Anthropometric and strength data of Indian agricultural workers for equipment design: a review

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Abstract: Anthropometric and strength data of agricultural workers is very essential for the safe, user-friendliness and efficient design of farm equipment. This paper presents the review on the studies carried out so far to generate the anthropometric and strength data of agricultural workers for equipment design and ergonomic evaluation of farm equipment. Review shows that many of the studies are focused on anthropometric data and very few have considered strength parameters. For very few regions in India, anthropometric and strength data is available and it is essential to generate exhaustive region specific data, which was found varying from region to region, for rest of the regions to suite the population in the particular region. Also, there is necessity of ergonomic evaluation and optimization of farm equipments to reduce musculoskeletal disorders (MSDs) and prevent injuries of farm workers.

Keywords: Agricultural ergonomics, equipment design, anthropometry, strength parameters

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1 Introduction

The word “Anthropometry” was created in 1870 by the Belgian mathematician, Quetlet. It is an integral part of the design where humans are involved.

India is an agriculture-based country. A large section of Indian population engages in agriculture. Although agriculture is generally recognized as the nation’s most hazardous industry and displays high rates of MSDs with evidence in which the ergonomic risk factors are involved and be pointed out, there is very little history of application of ergonomic approaches in agricultural equipment design. About 6.5% of the power used in crop production and related activities in the country is contributed by about 241 million workers, of which about 42% (i.e. 101 million) are female workers. Thus, the human workers play a major role in the country’s agriculture and due to that, attention needs to be given to their capabilities and limitations during design and operation of various farm equipments, so as to get higher productivity, enhanced comfort and ensure better safety (Woodson and Conover, 1973; Yadav et al., 2010). Manually operated equipments are extensively used in Indian agriculture for various farm operations starting from seedbed preparation to post-harvest operations.

In the present era of user centeredness and market competition, ergonomic considerations are a must for agricultural equipment design as the users are no more bound to cope with whatever design imposed on them (Kumar and Chakrabarti, 2009).

The availability of an anthropometric database has unlimited applications. Western countries, where ergonomic awareness is much higher than in other areas of the world, have created huge databases for anthropometric design reference (NASA, 1978; Syed,

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1993). The anthropometric data bank assembled and maintained by Aerospace Medical Research Laboratories, Dayton, Ohio (USA) is the largest single repository of raw anthropometric data in the world. ERGODATA is another data bank located at Anthropology Laboratory of Paris University, France. However, it does not contain any data on Indian (Asian) population (Yadav et al., 2010; Naqvi, 1993; Scott, 2009).

In order to safeguard the workers against accidents and ill health, a large number of safety legislations exist in India. However, the ergonomic factors concerning safety are not adequately addressed in these legislations. While environmental factors such as noise, ventilation, illumination etc. have been dealt with in detail, factors relating to man-machine- interaction need more emphasis in the legislation (Periyan and Iqbal, 2009). Ergonomics can be used as a tool for retaining employees and increasing productivity. It is therefore recommended that such tools could be used to reduce turnover rates and increase employee engagement. High rates of attrition not only increase costs but signify poor working conditions and low brand equity. Ergonomic interventions are increasingly used to reduce labour turnover rates, lower costs, increase revenue and accomplish more work with a little work force (Dempsey, 2007; Sen, 2009; Singh and Arora, 2010; Abarghouei and Nasab, 2012).

2 Manually operated farm equipments

Hand tools and manually operated equipments are extensively used for digging, weeding and harvesting operations in agriculture. Weeding is one of the most important farm operations in crop production system. The most commonly used hand tools and equipments by the farmers for manual operations are spade, weeders, threshers, sprayers, ploughs, sickle, paddy puller, straw puller, hoe, hand power tiller etc. Manual weeding requires a huge labour force and accounts for about 25% of the total labour requirement (Nag and Datt, 1979). So manually operated weeders are remained first priority of the researchers.

The most common methods of weed control are mechanical, chemical, biological and cultural methods. Out of these four methods, mechanical weeding either by hand tools or weeders are most effective in both dry land and wet land (Nag and Datt, 1979; Gite and Yadav, 1985; 1990). It has been observed that of the total labour involved in agricultural work during the cultivating season, as much as 15%, is spent in cutting weeds from irrigated or dry lands. Weeding utilizes about 20% of the total human energy used in crop production (Gite and Yadav, 1990).

In India, about 4.2 billion rupees are spent for controlling weeds in the production of major crops every year. At least 40 million tons major food grains are lost every year due to weeds alone (Singh and Sahay, 2001). Therefore, timely weeding is very much essential for a good yield and this can only be achieved by using mechanical weeders which perform a simultaneous job of weeding and hoeing and can reduce the time, cost and drudgery involved in manual weeding.

3 Instrumentation

In order to generate the anthropometric and strength parameter data of agriculture workers, various body dimensions and strength parameters need to be measured accurately. Some custom designed and/or specially developed instruments/equipments are used for this purpose (Davies and Shahnawaz, 1977).

Integrated Composite Anthropometer (ICA) (developed by Indian Institute of Technology, Kharagpur) is used by various researchers for measurement of various body dimensions and strength parameters. A weighing scale with accuracy of 0.1 kg and capacity of 120 kg, and a wooden conical shape device are used for measuring the weight and grip diameter respectively. Measuring tapes and vernier caliper are also used in addition to anthropometer for recording some parameters (Tewari et al., 2007; Agrawal et al., 2010a). Strength parameters in different postures are also measured by “Strength Measurement Set-up” (developed at Central Institute of Agricultural Engineering, Bhopal, India) (Yadav et al., 2010).

4 Literature review

Attempts are made by many researchers to develop anthropometric databases and ergonomic evaluation of equipments to minimize MSDs in operators and to improve their efficiency, comfort, safety etc. A concise literature review is shown in Table 1 and Table 2. MSDs have been a widespread problem in agriculture. Occupational risk factors include static postures, forward bending, heavy lifting and carrying, kneeling, and vibration in agriculture. Unfortunately, there has been limited application of research related to ergonomics and MSDs, although farmers frequently report musculoskeletal signs and symptoms (Meyers et al., 1995).

Kouchi et al. (1999) measured inter-observer errors in anthropometry. Different observers were asked to measure the same anthropometric items of the same subjects and errors were analyzed. Variance was more than 10% in five measurements. It was found that errors are reduced drastically by specifying the causes of inter-observer errors and the standardization of the measurement technique.

Table 1 Studies carried out for anthropometric and strength parameter collection

Approach followed	Subject type	Age range (yrs)	No. of subjects	Anthropometric/strength parameters measured	Study region	Reference
ADC	Male Female	--	--	01	Meghalaya	Grandjean, 1981
ADC	Male	15-60	39	52	Bhopal	Gite and Yadav, 1989
ADC	Male	--	134	29	Eastern India	Yadav et al., 1997
ADC	Male Female	20 and above	961	290	23 Locations in India	Chakrabarti,1997
ADC	Female	--	137	--	West Bengal	Philip and Tewari, 2000
ADC	Female	18-50	40	30	Gujarat, India	Yadav et al. 2000
ADC	Male	21-48	300	09	Chhattisgarh	Victor et al., 2002
ADC	Male Female	18-75 18-65	200 204	08	West Bengal	Kar et al., 2003
ADC SDC	Female	--	95	51 01	Ahmedabad (West India)	Nag et al., 2003
ADC	Male	18-70	407	26	Nicobar	Ravi Prasad and Rao, 2004
ADC	Male	20–30	280	33	North Eastern India	Dewangan et al., 2005
ADC	Male	21-55	104	12	Dibrugarh district (Assam State)	Baruah et al., 2006
ADC	Male Female	--	8025 4500	79	12 States in India	Gite and Majumder, 2007
SDC	Male Female	--	3423 2514	16	Six States in India	Gite and Majumder, 2007
ADC	Male Female	--	2000	21	West Bengal	Tewari et al., 2007
ADC	Female	18-60	400	76	Arunachal Pradesh and Mizoram	Dewangan et al., 2008
ADC	Male Female	6-25	417 330	03	Amritsar, Punjab, India	Koley and Melton, 2010
SDC	Male Female	6-23 6-21	417 330	01	Amritsar, Punjab, India	Koley and Melton, 2010
ADC	Male Female	20-40	51 51	03	Manipal	Ratn et al., 2010
SDC	Male Female	18-55	75 30	14	Saurashtra, Gujarat	Yadav et al., 2010
SDC	Male Female	20-40 25-42	944 757	02	Madhya Pradesh	Agrawal et al., 2010a
ADC	Male Female	19-51	566 461	34	Meghalaya	Agrawal et al., 2010b
ADC	Male	18-60	801	76	North-Eastern India	Dewangan et al., 2010
ADC	Male	18-62	878	37	Haryana	Chandra et al., 2011
ADC	Male	--	2500	19	Vidharbh, Maharashtra	Khogare and Borker, 2011
ADC	Male	18-25	15	08	Cooch Behar District, West Bengal	Sengupta and Sahoo, 2012

Note: ADC- Anthropometric data collection, SDC- Strength data collection.

Table 2 Studies carried out for ergonomic evaluation of farm equipment

Equipments evaluated	Study region	Major study	Reference
9 Sickles	Gujrat	Analysis of harvesting operation of sickles	Nag et al., 1988
Push-pull type manually operated dry land weeder	Bhopal, India	Optimum handle height determination	Gite and Yadav, 1990
A lever-operated knapsack sprayer	Bhopal, India	Ergonomic evaluation	Ghugare et al., 1991
Animal-drawn mould board plough	Bhopal	Optimum handle height calculation	Gite, 1991
Tool handles	--	Evaluation of a foam rubber grip for tool handles	Fellows and Freivalds, 1991
Handles of chisels and pliers	--	Ergonomic evaluation and design	Lewis and Narayan, 1993
Single-disc floor cleaning machines (buffers/polishers)	--	Ergonomic evaluation	Haslam and Williams, 1999
Sickle	Bhopal	Comparison of local and improved (commercial) sickles	Gite and Agrawal, 2000
Grain threshers	Haryana and Uttar Pradesh	Development of ergonomic cost effective threshers	Kumar et al., 2002
Fodder cutting machines	Northern India	Development of safer fodder-cutter machines	Mohana et al., 2004
Manually operated weeder	Junagadh	Ergonomic evaluation and Development	Yadav and Pund, 2007
Rotary weeder and Cono weeder	Kerala	The comparative study between weeders	Remesan et al., 2007
Groundnut harvesting mechanism	Tamil Nadu	Development of a groundnut combine	Padmanathan et al., 2007
Pedal paddy thresher	Orissa and West Bengal	Ergonomics of farm women	Mohanty et al., 2008
Manually operated weeder	Orissa	Performance evaluation and development	Goel et al., 2008
Pedal operated cashew nut sheller	--	Modification for improved efficiency	Swain et al., 2009
Spade (Phawra)	Udaipur	Modification for improved efficiency and comfort	Khidiya and Bhardwaj, 2010
Maize sheller	Chhindwara District	Ergonomic evaluation for improved efficiency	Singh A. et al., 2010
Paddy thresher	Uttarakhand state	Comparison paddy threshing activity	Kwatra et al., 2010
Handle grips	Kharagpur, India	Reduction of hand-transmitted vibration in hand	Dewangan and Tewari, 2010
Compound Lever Handle	--	Design and Development of Compound Lever Handle for Hand Pump	Ali, 2012

4.1 Anthropometric and strength data

Grandjean (1981) suggested that a comfortable range of elbow angle should be 100-110º. He measured the elbow heights (standing) at this elbow angle for the 5th, 50th and 95th percentile male and female agricultural workers of Meghalaya.

Gite and Yadav (1989) collected body dimensions (*n* =52) on farm workers (*n*=39) for the design of agricultural equipments. The standard deviation and 5th, 50th and 95th percentile values were calculated. Study recommended such extensive surveys in different parts of countries to generate necessary data. Yadav et al. (1997) reported anthropometric data (*n*=29) of male farm workers (*n*=134) of Eastern India as a reference for the ergonomic design and modifications of agricultural tools and devices such as khurpi or power tiller. Chakrabarti (1997) presented compiled Indian anthropometric dimension data for males and females.

Yadav et al. (2000) carried out anthropometric measurements useful for farm equipment design on female workers from Gujarat, India. It was found that the mean stature of West Indian female workers was 154.6 cm, while those for male workers from eastern, southern, central, northern and western regions were 162.1, 160.7, 162.0, 168.5 and 164.4 cm, respectively. It is recommended to carry out similar surveys in other parts of the country.

Victor et al. (2002) carried out an anthropometric survey and compared with available data of other regions. Anthropometric measurements were carried out on 5 males from each village randomly chosen from 6 districts of Chhattisgarh region. The data showed that the Indians (Chhattisgarh region) are smaller than western people (Americans, Swedes and Germans). The other body dimensions were also found to be lower than the western people except popliteal height (sitting) and buttock popliteal length in which Indians have the higher value of body dimensions. Kar et al. (2003) collected different hand dimensions of right and left hands of agricultural workers from different agricultural fields of Midnapore District, West Bengal State, Eastern India and compared them with the data of other parts of India and abroad. It was noted that there was a significant difference in body dimensions between right and left hand in both sexes. Nag et al. (2003) undertook study to generate hand anthropometric data of women, working in informal industries (beedi, agarbatti and garment making). The hand measurements of the right hand (lengths, breadths, circumferences, depths, spreads and clearances of hand and fingers) were taken and analyzed to determine the normality of data and the percentile values of different hand dimensions and regression analysis was done to determine better predictors of hand length and grip strength. Results showed that the hand breadths, circumferences and depths were approximately normally distributed, with some deviation in finger lengths. Hand length was significantly correlated with the fist, wrist and finger circumferences. The hand lengths, breadths and depths, including finger joints of the Indian women studied were smaller than those of American, British and West Indian women. Lee (2004) examined height-matched healthy males (*n*=7) for their maximum isometric lifting strengths across 13 exertion heights, ranging from 25 cm to 133 cm in increment of 9 cm. The results showed a nonlinear (increasing-decreasing-increasing) strength-height relationship for all subjects. Ravi Prasad and Rao (2004) collected anthropometric measurements (12 on head and face, 14 on body) for adult males of Nicobarese populations and observed remarkable heterogeneity among these populations.

Cheng and Lee (2005) examined maximum two-handed isometric back lifting, upper-body lifting, arm lifting and shoulder lifting strengths in three different horizontal distances of objects to be lifted (when toes were anterior to, aligned with and posterior to the exerted handle). The study showed that human lifting strength decreased significantly as the toe position shifted from anterior of the vertical plane to posterior of the vertical plane of the exerted handle. Baruah et al. (2006) collected anthropometric measurements of adult Tai-Phake males and examined the nature and extent of morphometric variation among five neighbouring mongoloid groups of Assam. Study revealed significant differences between Tai-Phake and other five neighbouring groups.

Anthropometric and strength data for agricultural workers has been collected. The mean stature and weight of Indian agricultural workers worked out are 163.3 cm and 54.7 kg for male workers and 151.5 cm and 46.3 kg for female workers. The mean values for strength data in pushing and pulling by both hands in standing posture are 224 N and 218 N for male workers and 143 N and 158 N for female workers, respectively (Gite and Majumder, 2007).

Tewari et al. (2007) collected the anthropometric data of male and female agricultural workers throughout the state of West Bengal, India. Dewangan et al. (2008) carried out an anthropometric survey for female agricultural workers of two north eastern hill states of India, namely Arunachal Pradesh and Mizoram.

The study was made to measure the isometric strength and investigate the effects of different handle heights and elbow angles on the pushing and pulling strengths of young men (*n*=8) at University of Windsor, Canada. Both the highest and the lowest isometric strengths for pulling were found at shoulder height (Mean = 60.29 lb., SD = 16.78 lb.) and elbow height (Mean = 33.06 lb., SD = 6.56 lb.) respectively (Badi and Boushaala, 2008).

Koley and Melton (2010) investigated healthy Indian males (325 right hand and 92 left hand dominant) and females (297 right hand and 33 left hand dominant) aged 6 - 25 years from Amritsar, Punjab, India to collect three anthropometric measurements, viz. height, weight and body mass index (BMI) and analyse the trend of handgrip strength. The findings of the study indicated a gradual increment of both right and left handgrip strength from 6 to 23 years in males and from 6 to 21 years in females. The mean values of all the three anthropometric variables for males were found higher than females. Ratn et al. (2010) carried out study of healthy Indian adults (*n*=102, 51 male, 51 female, aged 20 - 40 years) representing 14 states of India. Study identified age, gender and BMI to be a best predictor of the muscle strength and these variables accounted for 61%-75% of variability in muscles strength.

Anthropometric data was collected from four major and fourteen minor tribes of north-eastern region of India for efficient and safe design of agricultural hand tools, implements and machines. A significant variation in most of the body dimensions was found among four major tribes (Dewangan et al., 2010). Yadav et al. (2010) carried out analytical studies of strength parameters of Indian farm workers and found the average push/pull strength for male and female workers for both hands/legs in standing/sitting posture. Agrawal et al. (2010b) presented the anthropometric data to develop/modify the improved tools and machinery suitable for people selected randomly from seven districts of the northeastern region. A remarkable difference in anthropometric dimensions of male and female agricultural workers of Meghalaya was observed. The comparison of anthropometric dimensions with other parts of the country suggested that people of this region have lower body dimensions as compared to other parts of the country. The comparison of major anthropometric dimensions of male subjects of the north eastern region of India with those of other ethnic groups from China, Japan, Germany, Britain and the USA revealed that most of the dimensions are smaller for male farm workers of the north eastern region. Dewangan et al. (2005) revealed similar variations in anthropometric data of different countries.

The hand dimensions (n = 37) of male industrial workers (n=878) from the five age groups of Haryana state belonging to thirty-eight industries of Haryana state of India were analysed. Differences in most hand dimensions between five age groups were found (Chandra et al., 2011). Khogare and Borker (2011) undertook a study to suggest dimensions of manually operated weeders based on anthropometric data of the agricultural workers from five districts in Vidharbh Region of Maharashtra State and found that anthropometric data of agricultural workers of Maharashtra was significantly different from the other regions of the country. Different body dimension to stature ratio was also calculated and compared with other studies.

Sengupta and Sahoo (2012) carried out study on young male tea-garden workers (n=15, aged 18-25 years) from Cooch Behar District, West Bengal and found a significant difference in body surface area, BMI, percentage of body fat (% fat), blood pressure, physical fitness index, energy expenditure, anaerobic power, mean upper arm circumference, thigh circumference, waist circum-ference and buttock. No significant difference was observed in calf circumference and waist-to-hip ratio.

Brief summary of anthropometric and strength data collection studies is presented in Table 2.

4.2 Ergonomic evaluation of equipment

Singh and Arora (2010) reviewed the literature to determine the types and extent of MSDs of the farm women in India and to identify opportunities for ergonomic intervention. Authors concluded that numerous types of MSDs such as disorders of the back and neck, nerve entrapment syndromes, tenosynovitis, tendonitis, peri-tendonitis, epicondylitis and non-specific muscle and forearm tenderness were consequences of the occupational risk factors in agriculture such as static postures, forward bending, heavy lifting and carrying, kneeling and vibration. It is suggested for ergonomic interventions to design women friendly tools and equipments, improve work processes and stipulate rest periods for farm women.

Studies of noise level on tractors have indicated a relationship between the intensity of noise at the operator’s ear and the speed at which the tractor is set to work. The evidences showed that those drivers who have noisier vehicles are inclined to choose a lower engine speed to maintain a reasonably comfortable noise level and thereby carry out the work with the tractor at a lower forward speed and hence at a lower work rate (Matthews, 1983). Nag et al. (1988) analyzed sickle operation with reference to design features of nine different types of sickles and six farmers. The study indicated that the blade geometry contributes significantly to human performance and there is ample scope for optimization.

Gite and Yadav (1990) completed laboratory study to find out the optimum handle height for a push- pull type manually operated dry land weeder from ergonomic considerations. Four handle heights were compared with 8 subjects. Ghugare et al. (1991) carried out an ergonomic evaluation of a lever-operated knapsack sprayer. The data of 18 body dimensions and the shape of the back were collected for 10 subjects and their relevance in sprayer design was discussed. The study indicated that although the workload in the spraying operation was within acceptable limits according to physiological criteria, there was a need to make improvements in the mounting of the sprayer on the operator’s back to reduce the postural discomfort.

An investigation to find the optimum handle height for an animal-drawn mould board plough was carried out by studying the postural discomfort and physiological reactions of the operators at six handle heights (Gite, 1991). Fellows and Freivalds (1991) evaluated a foam rubber grip for tool handles and observed uniform distribution in grip force, but the tool grip force was found greater for the foam grip due to deformation of the foam and feeling of loss of control in the subjects. However, most subjects preferred the foam grip.

The handles for two commonly used hand tools, the chisel and pliers were designed following ergonomic principles. Results clearly showed that the ergonomically designed handle allowed higher work efficiency than existing handles (Lewis and Narayan, 1993). Haslam and Williams (1999) investigated ergonomic issues connected with the use of single-disc floor cleaning machines (buffers/polishers) which are somewhat similar to weeders and observed the scope to improve current design.

The study was undertaken to compare the local and improved sickles during wheat harvesting by women workers (n=6) in Bhopal region. The data showed that drudgery reduction due to the use of improved sickle was about 16.5% as compared to the local sickle (Gite and Agrawal, 2000).

The study was carried out for 100 threshers in villages of Sonipat District of Haryana State and Baraut District of Uttar Pradesh, northern states of India to develop a grain thresher based on ergonomic criteria. A total of 65 thresher injuries were investigated in detail and data were compared with the dimensions of threshers involved in injuries to identify the factors associated with injuries. The analysis of thresher chute parameters showed that chute cover length and chute-opening height are critical dimensions which influence the outcome of whether an operator sustains injuries or not. Increased chute heights and chute cover lengths are recommended for safer operation. The height of the platform and the work posture were found to influence the injury outcome. A safer design of thresher was prepared using anthropometric data of the Indian population (Kumar et al., 2002).

A study was taken up to have a comparative study on the ergonomics of farm women of Orissa University of Agriculture and Technology, Bhubaneswar, India in pedal threshing with single and double operators (n =15) and to suggest modifications for further reduction of human drudgery. The ergonomic evaluation of pedal paddy thresher revealed that when using two operators, the physiological responses and physiological cost of work are reduced significantly. The pedal force exerted by an individual operator was found higher than the mean leg strength of the women operators of eastern India (Orissa and West Bengal) (Mohanty et al., 2008).

Statistical analysis of anthropometric characteristics among four people, i.e., Chinese from Mainland, Chinese from Taiwan, Japanese, and Korean, in East Asia showed that there is a significant morphological difference among these people in the same region. The most of mean dimensions and all of the body proportions observed significantly differed (Lin et al., 2004).

Kishtwaria et al. (2004) conducted a study in Kangra District of Himachal Pradesh to study the socio-personal and physical characteristics (n=80) and the physiological workload (n=30) of respondents engaged in plucking tea leaves. It is recommended to generate awareness regarding faulty working habits and to develop women friendly technologies to improve efficiency and output of women workers.

Kuijt-Evers et al. (2004) investigated six factors (functionality, posture and muscles, irritation and pain of hand and fingers, irritation of hand surface, handle characteristics, aesthetics) which determine comfort/ discomfort in using hand tools according to users. These six factors classified into three meaningful groups: functionality, physical interaction and appearance. The results of the study showed that functionality is most related to comfort in using hand tools, followed by physical interaction and appearance.

Fodder cutting machines constitute a significant proportion (11% and 31% in Phase I and Phase II) of all injuries to the hands of both adults and children in the villages of northern India. In the adults, injuries occur from feeding side while feeding the fodder to the machine while children get injured while playing with the machine. Study suggested simple but effective engineering interventions to prevent injuries (Mohana et al., 2004).

Jung and Hallbeck (2005) redesigned the handle of a commercial bar clamp using ergonomic principles and compared with an original clamp. The redesigned clamp produced larger clamping force with lower handle-squeezing forces than the original clamp with enhancement of efficiency and usability.

Yadav and Pund (2007) developed a manually operated weeder and tested it ergonomically ($n = 20$, aged 20-55 years) on the farm of Junagadh Agricultural University, Junagadh. Various parameters such as speed of travel, time of operation, field capacity, weeding efficiency and horse power requirement were considered during the testing. The developed weeder showed an up to 92.5% higher weeding efficiency. The average draft required for weeding was found to be 39.15 kg and maximum pushing force from 25 to 30 kg.

Goel et al. (2008) developed a manually operated weeder for dry land crops and evaluated its performance. It was compared with other available weeders namely a wheel finger weeder, a wheel hoe and conventional weeding by using a trench hoe. The highest performance index of 3689.74 was found with developed weeder at 11.63% moisture content. For maximum work efficiency, it was suggested that the elbow flexion angle should be 85-110º (Grandjean, 1988). For push-pull operation of a machine, the elbow flexion angle would be 90º (Tewari, 1985) and the optimum holding height for males is 630-677 mm and that of females is 534-630 mm (Tewari et al., 2007).

The comparative study between Rotary weeder and Cono weeder revealed that both weeders have their own strengths and limitations. Rotary weeders can be recommended in the later stages of weed growth showing better weeding efficiency, more turning of the soil and uprooting of weeds which overrules the higher cost of operation. Cono weeders performed the task with a comparatively higher field capacity and a better performance index in the early stages of weed infestation (Remesan et al., 2007).

Alizadeh (2011) compared the field performance of four types of mechanical rice weeders (single row conical weeder, two rows conical weeder, rotary weeder and power weeder) to hand weeding. Study registered the highest weeding efficiency (84.33%) and effective field capacity (0.087 ha h^{-1}) in the power weeder. The weeding operation time in single row conical weeder, two rows conical weeder, rotary weeder and power weeder was found to be reduced by 57.07, 77.57, 62.80 and 90.27%, respectively compared to hand weeding. Weeding cost in single row conical weeder, two rows conical weeder, rotary weeder and power weeder was found to be decreased by 15.70, 38.51, 22.32 and 48.70%, respectively compared to hand weeding.

The influence of the width of the harvester blade, the peripheral velocity of the picker conveyor and the forward speed of the plant travel belt conveyor on picking efficiency and conveying efficiency of groundnut harvesting mechanism was investigated. The effect of peg end projection angle, flight spacing, and peripheral velocity of flight elevator and slope of elevator on conveying efficiency of flight elevator was also investigated and the appropriate levels of variables were optimized (Padmanathan et al., 2007).

Kuijt-Evers et al. (2007) investigated whether the same factors underlie comfort in using different kinds of hand tools and concluded that the same factors (functionality, physical interaction adverse effects on skin and in soft tissues) underlie comfort in different kinds of hand tools, however their relative importance differed. Also the relationship between objective measurements and subjective experience of comfort and discomfort in using handsaws was examined. Twelve carpenters evaluated five different handsaws. The study did not find any relationship between muscle activity and comfort or discomfort.

Drakopoulos and Mann (2007) reviewed the published literature and identified guidelines related to seven types of controls, control placement, control labelling, and functional reach for six agricultural tractor workstations to find the degree to which tractor manufacturers comply with published recommendations. It was found that the controls used in modern tractors are consistent with the design recommendations and the least conservative values were chosen for separation distance. The majority of controls (95%) were labelled using either a symbol or text, but there was a tendency to use symbols rather than text. Most controls (89%) were located so that they can be operated by the driver’s right hand, however, only 75% of controls were found within the functional reach envelope (i.e., 750 mm from the seat reference point). It was speculated that space may be a limiting factor due to the large number of controls required to operate modern agricultural equipment.

Powar et al. (2009) designed a truck cabin for improved ergonomics and comfort for driver in Indian driving condition. The study concluded that the cabin of the truck is like the interior of a home and there is a need to include various types of accessories to the dashboard for comfortable and enjoyable driving, a proper storage system of water, cooking stove and a foldable bedding system for two persons.

Ren and Xiao (2009) used CATIA V5 to study ergonomic characteristics of fitness equipments with a preliminary evaluation of elliptical trainer and the dynamic assessments for the rationality of the ergonomic design like the comfort level. Sanjog et al. (2012) highlighted a relevance of digital human modeling (DHM) software in indentifying ‘fit’ of product to intended users during product conceptualization stage to avoid preparation of costly, time consuming physical-mockups for ergonomic studies with real human trial and ensure user friendly product with saving in production cost, time and manual labour.

Swain et al. (2009) ergonomically evaluated a pedal operated cashew nut sheller and modified it to increase its efficiency. Khidiya and Bhardwaj (2010) prepared a modified design of hand operated spade (phawra) using principles of ergonomics and software such as CATIA and ANSYS. The comfort level has been improved by 44.2% due to the modified design and could offer an improved working environment and a reduction in workplace injuries. Melemez and Tunay (2010) investigated ergonomic aspects of noise caused by loading machines and concluded that machine type, machine-cab condition, ground roughness condition, machine use duration, rear wheel pressure and land slope generally affect the noise level. Singh A. et al. (2010) developed a new maize sheller which allowed twice of the work efficiency compared to manual maize shelling and also lowered the efforts required.

Dewangan and Tewari (2010) evaluated handle grips made of foam rubber (HG1) and styrene butadiene rubber (HG2) for reducing hand-transmitted vibration in hand tractor. The results indicated that HG1 and HG2 reduce frequency-weighted vibration acceleration (rms) by about 11% and 5%, respectively, from the existing handle grip. Handle grip made of foam rubber was most preferred by all the subjects over the existing handle grip.

Kwatra et al. (2010) undertook an ergonomic study to compare paddy threshing activity by farm women using two methods viz. manual beating of paddy and by using manually operated paddy thresher. Study revealed that the physiological responses and physiological cost of work reduced significantly by using paddy thresher.

Lin (2011) investigated the factors of sitting discomfort of excavator seat with 20 subjects. The results showed that seat type significantly affects mean body part discomfort and mean subjective preference score. Hence, adjustment range of seat features and mechanism of seat can meet operators’ more requirements and decrease body part discomfort and increase subjective preference. Ali (2012) designed and developed a compound lever handle for hand pump. He observed reduction in force required to operate the pump and change in posture of the operator, resulting in less fatigue and stress.

Brief summary of ergonomic evaluation of farm equipment studies is presented in Table 2.

5 Discussion

In any anthropometric and/or strength parameter study some variables must be selected such as sample size (no. of subjects), type of subject i.e. male and/or female, region of population under study and uniformity of the sample. The sample size should be large enough in order to represent a particular population. Type of subject can be male and/or female depending on the workers involved in the work. The smaller the area in the study, the more suitable must be the population data in this region (nation, state or region in the state). Uniform sample for a state population is one in which equal number of subjects from all the districts or some districts which will represent entire state population. For ergonomics point of view uniformity of the sample is essential. Physical measurement of anthropometric dimensions is very time consuming process and also subjects are sometimes not ready (especially in case of female subjects). So some non contact type methods should be developed and used.

The data of male and female subjects may be used for designing tools separately for them. Further, considering the socio-economic condition and common habitual practice of the Indian farmers, the design of hand tools having the same dimensions for both men and women may be adopted by taking the same sample and computing the percentile values. Personalized tools are desirable when they are used by one person alone. When a number of workers use them computation of population data is essential because people differ significantly in their anthropometric characteristics (Okunribido, 2000). The percentile values may be used for designing common agricultural hand tools like, weed spade, sickle, paddy pullar, straw pullar, hoe, hand power tiller etc. for Indian workers particularly for Eastern India. (Kar et al. 2003).

The manufacture of agricultural machinery/equipment in India is quite multifaceted and comprises village artisans, tiny units, and small-scale industries. A little attention is paid by the manufacturers to incorporate anthropometric and strength parameters in the design due to economics involved and lack of awareness among manufacturers. Moreover, in India, in case of agricultural machinery, requirement of quality certification is limited to the sale of agricultural machinery financed under government schemes.

6 Conclusions

MSDs have been a widespread problem in agriculture. The proper matching of machine requirements with the human capabilities is basically necessary for optimum performance of any man–machine system and to guarantee safety of workers. For that, anthropometric and strength data have greatest importance in design and development of farm implements or machinery under ergonomic considerations. There are large differences in body dimensions between Western and Indian populations and even within Indian population, as they vary from region to region. In India, attempts are made to generate region specific anthropometric and strength data for agricultural equipment design, but they are limited to very few regions and in many studies only anthropometric data is considered. There is a need to go for extensive surveys focusing on both male and female farm workers in different regions of the country in order to generate region specific anthropometric and strength databases for safe and efficient design/modification of agricultural equipments.

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