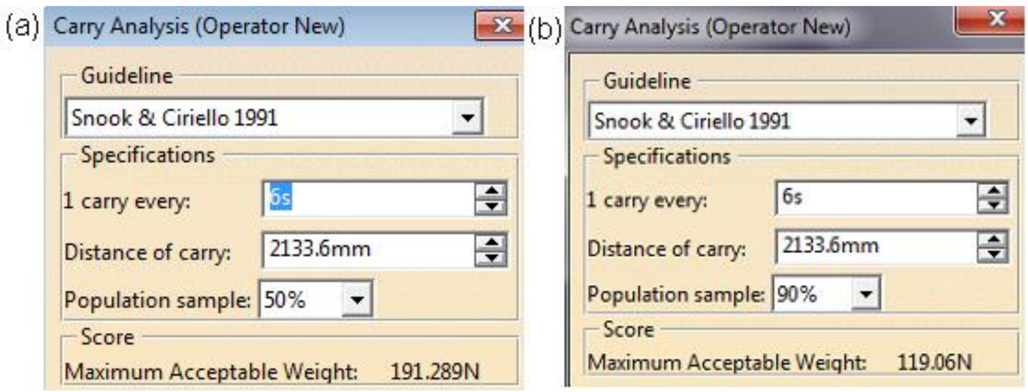

Figure 7 Carry analysis dialogue box (a) for posture 1; (b) for posture 2

This analysis was carried out in order to analyze if the carrying of a hedge trimmer weighing 3.25 kg with carry frequency every 6 seconds, is ergonomically suitable for a 50% and 90% of male population and a carry distance of 2.1 m. Carry analysis shows that the maximum weights allowed are more than the actual weight of the hedge trimmer i.e. 32.5 N. Thus, carry analysis has depicted acceptable results for hedge trimmer carry task. Table 5 presents acceptable weights for 50th and 90th male percentiles.

Carry analysis shows that actual weight of hedge trimmer carried by hands of the operator is less than the maximum allowed weight (Table 5). Thus, carrying analysis gives acceptable results.

Table 5 Acceptable weights for male population for posture 1 and 2

Posture	Male Percentile	Acceptable weight (N)
1	50th	191.28
	90th	100.42
2	50th	214.23
	90th	119.06

3.3 Biomechanics single action analysis

This ergonomic tool that presents in CATIA evaluates biomechanical data of a worker in a given posture. This tool computes information such as the lumbar spinal loads and the forces and moments on manikin joints. The results of this tool are based on research results and algorithms published by the scientific community. The tool takes into account forces or loads coming on the manikin's hands only for analysis.

Biomechanics single action analysis gives values of L4-L5 moment, L4-L5 compression, body load compression, axial twist compression, flex/extention compression and L4-L5 joint shear which are tabulated for postures 1 and 2 in original workstation and new improved workstation (Table 6). The L4-L5 Moment has been reduced from 57 to 3 Nm, L4-L5 Compression reduced from 1296 to 301 N, Body Load Compression from 382 to 240 N, Axial Twist Compression from 13 to 0 N, Flex/Ext Compression from 954 to 56 and L4-L5 Joint Shear from 108 Anterior to 1 N posterior. Thus, the values of moments and forces coming on body are significantly reduced for new modified workstation due to transfer of load from hands of operator to cart and improved posture of the operator during trimming operation. In new modified workstation, operator need not carry any load and only a little force may be required to push the cart forward or backward to trim the shrubs. Moreover, operator is not required to take posture 1 by raising hands nor required to bend to take posture 2. In newly developed workstation, height of the handle can be adjusted to suite any population and position of hedge trimmer can be changed depending on the size of shrubs to be trimmed.

Table 6 Biomechanics Single Action Analysis results

Description	Posture 1 original workstation	Posture 2 original workstation	New modified workstation
L4-L5 Moment (N m)	18	57	3
L4-L5 Compression (N)	734	1296	301
Body Load Compression (N)	382	283	240
Axial Twist Compression (N)	1	13	0
Flex/Ext Compression (N)	293	954	56
L4-L5 Joint Shear (N)	47 Posterior	108 Anterior	1 Posterior

4 Conclusions

Thus it is clear that DHM and human simulation techniques can be successfully used to develop the ergonomically sound products based on anthropometric data of user population. Tools such as RULA, carry analysis, biomechanics analysis can be used together for detailed analysis of the equipment or workstation so as to best fit to the user population. Moreover, use of virtual model of the product for the analysis purpose reduces cost of the development of the product. Also reach and fit of the operator to the product can be checked easily. Further various activities that are demanded by particular operation can be simulated virtually for detailed analysis of the workstation. New developed workstation can be used for trimming shrubs near the road or shrubs on plain ground where cart can walk smoothly.

References

Dooley, W. K. 2012. Ergonomics and the development of agricultural vehicles. In *Agricultural Equipment Technology Conference*. Louisville, Kentucky, USA, 13-15 February.

Gilad, I., and E. Byran. 2007. Ergonomic evaluation of the ambulance interior to reduce paramedic discomfort and posture stress. *Human Factors*, 49(6): 1019–1032.

Kuijt-Eversa, L. F. M., L. Groenesteijn, M. P. Looze, and P. Vink. 2004. Identifying factors of comfort in using hand tools. *Applied Ergonomics*, 35(5): 453–458.

Ren, J., and D. Xiao. 2009. Ergonomic simulation and evaluation of elliptical trainer with CATIA V5. *CADDM*, 19(1): 81-86.

Sanjog, J., H. Karmakar, C. Agarwal, and D. Patil. 2012. Designing and ergonomic evaluation of a shoe-rack in

CAD environment. *International Journal of Computer Applications*, 49(20): 38-41.

Singh, S., and R. Arora. 2010. Ergonomic intervention for preventing musculoskeletal disorders among farm women. *Journal of Agri. Science,* 1(2): 61-71.

Singh, T., and J. Singh. 2014. Ergonomic evaluation of industrial tasks in Indian electronics industries. *International Journal of Science and Research*, 3(7): 1056-59.

Snook, S. H., and V. M. Ciriello. 1991. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics*, 34(9): 1197-1213.

Somasundaram, A., and P. Srinivasan. 2010. Design optimization of dosa making workstation for smooth ergonomic interface. *Journal of Scientific and Industrial Research*, 69: 221-224.

Vyavahare, R. T., and S. P. Kallurkar. 2015. Anthropometry of male agricultural workers of western India for the design of tools and equipments. *International Journal of Industrial Ergonomics,* 53: 80-85.

Vyavahare, R. T., and S. P. Kallurkar. 2012. Anthropometric and strength data of Indian agricultural workers for equipment design: a review. *Agric Eng Int: CIGR Journal*, 14(4): 102-114.

Yadav, R., and S. Pund. 2007. Development and Ergonomic Evaluation of Manual Weeder. *Agricultural Engineering International: the CIGR Journal*, 9:1-9. .