Ergonomic Design Modification of 'Pedal Operated Paddy Thresher' Adoptable for Agricultural Needs of Northeast India

A thesis submitted

in partial fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

by

Thaneswer Patel

Department of Design
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Under the supervision of

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July 2015

DECLARATION

It is certified that the work contained in this thesis entitled "***Ergonomic Design Modification of 'Pedal Operated Paddy Thresher' Adoptable for Agricultural Needs of Northeast India***" is exclusively carried out by me, a bonafide student in the Department of Design, Indian Institute of Technology Guwahati, Assam, India under the able direct supervision of Dr. Sougata Karmakar being submitted for the award of Doctor of Philosophy. This work has never been submitted elsewhere for any degree, diploma or honour.

Date: July 20, 2015

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CERTIFICATE

The research work presented in this thesis entitled "***Ergonomic Design Modification of 'Pedal Operated Paddy Thresher' Adoptable for Agricultural Needs of Northeast India***" is a bonafide work of Mr. Thaneswer Patel, submitted for the degree of Doctor of Philosophy at Indian Institute of Technology Guwahati and carried out under my direct supervision. This work is original and has not been submitted for any other degree, diploma or honour to this institute nor to any other institute or university.

He has undergone four specified courses and fulfilled all the requirements as per the extant rules and regulations for the award of the degree of Doctor of Philosophy at Indian Institute of Technology Guwahati.

Date: July 20, 2015

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July 20, 2015 (Thaneswer Patel)
IIT Guwahati

ABSTRACT

Paddy threshing in northeastern region (NER) of India is carried out usually by traditional methods such as bullock treading, beating or crushing the grain by hand or foot, which requires an enormous human effort. These discomfited situations expose workers to many risk factors from ergonomics point of view. Furthermore, pedal paddy threshers available in this region are not suitable for local agricultural worker due to anthropometric incompatibility, substantial weight and lack of portability features. Therefore, the present research focused at ergonomic design modification of the existing pedal operated paddy thresher for making it suitable for the intended users as well as portable to carry across all terrains in NER; and India, at large. Among the seven states of NER, Assam is the largest one. Assam is among top 10 rice producing states of India and largest across NER. Agriculture and allied activities in Assam are considered as the mainstay of the economy and supports livelihood of its 70% people. Hence, in the present research endeavor to focus on NER India, a case study regarding design and development of pedal operated paddy thresher' has been reported based on studies carried out in Assam. Two hypotheses which were conceived for ensuring a proper direction to the research work are as follows:

H1. Regional anthropometric and biomechanical database are essential for design and development of agricultural tools and equipment suitable for agricultural workers of northeastern India, as those database are significantly different from other regional and national database of India.

H2. Design of agricultural tools and equipment for agricultural workers of Northeast Region of India should not only be as per anthropometric and biomechanical characteristics of the potential users but also to be portable to ensure easy and comfortable carriage at different terrains.

Anthropometric and biomechanical database which are the very first requirements for starting human centered design of equipment are not available for intended user group i.e. Assamese (residents of 'Assam', a state from northeast region of India) population. Therefore, the present research work was initiated with the standardization anthropometric and isometric strength (vertical leg strength and hand grip strength) data collection process through a pilot study involving 40 participants (male - 20 and female - 20). As there is no ready-made instrument available in the market for vertical isometric

leg strength measurement, a device was developed to measure isometric leg force at desired knee angles and calibrated for its reliability. Following the pilot study, field experiment was conducted for collection and compilation of anthropometric data of 27 body dimensions and isometric leg strength data (at knee angle 120 degree) of Assamese agricultural workers (sample size - 200, male - 130 and female - 70) were collected. Following statistical analysis, these anthropometric data were used for deciding the design dimensions of the modified thresher while isometric leg strength data were utilized for calculating actuating force for pedaling the thresher. When anthropometric data of agricultural workers of Assamese were compared with other states (Meghalaya, Mizoram, Arunachal Pradesh, Manipur, Nagaland and Tripura) of northeast region of India, significant ($p<0.05$) differences were observed for most of the body dimensions. Further, anthropometric data of Assamese agricultural workers were compared with different zones of India (viz. Northern, Southern, Eastern, Western, Central and Northeast region), in many cases significant differences ($p<0.05$) were noticed. Similarly, handgrip strength of Assamese agricultural workers were also found significantly ($p<0.05$) different while compared with the similar data from other regions zones of India (viz. Northern, Southern, Eastern, Western and Central) as well as various states from Northeast India like Mizoram, Arunachal Pradesh and Meghalaya. As vertical (standing) isometric leg strength data were not available for any other region / states of India, it was not possible to make any comparison with the collected data of Assamese agricultural worker population. Differences in anthropometric and biomechanical data of Assamese population in comparison to various regions of India as well as northeastern states indicate that regional anthropometric and biomechanical database are essential for design and development of agricultural tools and equipment suitable for agricultural workers of NER of India (establishing ***Hypothesis-I)***.

Two factual surveys were also conducted with manufacturers and users of the available pedal-operated paddy threshers to gather knowledge regarding (i) exploration of material, dimensional and other requirements for the paddy thresher and (ii) musculoskeletal issues and risks of operating the pedal operated paddy thresher. Following the surveys, a desired 3D-CAD model (using CATIA software) of portable paddy thresher was conceptualized based on brainstorming on feasible solutions. Important design features such as availability of proper clearance, protection from paddy dust, portable, compact size and safety in operation were also considered during creation of this model. The finite element analysis (FEA) using COMSOL Multiphysics Software was applied in order to predict deflection and stress distribution for the relevant components of the CAD model of the thresher, to make sure that it could sustain the applied load. For virtual ergonomic evaluation of the CAD model of the threshers (both the newly developed and the pre-existing), customized digital manikins (5^{th}, 50^{th} and 95^{th} percentile models of both male and female) representing diverse anthropometry of Assamese agricultural workers were created in DELMIA software. Following interfacing of digital manikins with CAD models of both the pre-existing and the newly developed threshers, various human factor aspects were evaluated to find out anthropometric compatibility of existing one and to what extent it has been solved in the new design.

Following required virtual ergonomic evaluations and thereafter necessary design modification of the thresher model, full-scale physical prototype was developed. The pre-existing and newly developed threshers were tested under both laboratory and field conditions to compare the physiological load (in terms of force requirement, muscle fatigue, body parts discomfort mapping, heart rate, energy expenditure etc.) as well as cognitive load (subjective ratings on NASA-TLX scale) during their operation. Newly designed pedal operated paddy threshers were found to be superior in comparison to the existing one.

Conventional combine harvesters or modern threshing machines are not feasible in NER of India, due to hilly topography (nearly three forth of total area of this region is hilly in nature), socio-economic conditions, small land holding etc. Anthropometric incompatibility and requirement of high actuating force for pedal operation are the main hindrance for wide adoption of existing / available pedal-operated paddy threshers in this region. Moreover, from contextual enquiry, it was found that the heavy weight (about 45.8 kg) and lack of dismantling feature make the available / existing threshers unsuitable for the hilly terrains of NER. Agricultural workers found it difficult to carry the threshers from their residence to agricultural land or for local transportation / shifting. Hence, weight of the redesigned paddy thresher was reduced to 23.5 kg (+ 3.5 kg for electric motor, if attached) with features for easy assemble / dissemble of components (i.e. cylinder, grain shield, frame and power transmission mechanism etc.). It would help in easy and comfortable carriage from one place to another. Thus, it could be stated that during design of agricultural tools and equipment for agricultural workers of Northeast

Region of India, designers / engineers should not only concentrate on anthropometric and biomechanical (muscle strength) data but also consider the use context and local topo-geographical conditions (establishing ***Hypothesis-II***).

Important design features of the newly developed paddy thresher considering the prerequisites of agriculture of NER are (a) grain shield for reducing spread of dusts / husks and thus respiratory protection; (b) 'chain gear' mechanism instead of 'four bar linkage' mechanism, to simplify power transmission system; (c) adjustable pedal height with variable range of movement to satisfy the user with varying lower limbs' heights; (d) attachable wheels for translocation of the thresher within short distance; (e) substantial reduction in overall weight of the thresher by modifying the design and selecting lighter materials; (f) easy assemble / dissemble of components (i.e. cylinder, grain shield, frame and power transmission mechanism etc.); (g) comfortable pedaling speed of thresher (i.e. 60 cycle per minute) to achieve the required minimum peripheral speed of threshing cylinder at ~300 rpm.

Key contributions of present thesis towards agricultural research:

- Design and development of first-of-its-kind indigenous isometric vertical leg strength measurement device along with subsequent normalization of its measurement techniques.
- Development of anthropometric and biomechanical reference database for Assamese agricultural workers (sample size - 200, male - 130 and female - 70).
- Application of digital human modeling based approach in design of agricultural machinery in Indian scenario.
- Final prototype of redesigned paddy thresher was fabricated and tested under both laboratory and field conditions to assess its usability, performance and acceptability among farmers.

Limitations of the present research and future research directions have also been elaborated in the thesis. The systematic approach of ergonomic evaluation techniques such as direct measurement, observational method and subjective assessment were found very useful for identifying and analyzing the various workloads and risk factors in order to improve agricultural workers' comfort, safety and productivity. Similar research

approach can be extended for ergonomic interventions and development of other agricultural tools and equipment. From present research it is evident that use of anthropometric and biomechanical data along with consideration of regional constraint of topo-geographic characteristics might help in design and development of suitable tools / equipment of the intended users. Moreover, this exercise of ergonomic design and evaluation method should be supported with state-of-the-art technology and know-how as demonstrated in current thesis. This type of research endeavor would not only improve occupational health and efficiency of the intended population but also improve their livelihood and living standard.

Keywords: ergonomics, product design, anthropometry, isometric strength, agriculture, CAD and DHM, physiological parameters

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Chapter 1

Introduction

Abstract – *North-east region (NER) of India comprises of the states of Assam, Arunachal Pradesh, Manipur, Mizoram, Tripura, Nagaland, Meghalaya and Sikkim, encompassing an area of 2.62 lakh sq. km. Even though NER has only 3.4% of land available for agricultural purposes, agriculture has been the main source of income, providing livelihood to ~70% of the population inhabiting herein. Unfortunately, the region is still lagging much behind than other parts of the country on various reckonings of agricultural development. NER farmers, thus compared to other Indian counterparts, mostly use locally manufactured age-old tools / equipment, which do not meet the local users' dimensional standards appropriately and thus, are incapable of providing better comfort, safety, thereby productivity. Use of mechanical power which is very limited in NER, confined to a few operations like threshing, ploughing, puddling etc. in plain land terrains only. In addition, several other factors also deem accountable for low productivity of agriculture like traditional subsistence farming, hilly terrain, unpredictable climate, smaller land holdings etc. Most of the agricultural activities use animal and human energy as the primary source of power. The multi-disciplinary approach of ergonomics appears vital to address the judicious involvement of human energy aimed at improving labour efficiency, reducing drudgery and improving safety, leading to uplift overall productivity.*

Agriculture has always been the lion-share contributor to our national economy; especially during the last four decades of green revolution, that ushered in the giant leap of progress in the area of crop production. The uplifted production of crops (e.g. food-grains from 50 million tons in 1950 to 241 million tons in 2010 - 11) is hailed as a cardinal breakthrough in Indian agriculture scenario. Agriculture and allied sectors, being the fulcrum of the Indian economy, contribute closely to 30% of the gross domestic product, thus encompassing over 70% of the gross population for their fundamental source of economy. Agriculture also provides raw materials for the manufacturing sector and therefore, stimulates industrial growth and non-farm incomes. However, despite its importance, full potential of agriculture has not been apprehended because of many factors like declining crop yields, decreasing farm sizes, use of inappropriate technology, costly farm inputs, lack of land use policies, to name a few. The size of Indian population is progressively incremental with relatively constant land for agriculture, rather gradually decreasing day by day – thus leading to the necessity to increase the production and yield, in order to meet the demand and supply for the increasing population. To match this supply with the rising demand, it is the need-of-the-hour to mechanize / automate different levels of agricultural operations and practices with less expenditure per unit area, along with consequent assurance of timely completion of the farm operations. Agricultural growth pattern is uneven across different regions of India and along with disparities among sectors and farming communities. The Northeast Region (NER) of India which is comprised of the states like Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim (Fig. 1.1)

Fig. 1.1 Map showing different states of Northeast Region of India

The NER is surrounded by Bangladesh, Bhutan, China, Nepal and Myanmar, are lagging behind, although bestowed with rich natural resources (Patel et al., 2013). Agricultural operations of the northeast, even today, are mostly dependent on old hand-tools employing animal power, human power or both. Output by such local tools and implements is very low with speciously high drudgery, because of poor knowledge of manufacturing material and technique. Mostly the local artisans and blacksmiths who manufacture the tools do not have relevant knowledge and proper training on latest manufacturing technologies. Furthermore, low productivity is attributed by several other factors like prevalence of shifting cultivation, hilly terrain, unpredictable climate, less frequent use of high yield options (seeds, tools etc.), poor mechanization etc. (Karmakar, 2008; Barah, 2006). Need-based mechanization can possibly be more convincing approach to increase agricultural output.

1.1 Northeast India – At a Glance

North East Region (NER) of India comprises of Arunachal Pradesh - the land of the rising sun, Assam - the home of Brahmaputra, Manipur - famous for Loktak lake, Meghalaya- the prettiest and the youngest state, Mizoram - the most peaceful state of NER, Nagaland - a place of rich, colorful tradition and great hospitality, Tripura - distinct agro-climatic zone of the country and Sikkim - the least populated state in the country. It constitutes of ~3.1% of the total Indian population (Chandramauli, 2011), with unevenly distributed population density having ~68% residence in Assam alone. The NER has about 96% long international boundary shared with China and Bhutan in the north, Myanmar in the east, Nepal in the west and Bangladesh in the south and west.

The hilly States i.e., Arunachal Pradesh, Meghalaya, Mizoram and Nagaland are predominantly inhabited by tribal people stretching upto 94.5% in Mizoram with Assam populating the minimum tribal life of 19.3% (NEC, 2008). The population distribution is predominantly rural with over 84% of them being villagers. NER is characterized by nominal or scanty opportunities in the manufacturing and public-private sectors leading to the population's indispensible reliance on the agricultural sector. Moreover, by virtue of having more than 64% of its geographical landscape under forest (Fig. 1.2), the larger part of this region is not available for agricultural manipulation (Patel et al., 2013).

The NER has distinct climatic variations within short distances, believed to be attributed by the rapid changes in topogeography. This region shows great variation in temperature throughout the year, from 15^{o}C to 39^{o}C in summer and -4^{o}C to 26^{o}C in winter. The total annual rainfall across the region varies from 2000 to 4000 mm, contributed mainly by the south-west monsoon from middle of May and continues till October (Patel et al., 2013).

Here, agriculture is extremely vulnerable to climate changes, and therefore any change in weather may affect the agriculture production and subsequently living standard.

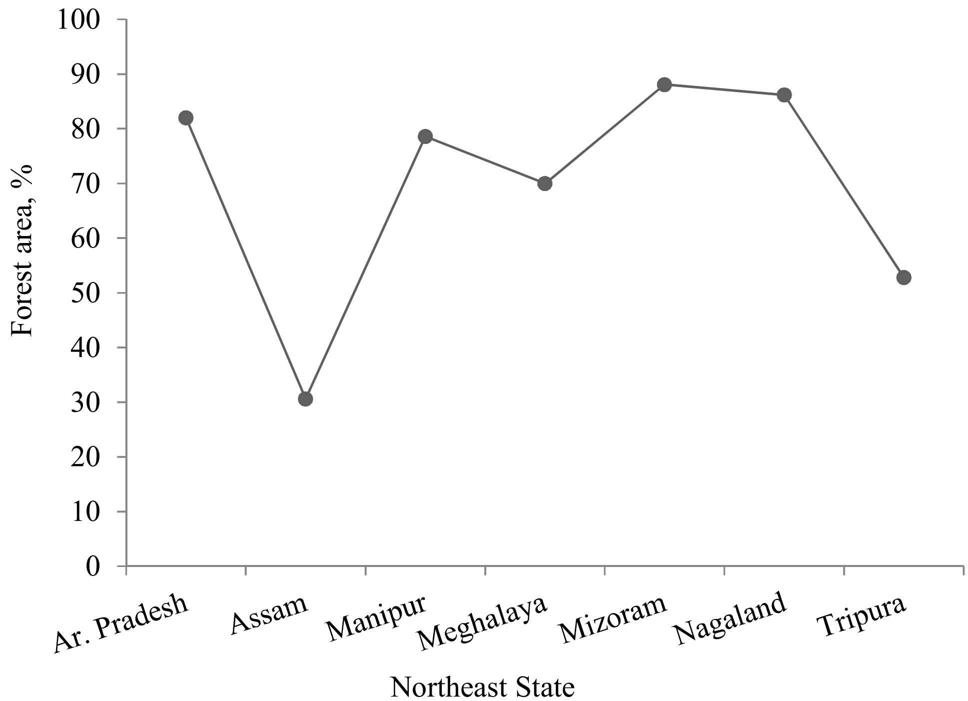


Fig. 1.2 The forest area present as % of geographical area of various states of NER of India (*Data Source: Patel et al., 2013*)

The average per capita income in NER lays pointedly below the average to that of the country with noteworthy difference in the standards of living between different states of NER. Assam, the largest among the NER states has the least per capita income being ~40% less than the country. The primary cradle of the NER economy is agriculture. Tribal populations in the hills have practiced shifting (Jhum) cultivation across generations. The Jhum cultivation started with a cyclic rest enough to recoup the soil fertility; but with increasing population density, the shift length has reduced considerably with substantial environmental damage. Despite the common belief that this traditional system should continue as the tribes are comfortable with it, in order to preserve forest land notwithstanding the increasing productivity and improving the income and living standard of the tribal population, it has become need-of-the-hour to gradually demonstrate the benefits of settled cultivation. Double cropping in Assam has generated very encouraging results and this should be implemented in the other NER states also. Special attention is required to upkeep increase in the productivity of miniature / micro lands held by the marginal and small farmers; since most of them are poor and self-freelancing in agriculture. It also calls for bringing under the plough vast tracts of vacant land lying largely unused. Agriculture being the primary source of the economy, increase in per capita income and improvement of lifestyle should be approached by achieving self-sufficiency in food grains production. The gross picture presented above thus calls for the advocacy of investment at a much augmented scale in these rural areas.

1.2 NER – The Agricultural Perspectives

Farming is practiced in different ways depending upon geographical conditions, levels of technology and available size of lands. Farming can be classified into two major types (i) Subsistence Farming and (ii) Commercial Farming as shown in Fig. 1.3.

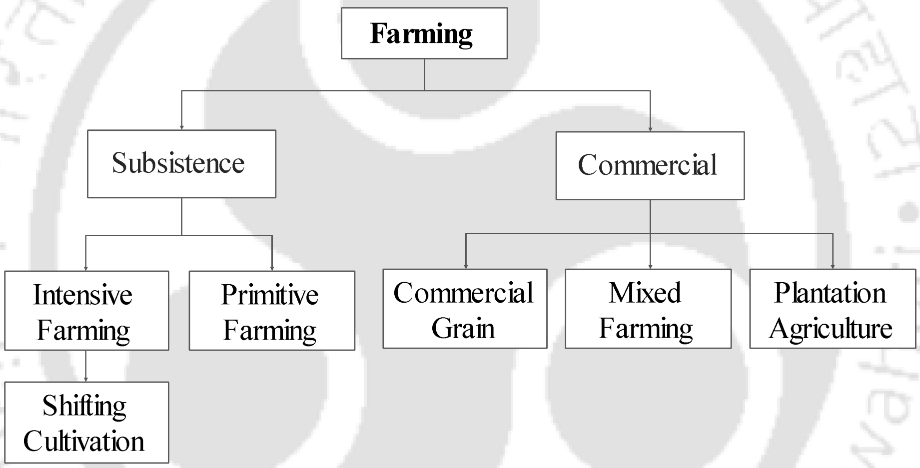


Fig. 1.3 Different types of farming practices used in India

Subsistence farming can be further classified as *intensive subsistence*, where the farmer cultivates a small plot of land using simple tools and more labor and *primitive subsistence*, the Jhum cultivation, also known as '*slash-and-burn*' farming. For commercial farming methods, *commercial graining* uses machines for most of the agricultural activities. In *mixed* farming, the land is used for growing food and fodder crops and rearing livestock. *Plantations* are that type of commercial farming, where single crop of tea, coffee, sugarcane, rubber, banana etc. are grown over a large area. The *NER is characterized as subsistence agricultural practices* with settled cultivation in plain land, valleys, foothills and terraced slopes; and shifting cultivation on hill slopes. Due to prevalence of hilly terrain, settled cultivation constitutes only a small segment of the total cultivated land and is mostly confined to the valleys only. Around half a million hectare land and nearly 600,000 families are involved in shifting cultivation all over India, out of which 90% are from NER (Keitzer, 2001) – thus entitling NER to be appropriately popular as '*the land of shifting cultivators*'. Shifting cultivation is practiced nearly over 19.91 lac hectare, accounting for ~83.73% of the total shifting cultivation lands of India (GOI, 2000; Mandal, 2011). Shifting agriculture involves cutting down a patch of forest partially or fully, leaving them to dry and finally burning them. In the cleared land, seeds are dibbled into holes or broadcasted without using ploughs or animal power for crop cultivation (Jeeva et al., 2006). After harvesting the crops, the used field is left to lay 'fallow' for periods of varying length to allow for natural succession for crop harvesting in next season.

Fig. 1.4 Agricultural activities in paddy cultivation (*Source: flickriver*)

Settled cultivation, actually the permanently maintained mode of cultivation, ought to replace the erstwhile shifting cultivation (Fig. 1.4). Out of the total geographical area in NER, 54.4% consists of forest and ~14.5% comprises existing settled cultivation (Mishra and Misra, 2007). Settled cultivation is done by crop rotation, unlike field (plot) rotation in Jhum. The main advantage of this cultivation is the consistency of yield across seasons on the same field, if climate and soil conditions permit. Loosening and breaking up (tilling) of the soil is generally done by animal or mechanical power such as tractors, power tillers, mechanized ploughs mostly in plain lands. In fact, mostly the work is done by human power only using traditional low-end technologies. Meagre knowledge and lack of modern inputs in agriculture is the challenge of today for the farm households to cope with high risks in production and income.

1.3 Agricultural Mechanization Status in Northeast India

The main foundation of NER economy grounds on agriculture – the major lattice of employment and livelihood for around 80% of the population. Apart from the economic condition of these people, their socio-cultural facets also are largely shaped by agriculture; because the NER has a workforce of 41.6% cultivators and 13% tenant farmers. The land-to-person ratio for the NER (0.68 hectare per person) is much higher than the national average (0.32 ha per person) (Patel et al., 2013). Yet the NER states continue to import food grains even for their own sustenance, despite covering 8.8% of the country's total geographical area – they contribute to only 1.5% of the country's total food grains production. Poor agricultural productivity of the region is primarily due to low-end agricultural inputs along with lack of location-specific and system-based technologies. Assam has the largest cultivatable land among NER states; still having extremely poor levels of farm mechanization with human, animal and mechanical farm power of about 68, 152 and 6 watts respectively (Anon., 2000).

Use of mechanical power which is very limited in NER, confined to a few operations like threshing, ploughing, puddling etc. in plain land terrains only. In the plain areas, limited span of landholdings (0.63 acre per usable holding in Assam) of the region preclude mechanization of agriculture. In fact, farm power available per unit cropped area in this region is ~0.67 kW/hectare, which is much below the national average of ~1.15 kW/hectare (Kaul, 2001). The average plot size is too small for mechanization of agriculture and adoption of modern farming practices, ranging from 0.60 hectare in

Tripura to 1.33 hectare in Meghalaya as compared to 1.42 hectare at all-India level. This is primarily because hilly terrain constitutes nearly two-third of the NER topogeography, and large sized holdings are not feasible.

Underprivileged mechanization is one of the key constraints for deprived agricultural productivity in NER. Owing to this, agriculture in this region has never been able to generate surplus for investment to augment livelihood, leaving the possibility to speak of employment generation far beyond. However, the pattern of agricultural growth has remained uneven across regions (Fig. 1.5). The total land under cultivation is highest in Assam compared to other states of northeast India. In 2010-2011, Tripura recorded highest food grains yields among the NER states and Mizoram, the minimum. Achieving self-sufficiency in crop-yield necessitates special emphasis to mechanize agriculture, practice mechanized farming, encourage hybrid cropping and thus to move from subsistence farming to 'cash crop' type.

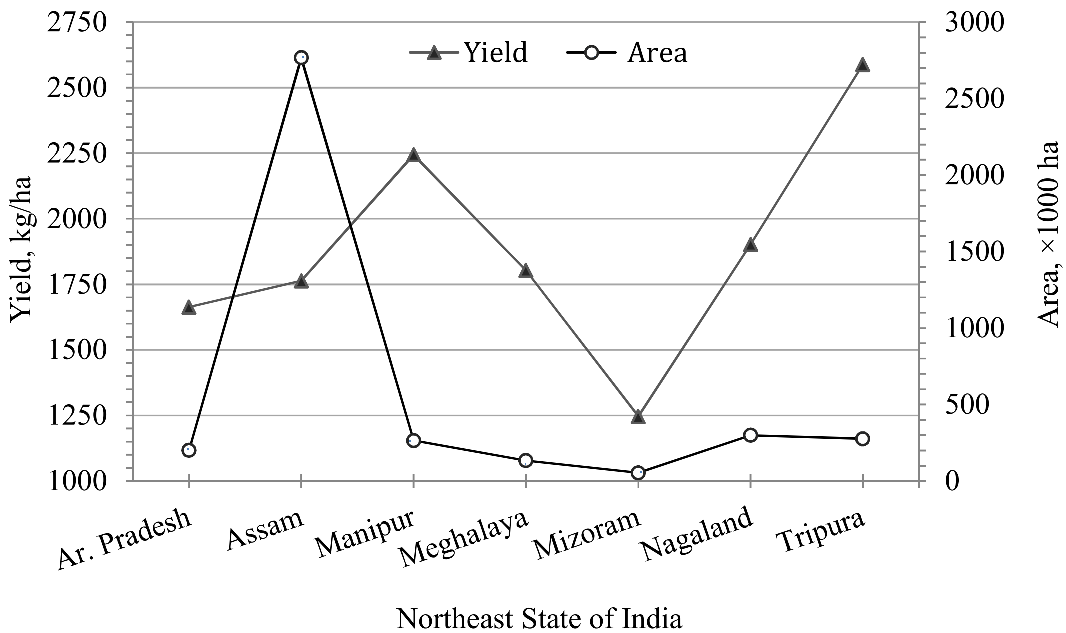


Fig. 1.5 Area and yield of foodgrains production in NERI, 2010-11
(*Data source: NEDFi, 2010*)

Although paddy is one of the major cultivated crop in NER, paddy threshing has witnessed very little course of evolution over the decades. The different means of threshing continue to be the traditional such as rubbing the crop against an abrasive surface, animal treading and beating the crop against stationery objects (Fig. 1.6).

Rubbing with foot

Beating on surface

Treading on the road

Animal treading

Fig. 1.6 Traditional methods of paddy threshing seen in northeast India

Threshing operation requires a considerable amount of energy. On an average, a healthy labourer can thresh about 15-22 kg/h of grain by hand-beating or 110-140 kg/h by treading the grain by animals. In either way, solid grains are separated using a winnower operated by human or by a power unit or dropping the mix against the medium to high natural wind. Thus, the separation of solid grain and manual bagging require additional labour, making the entire process tiresome and time-consuming. It thus brings down the overall threshing ability of a labourer to 12-18 kg/h in manual threshing and 80-120 kg/h by animal treading. Therefore, using some mechanical threshing means helps one to thresh more grains in a shorter timeframe, reducing the loss and thus, boosting the final productivity. Therefore, a low-cost paddy thresher appears to be inevitable for small and marginal farmers of this region. It has to be lightweight, portable and fairly mobile for easy transport from one terrain to another. Their design should be basic, uncomplicated and thus convenient for production by local small manufacturing units in rural areas.

1.4 Northeast Agriculture – Ergonomics Awareness Status

The agricultural cultivation practices down the hills differ from the plough cultivation in the plains. Working and living conditions of agricultural workers are commonly poor throughout NER. Several households located at extremely remote and adverse terrains are virtually never exposed to the feasibility and advantages of modem cultivation features. Exasperating physical work, inappropriate working techniques and ill-mechanised tools not only results in undue fatigue and occupational risks, but also leads to truncated productivity. The improvisation of safety, health, well-being and productivity are basic requirements for prosperity of any community; and judicious use of available farm powers by the farmers plays a very important role therein. Whereas plain land mechanised cultivation practices flourished nationally, age-old farming practices dominates the NER, leading to a slow upcoming of mechanization in NER over the decades. This is perhaps due to socio-economic conditions of the natives, fragmented land and lack of industries manufacturing farm machineries, in comparison to that technically possible around the rest of India. Most of the agricultural operations are labour intensive and performed manually with the help of hand tools (not designed ergonomically) resulting in low yield and very high drudgery, which nurtures many adverse issues on farmers' safety, comfort, working efficiency etc. – unfortunately very often overlooked.

Although across India, anthropometric and biomechanical database of agricultural workers have been compiled and utilised by various researchers for design, development, design modification of various tools and equipment; while anthropometric database (Dewangan et al. 2005, 2008 and 2010; Agrawal et al., 2010) and muscular strength database (Dewangan et al. 2010a; Agrawal et al. 2009) are mostly incomplete for hilly NER agriculture. Moreover, tools / technology based on database from other topo–geographic areas can never be adopted blindly due to the dissimilarity of anthropological, socio-cultural and economical characteristics of farmers of this region from others. Furthermore it has been observed that, very limited work has been done for tools and equipment used in hilly terrain agriculture. Indeed it has also been shown in different circumstances that, although farmers are rational and intelligent enough, technological stagnation or slow improvements may still withstand them. Application of practical knowledge from various disciplines of ergonomics like agricultural ergonomics, occupational health and safety, environmental ergonomics and design ergonomics may be useful for developing sustainable agricultural practices leading to a better productivity and uplifted farmers' wellbeing. Anthropometric, biomechanical and environmental database along with information regarding cause and prevention of injury / accidents, socio-economic ethnicity of people are basic requirements for design and development of appropriate tools / equipment; while need-based ergonomic designs in NER principally lack such database. Therefore, introduction of improved technology in the present farming system demands selective use of mechanization with ergonomic design criteria fitting the target users. The database for anthropometry, strength and physical work capacity must be standardised first to intervene comprehensive and realistic user-friendly solutions so as to ensure workers' strength, skills and abilities through improved design and application. This, in turn, will impart multilevel impact on holistic socio-economic makeover of tribes towards sustainable development.

1.5 Scope and Rationale behind Present Research

Agriculture supports livelihood for more than 70% of NER population. The agriculture based economy in this region is mainly characterized by the typical low yield, technically unmatched with its theoretical feasibility. Need-based farm mechanization is the focal conduit in improving the productivity, profitability and sustainability in agriculture. While designing various agricultural hand-tools and equipment for NER, little attention has been given to the users' competencies and limitations (Dewangan et al. 2005, 2008 and 2010; Agrawal et al. 2009 and 2010). Cases of injuries and morbidity among agricultural workers may be reduced with relatively low cost ergonomic interventions, remediating other risk factors inherent in tool design and working environment, thereby finally securing the task itself. Any improvements in mechanical farming process, methods or working environment are considered under basic ergonomic interventions for enhancement in comfort, safety and overall productivity. The importance of the present piece of research is to develop a database of target user population, essential for designing agricultural tools and equipment (like, the paddy thresher in present research), as well as to opine design recommendations therein; because any improvement in agricultural mechanization has always been, and will ever remain the chauffeur of agricultural growth.

The socio-economic condition of Northeast Region of India largely depends on agriculture. Rice is the predominant food for the people of NER. As mentioned earlier (section1.3), use of some mechanical threshing means would be helpful for efficient threshing of more paddy in a shorter timeframe. Therefore, a low-cost paddy thresher appears to be inevitable for this region. Moreover, mechanical thresher operated by human power intended for NER to be designed considering the topo-geographic characteristics of NER; small and marginal land holdings; socio-economic condition of the agricultural workers and anthropo-biomechanical characteristics of the targeted user population. Among the eight states of NER, Assam is the largest one. Assam is among top 10 rice producing states of India and largest across NER. Agriculture and allied activities in Assam are considered as the mainstay of the economy and supports livelihood of its 70% people. More than 50% of farmers are engaged in cultivation of paddy and its allied activities. Assam is a state where paddy cultivation is practiced in both pain land and hilly terrain. Hence, in the present research endeavor to focus on NER India, a case study regarding design and development of pedal operated paddy thresher' has been reported based on studies carried out in Assam.

Paddy threshing in Assam is carried out by traditional methods such as bullock treading, beating or crushing the grain by hand or foot, which requires an enormous physical effort. Conventional combine harvesters or modern threshing machines are not suitable in this region owing to socio-economic conditions, small land holding etc. Therefore, a systematic approach complying ergonomic design needs of paddy threshing operation along with the users' physiological determinants and other important factors (if any), deems to be the most crucial yet fundamental step to understand the scope of the problems and eventually advance the scenario.

1.6 Lacuna – Queries to be Resolved

With the existing paddy thresher, one has to apply greater force (Mohanty et al., 2008) in a maintained awkward posture, which is highly susceptible to the risk of muscle injury. Till date, there is only one literature support against anthropometric database of Assamese agricultural workers (n = 40; Dewangan et al., 2010). Therefore, there is a crucial need to develop/generate a larger sample size of anthropometric and biomechanical database to facilitate research and development in Assam agricultural scenario. Since a regional database is more appropriate to consider while undertaking any research with that very regional population.

There is no published/formulated database in the area of vertical isometric strength required for pedal threshing job so far. Existence of such database is a fundamental requirement for evaluation of performance on a pedal operated paddy threshing equipment and recommendations for design modification there to, if any.

The above discussion regarding problems and design flaws of the existing paddy thresher gives rise to some questions needs our serious attention towards ergonomic resolution.

1. How could understanding of ergonomics knowledge related to design and manufacturing contribute to develop a portable paddy thresher which is more acceptable to the farmers across all terrains of the NER?
2. How could design modification of existing paddy thresher improve farmers convenience across all terrains ensuring due safety, thereby enhancing performance, efficiency and, finally the productivity?
3. What should be the efficacy of the new design in terms of feasibilities like minimizing requirement of rest-pause and pedaling force (leg strength), thereby ensuing longer stretch of performance (man-hour to work-hour), thus making the product more user friendly?

1.7 Aim

Aim of the study was to develop a prototype of 'pedal operated paddy thresher' adoptable for agricultural need of Northeast India, using strategies of ergonomic design interventions.

1.8 Objectives

To achieve the aim, following objectives were articulated:

1. To develop anthropometric and biomechanical (relevant to pedal operated paddy thresher operations) normative database of Assamese agricultural workers.
2. To simplify the working mechanism of the pedal operated paddy thresher by replacing power drive (gear-based) with chain-based mechanism ensuing unaffected or better performance.
3. To evaluate the superiority (in terms of operational force, anthropometric compatibility, working posture, performance, efficiency productivity, cost effectiveness, portability in diverse terrain etc.) of the proposed design intervention in comparison to existing one through laboratory and field testing.

1.9 Hypothesis

In-depth study and understanding of the various aspects of paddy threshing by traditional methods like bullock treading, beating or crushing the grain by hand or foot which requires a large amount of energy and hard physical labor. Ergonomic design intervention considering operational demands of the machine and operator's capability may improve productivity and work efficiency. Thus, two specific issues were considered to be addressed. At first, attempt was made to collect anthropometric and biomechanical database of targeted user group and secondly, effort was made to develop portable paddy thresher compatible with end-user's physical capabilities and limitations. Two hypotheses which were conceived for ensuring a proper direction to the research work are as follows.

H1. Regional anthropometric and biomechanical database are essential for design and development of agricultural tools and equipment suitable for agricultural workers of northeastern India, as those database are significantly different from other regional and national database of India.

H2. Design of agricultural tools and equipment for agricultural workers of Northeast Region of India should not only be as per anthropometric and biomechanical characteristics of the potential users but also to be portable to ensure easy and comfortable carriage at different terrains.

1.10 Framework of the Research

This thesis made an attempt to apply various ergonomic theories and assessment techniques for design intervention of tools and equipment suitable for hilly region of agricultural workers. The research design adopted to accomplish the research goal for the thesis is shown is Fig. 1.7. The aimed of the research was to find out feasible alternative solution of traditional methods of paddy threshing. Therefore, different risk factors associated with manual paddy threshing activity were reviewed systematically and issues were identified. Anthropometric and biomechanical database which are the very first step for starting human centered design equipment, not available for targeted user group i.e. Assamese population. Therefore, context specific, vertical force measuring device which is not available for procurement in local and national market for biomechanical force analysis was developed in Department of Design at Indian Institute of Technology (IIT) Guwahati. This device would help to acquire isometric vertical push force of legs. A pilot study was conducted for standardization of anthropometric and muscular strength data collection procedures. Pilot study helped for addressing some important issues related to accuracy, repeatability and reproducibility of data measurement. For anthropometric data collection, a pilot study was conducted for 40 participants (Male - 20 and Female - 20) for measurement of a set of twenty five body dimensions. Each anthropometric measurement was carried out twice in consecutive days, once by each observer, who records their results independently.

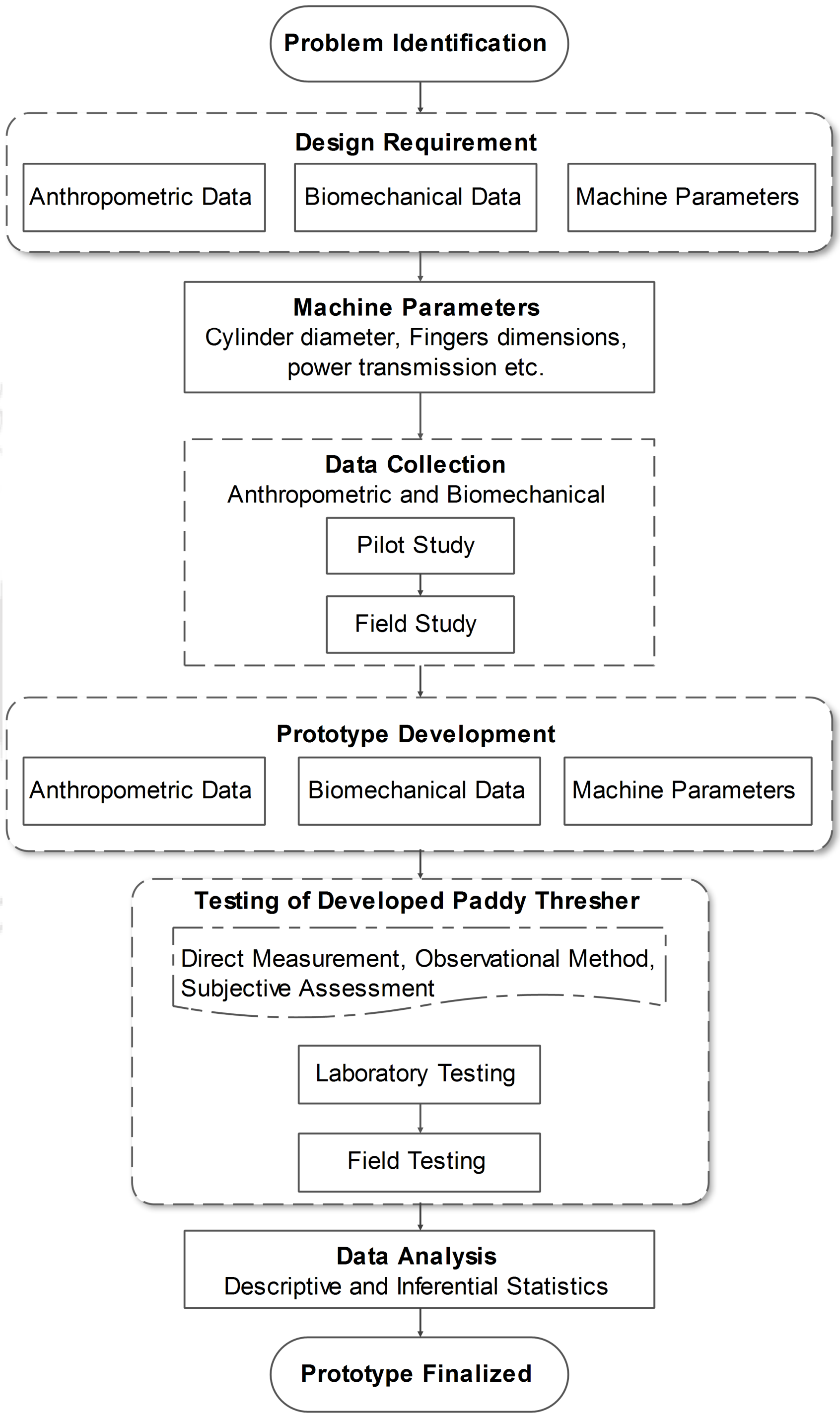


Fig. 1.7 Schematic diagram of the research design followed for present work

Reliability and technical error of measurement for twenty five anthropometric parameters were assessed. The intra-observer assessment was performed with the data collected by the same observer on different days. However, inter-observer assessment was performed with the measurements made by two observers on the same days. Technical error of the measurement (TEM), relative technical error of the measurement (%TEM) and coefficient of reliability (R) were calculated. Similarly, a pilot study was conducted for vertical leg force measurement of same participants under different knee joint angles i.e. 90°, 120° and 150° for both dominant and opposite legs. Based on the results of vertical force measurement at three different knee angles, 120° knee angle was considered for field survey. A representative sample of 200 participants for anthropometric and biomechanical, is selected to attain good correlation (r >0.8) with 90% and 95% power and significance level, respectively (Chandrasekaran et al., 2010).

A systematic assessment of the outcome was carried out for design intervention of pedal operated paddy thresher. Trial and testing of developed and existing paddy threshers were carried out in laboratory and field condition to evaluate efficacy/efficiency/productivity. The various tools and instrument used for assessments are EMG, Heart Rate monitor, Body Pain Map, Borg's pain scale, RULA, NASA TLX etc. Thus, the research design was broadly divided into three phases i.e. Anthropometric and biomechanical data collection, design intervention of pedal operated paddy thresher, and evaluation of the proposed intervention.

1.11 Layout of the Thesis

As per the content of the work and chronological order of the various activities during the research, the thesis is divided into five chapters as given below:

Chapter - 01	Introduction
Chapter - 02	Design, Development and Calibration of Isometric Vertical Leg Strength Measuring Device
Chapter - 03	Development of Normative Anthropometric and Biomechanical Database for Assamese Farmers
Chapter - 04	Ergonomic Design Modification, Testing and Evaluation of Pedal Operated Paddy Thresher
Chapter - 05	Summary and Conclusion

First Chapter of the thesis outlines the background, motivation and rationale of research. This chapter is a justification of the research which establishes the need to study tools and equipment design compatible to anthropometric and biomechanical database of prospective user groups. It reviews existing methods of paddy threshing in NER. It describes the problems of traditional methods of paddy threshing and possibility of ergonomic intervention to overcome various musculoskeletal disorders associated with threshing activities. The final section explores the various research gaps for posing specific research questions leading to the proposed hypothesis for thesis work.

Second Chapter deals with the importance and need of isometric vertical force measuring device. The detail procedures for development and testing of isometric vertical force measuring were discussed. The product features were tested with 3D virtual environment with digital human manikins before finalizing for prototype development.

Third Chapter contains tools, techniques, and methodologies for measurements of anthropometric and biomechanical database. A pilot study has been conducted for standardization of anthropometric and muscular strength database collection procedures. The sampling plan for field survey including locations, number of subjects required and subject demographics have been defined. The statistical analyses validated the overall outcomes pertaining to the compilation of the reference normative anthropometric and biomechanical database. The results of the research findings have been explained and compared with other research findings.

Fourth Chapter covers development and step by step methodology for ergonomic evaluation of pedal operated paddy thresher. Participatory approach has been used for design intervention of equipment i.e. paddy thresher, taking the views of the workers and their requirements appropriate for the given context; leading to conceptualization of a portable paddy thresher, development of its 3D model, determination of the strength of critical parts of the machines using finite element analysis and finally, followed by design and fabrication of the physical prototype conforming ergonomic principles. The final workout involved the experimental trials (both lab and field) to evaluate and compare the ease, safety, economy, comfort, portability and other advantages of the developed paddy thresher over the existing one.

Fifth Chapter abridges the complete research work carried out (starting from pilot and field survey studies, through development of isometric strength measurement device, a series of design and evaluation done for paddy thresher at various stages, upto results obtained from laboratory and field testing etc.). Conclusions based on the findings of the studies undertaken herein have been placed here. Furthermore, this last chapter of the thesis also labels the novel contributions along with how hypotheses of the present research have been validated.

Chapter 2

Design, Development and Calibration of Isometric Vertical Leg Strength Measuring Device

Abstract – *The precise measurement and analysis of isometric vertical leg strength is one of the key determinants of users' effort and related efficiency regarding the operation of any pedal-operated equipment. This would help to optimize users' performance, thus minimizing the requirement of rest pause. An exhaustive review of literature reinforced a meager of such important database of strength, with no such measuring device available / reported. Therefore, one of the objectives of this research was to design an isometric vertical force measuring device. The device consisted of the three main components namely the pedal, pedal frame and load cell; lifting and lowering mechanism fitted in the main frame. The finite element analysis (FEA) was performed using the 3D-CAD model of the conceptualized isometric force measuring device, in order to predict deflection and stress distribution accurately for the relevant components, and also to reassure its operational safety. The calibration of the developed system showed excellent agreement between measured and predicted values (*R^2 *= 0.999). Therefore, the developed strength measuring device was considered reliable for measuring the isometric vertical leg strength, and thus contemplated advantageous for evaluation of human efficiency for human–machine interfaces.*

2.1 Introduction

Human muscular strength finds its most extensive use probably in Indian agriculture for operating various push-pull type farm tools and equipment. Typically the uses encompass lifting, lowering, pulling, pushing and carrying objects by hand. Incongruity between users' physical dimensions (anthropometric and biomechanical) and physical workloads to operate tools / equipment often leads to poor performance, resulting in low output due to safety concerns. Although anthropometric data are commonly considered for ergonomic designs, an inadvertent negligence of referring to strength database while designing agricultural tools / equipment is also very common in countries like India. Therefore, design of tools and equipment through research on human biomechanics is today's need-of-the-hour, since implementation of biomechanical database would be advantageous for instigating comprehensive and user-friendly solutions to ensure appropriate utilization of user's strength, skills and abilities, through improved equipment and workplaces. In other words, ergonomic design of tools / equipment is a negotiation between user's physical capacities and energy / force demands by tools and equipment in use (Dhimmar et al., 2011; Chandra et al., 2013). Therefore, ergonomic design of farm tools and equipment by designers and manufacturers solicits immense importance to the database of hand push-pull forces or leg / foot forces exerted by operators (Agrawal et al., 2009) to prevent prevalence of musculoskeletal issues (Mital and Kumar, 1998).

2.2 Background

Near about 58% of Indian population is engaged in agriculture spread over 640,000 villages, representing ~10% (225 million) of global agricultural workforce (Nag and Nag, 2004). Despite countrywide advancement of farm mechanization during the recent decades in Indian agriculture, human muscular strength is still extensively used for operating various push-pull type farm tools and equipment such as manual ridgers, rotary dibblers, rice transplanters / seeders, push / pull weeders, field rakes, long-handled tools, chaff cutters, groundnut / castor decorticators etc. (Tiwari et al., 2010; Agrawal et al., 2010). Leg and foot operated controls on machinery and equipment such as the foot operated sprayers, threshers and dibblers are prominently used in India (Yadav et al., 2010). These activities impose a critical extent of psychophysical exhaustion on farm workers. With an aim to reduce the human exertion considerably, 16 strength variables were identified and recommended by All India Coordinated Research Project on Ergonomics and Safety in Agriculture, India (Gite and Chatterjee, 1999) for ergonomic design of such farm tools, as appended hereunder.

1 Right hand grip strength,
2 Left hand grip strength,
3 Preferred hand grip torque,
4 Left hand push strength in sitting posture,
5 Right foot strength in sitting posture,
6 Left foot strength in sitting posture,
7 Right leg strength in sitting posture,
8 Left leg strength in sitting posture,
9 Left hand pull strength in sitting posture,
10 Both hand push strength in standing posture,

11 Both hand pull strength in standing posture,

12 Right hand push strength in sitting posture,

13 Right hand pull strength in sitting posture,

14 Preferred hand torque strength in standing posture,

15 Torque strength in standing posture-both hands, and

16 Both hand torque strength in sitting posture.

Unlike the fairly extensive strength database existing for Western populations (Xiao et al., 2005; Yadav et al., 2010), availability of strength data of Indian agriculture workers are quite limited (Mehta et al., 2007; Agrawal et al., 2009; 2010; Yadav et al., 2010; Tiwari et al., 2010; Gite et al., 2009; Dewangan et al., 2010) and even the available information is seldom utilized by the manufactures. It is an accepted point that any efficient and ergonomic design takes both the anthropometric dimensions and strength parameters of intended users into account. Strength database have paramount importance for ergonomic design and development of farm tools (Vyavahare and Kallurkar, 2012). The required amount of force developed by the human musculoskeletal system depends on factors like race, gender, age, body weight and lifestyle (Gite and Singh, 1997). The amount of force exerted depends on the following factors:

- ✓ Strength of muscle,
- ✓ Strength of bone,
- ✓ Structural geometry of the body,
- ✓ Extent of physical exhaustion of the person, and
- ✓ Psychological factors like willingness / motivation of the person.

Normative / standardized database of muscular strength of any population (equally applicable for agricultural workers also) stands to be the fundamental requirement to determine effective percentile force for operating any tools / equipment. Depending on application, a certain percentile of strength value can therefore ensure that, majority of the given working population should be able to perform an assigned task (like clutch and brake, gear-shift lever, gear control lever, accelerator pedal, human powered push-pull equipment etc.) without undue fatigue and discomfort. Greater and repetitive demand of muscle strength to perform any physical task is a potent contributor for development of any kind of musculoskeletal problems.

The relationship between the physical demands of the task and the competencies of the user is of immense practical importance for designing tools, equipment, and consoles. Compatibility of tools and equipment according to physical capacity of users is frequently endorsed for manual materials handling activities. This controls injury by reduction of muscle overloading. Strength of thigh and calf muscles plays an important role in employing the vertical force required to operate a pedal-operated or gear-based paddy thresher. The thigh muscle contracts and calf muscle extends while pushing the pedal downward. During this process, the leg extends and the angle between leg and thigh (knee angle) increases from its initial value. The knee angle is shown in Fig. 2.1 while measuring force in standing posture. Therefore, knowledge of human strength capabilities and understanding of the key elements involved is an important consideration in design (Mital and Kumar, 1998).

Any agricultural activities with a repetitive nature of execution should ergonomically be so designed that, the requirement of working force will never exceed 30% of the 5th percentile value of maximum strength of corresponding female working population. This will ensure the force to be executed well within the safe limits. The force exerted may be raised up maximum to 50%, till the effort applied is below 5 min (Agrawal et al., 2009; Gite et al., 2009; Tiwari et al., 2010).

Fig. 2.1 Measurement of leg strength in standing posture at 130^0 knee joint angle

In some instances, where the physical tasks are performed by male agricultural workers (like operation of tractor clutch, brake and steering etc.) only, required working force should be set at 5th percentile of maximal strength value of male workers. For example, the sickle is used by both male and female workers with characteristic pull / sawing mode of operation for more than 5 min. Therefore, 30% of 5th percentile value of pull force with right hand in sitting posture for female workers was considered using 30% criterion. Gite et al. (2009) recommended pull force with right hand in sitting posture 12 N for Indian population. On the other hand, for the tractors mainly operated by male workers, required working strength of males should only be considered for design of various controls in the tractor, such as clutch, brake, steering wheel and gear lever. These controls are operated frequently for short durations (less than 5 min) and therefore, required effective force may be calculated to be 30% of the 5th percentile of male strength value. The baseline information on various tools and equipment provided by Patel et al. (2014) would be helpful for design or design modification of agricultural tools – pertaining to the executed working force fairly within safe limit.

2.3 Requirement of Leg Strength Measurement Device

Determination of executable pedal force is a basic prerequisite to analyze the efficiency and proficiency of pedal-operated paddy threshers from a biomechanical perspective. Review of available literature perceived that, there was no information on isometric leg force in standing posture published or reported earlier, as well as no device is available till date for measurement of such isometric forces. Therefore, ergonomic design and development of a device prototype for measurement of leg force was a paramount requisite not only to serve the purpose of this study, also a first-of-its-kind simplified supporting instrumentation to augment prevailing research trends and interest, in addition to its distinctive contribution for developing the standardized / normative database for isometric vertical leg strength. One of the objectives of this research was to develop an isometric leg strength measurement device suitable for the 5th to 95th percentile range of the population.

2.3.1 Essential design principles

Before embarking on the design and development of the said measurement system, following principles were defined as relevant: (1) versatility, (2) safety, (3) comfort, (4) use-reuse flexibility, (5) system calibration, (6) accuracy and (7) cost.

1. *Versatility* is the capability to measure 5th to 95th percentile range of force for different body dimensions, so as to conduct comparative studies conveniently.

2. *Safety* of the equipment ensures user's safety during the measurement of isometric vertical strength. Furthermore, participants should perceive the system to be stable and safe to demonstrate true maximum strength exertions.
3. *Comfort* of use makes the equipment more users friendly and provides the user with a feeling of better acceptance and effortlessness.
4. *Use-reuse flexibility* assures convenient resetting / calibration of equipment between consecutive trials, so that data collection of all the measurements of same person is possible with short rest pause period, thus facilitating data collection.
5. *System calibration* entails the equipment to be factory calibrated so as to compensate for gravitational force and any dead load of device itself; and isolate this from the user exerted force components.
6. *Accuracy* of the device makes it free from random and systematic errors (except inbred mechanical error negligible or nearest to zero) to ensure precision of measurements across different trials.
7. *Cost* of the instrument should be economic enough and thus affordable to the local working population, without compromising in precision of measurement.

2.3.2 Development of the device

The process of product development consisted of two phases (Fig. 2.2) – ideation and prototyping. The ideation phase entailed about research, brain storming, concept generation and concept refinement of selected ideas; whereas prototyping phase comprised of visualization, concept detailing, test and refine prototype, finally leading to product development.

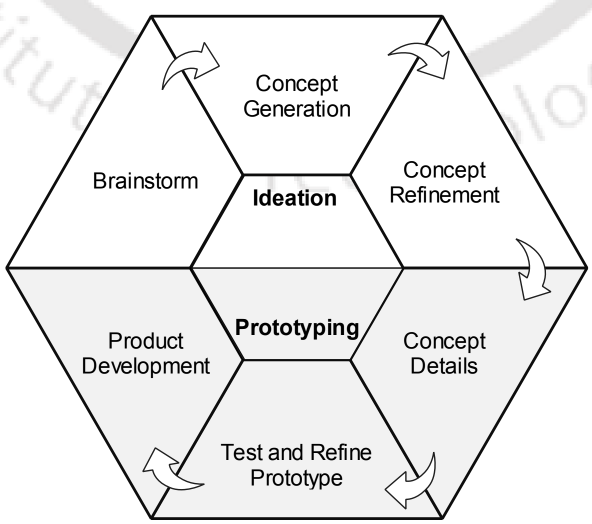


Fig. 2.2 Product development process followed in present study

2.3.3 Conceptualization

Based on the available information and research inputs gathered therefrom, various ideas were hypothesized to explore possible means to measure isometric vertical leg strength. Thus the objectives of the isometric leg strength measurement in standing posture came up with several approaches to satisfy the parametric requirements. A series of sketch explored the concepts / options for product outlook, working principle, manufacturing and assembling feasibilities. Some of the competent thoughts for the proposed isometric vertical force measuring device were depicted in Fig. 2.3.

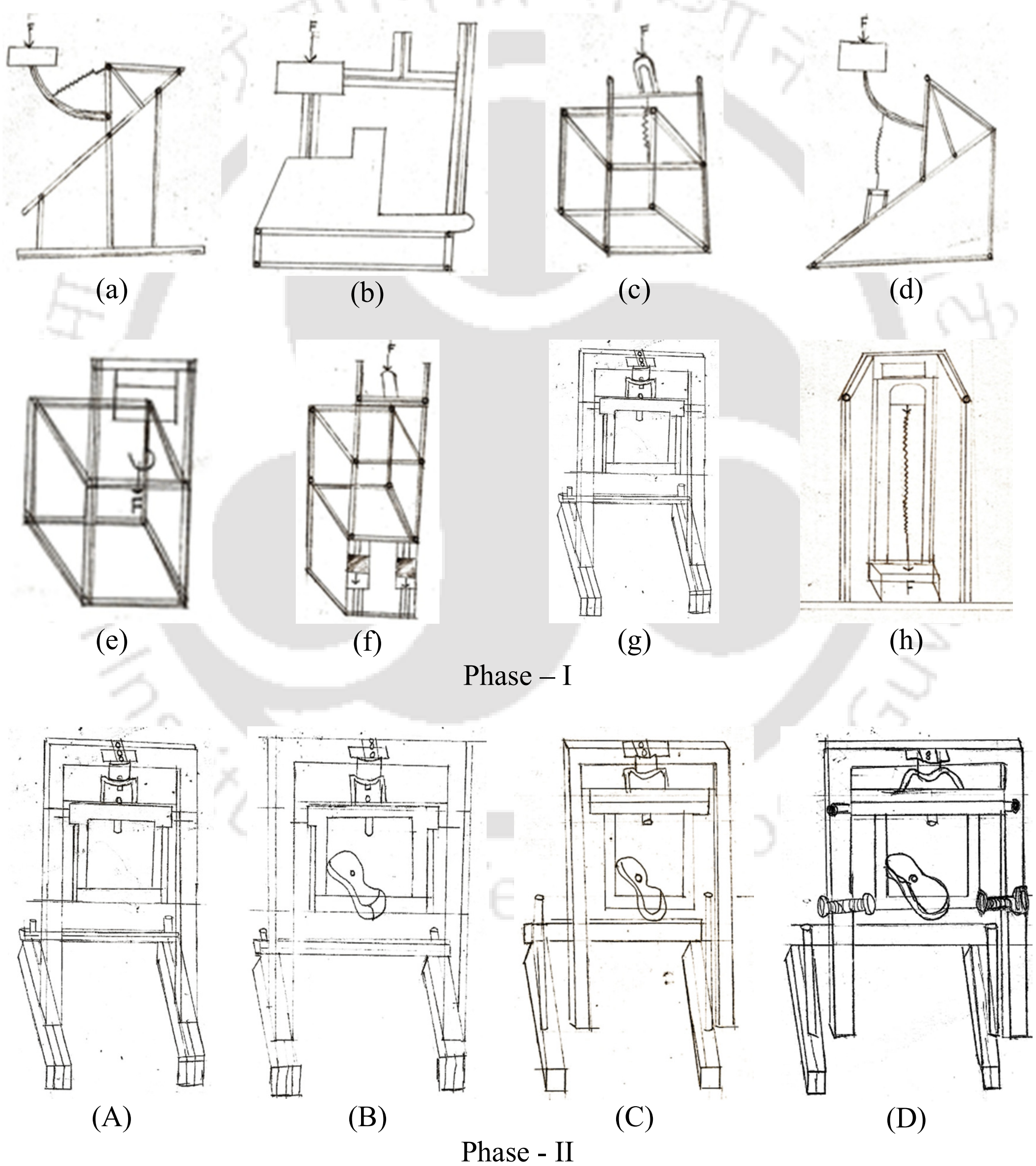
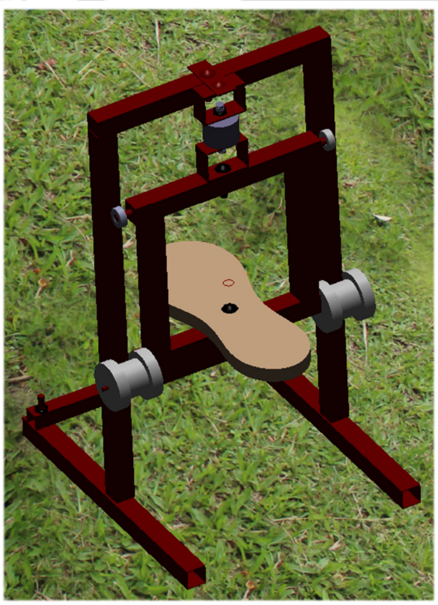


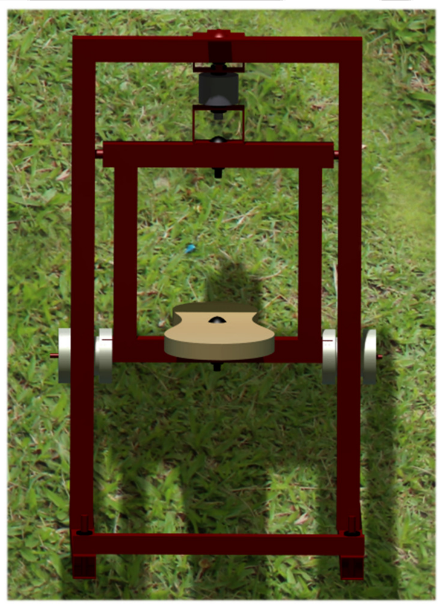
Fig. 2.3 Schematic diagram of some final concepts for isometric leg strength measuring device (phase – I: Some feasible solutions; phase – II: selected solution)

2.3.4 3D digital prototype of the device

Conceptualizing any device prototype (like an isometric force measuring device) need several multidimensional inputs to be considered. In addition to the factors viz. versatility, safety, comfort, use-reuse flexibility, system calibration, accuracy and cost, feasibility of manufacturing with locally available resources also behold pronounced importance. Taking this into consideration, a leg force measuring device was hypothesized to meet the possible needs of every user. The 'mechanical design' option in *Delmia* Human Modeling Software (v.5.19) was used to create 3D CAD model of hypothesized force measuring device as shown in Fig. 2.4. The leg force measuring device comprised of two vertical posts, a base frame to support vertical posts, a middle frame with foot rest attached for application of force during experiment. The load cell was bolted between the frame attached for foot rest and the vertex of the main frame. One end of the base frame was supported with rod through nuts appended for stability of the device. Due effort was put to make the leg force measuring device compact and portable.



(a) Isometric view



(b) Front view

Fig. 2.4 Isometric vertical leg force measuring device – 3D CAD model

2.3.5 Creation of digital human models and rendering for range of adjustment

Review of literatures revealed serious lack of normative database for Assamese agricultural workers, except Dewangan et al. (2005, data of 40 male farmers). So manikins (digital human models, to decide the fitting range of adjustment) were created using Indian national anthropometric database for agricultural workers, where Smallest, average and largest dimension of agricultural workers were represented by 5^{th}, 50^{th} and 95^{th} percentile manikins respectively. The effective range was demarcated by 5^{th} percentile female manikin and 95^{th} percentile male manikin. The knee joint angle of 5^{th} (female) and 95^{th} (male) percentile manikin was adjusted approximately about 150^0 and 90^0 in order to get maximal promising range of adjustment as shown in Fig. 2.5. The investigations and design reiterations using DHM registered the maximum capable range of adjustment to be 150 mm for efficient operation by everyone (from 5^{th} to 95^{th} percentile of body dimensions) measured. Therefore, suitable mechanisms for adjustment for regulating height of isometric force measuring device were essential in order to analyze at different knee-joint angles viz. 90°, 120° and 150°, with right and left legs.

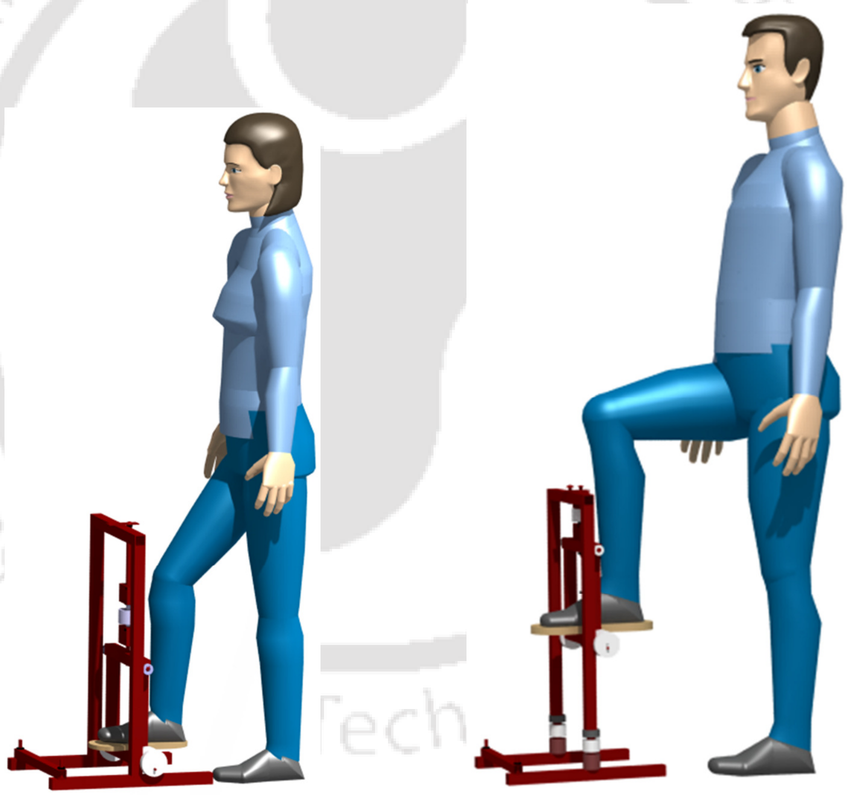
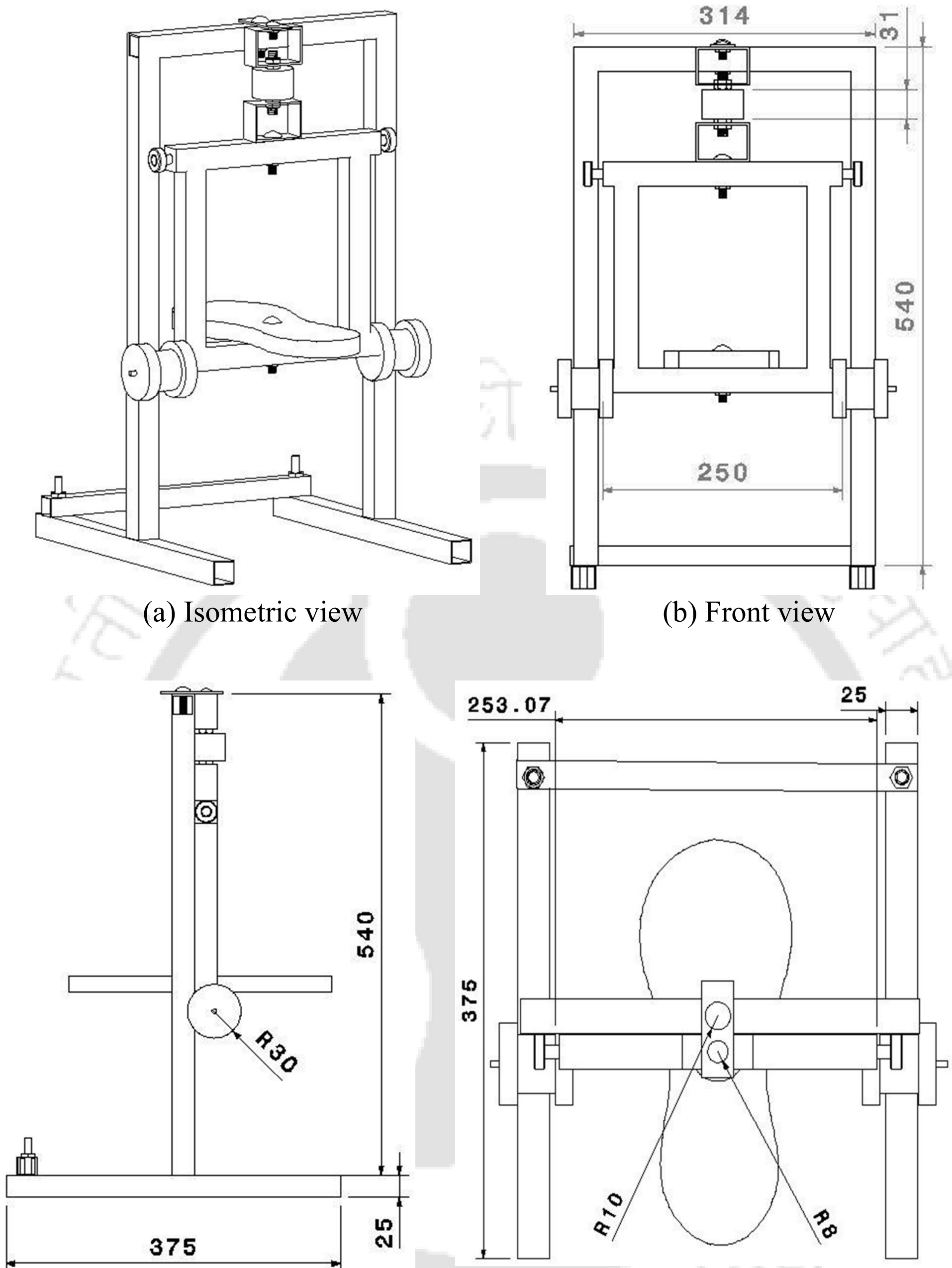


Fig. 2.5 Manikin of 5^{th} and 95^{th} percentiles at 150^0 and 90^0 knee angles

Based on the results attained from manikins, various dimensions of leg force measuring device was finalized. Different views and dimensions (scale 1:5) of isometric vertical leg force measuring device is shown in Fig. 2.6.



(a) Isometric view (b) Front view

(c) Side view (d) Top view

Fig. 2.6 Different views and dimensions of isometric vertical leg force measuring device (Scale 1:5; all dimensions are in mm)

2.3.6 Finite element analysis

The Finite Element Analysis (FEA) is a numerical method to find an estimated solution by dividing any region into small sub-regions. The solution within each sub-region that satisfies the governing equations can be reached more simply than that required for the entire region. FEA was used for isometric force measuring device in order to predict deflection and stress distribution accurately for the relevant components, to make sure that, it could be operated safely. The tetrahedral element type was used in this study for the FEA analysis. The load / force applied for all the components were 1000 N. The number of elements was 8200, 180000 and 16000 for middle frame, main frame and upper clamp respectively as shown in Fig. 7. The total deflection, von mess and tensile yield were found to be 0.1127 mm, 92 MPa and 370MPa for middle frame, 0.910 mm, 102 MPa and 370 MPa for main frame, 0.214 mm, 301.11 MPa and 370 MPa for upper clamp respectively, as shown in Figs. 2.7 – 2.10. Since the proposed design satisfied the criteria, the design was considered as 'safe'.

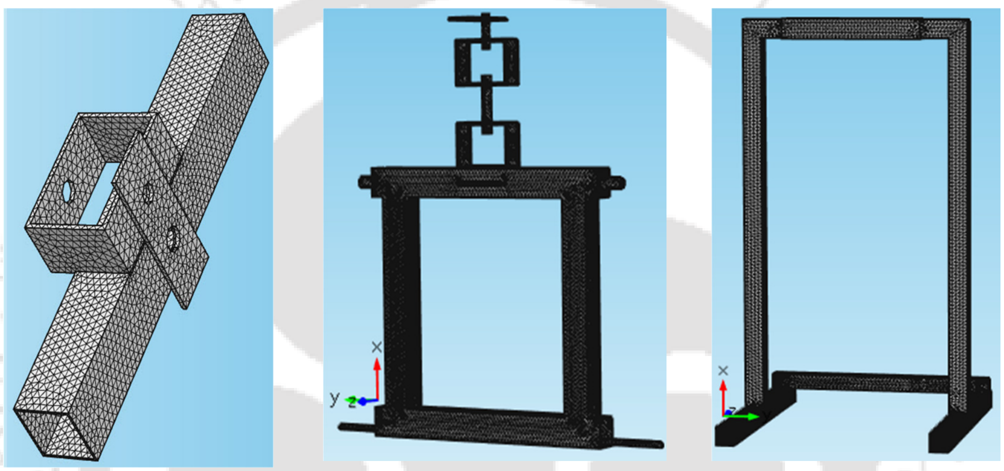


Fig. 2.7 CAD model/meshed model for upper clamp, middle frame and main post

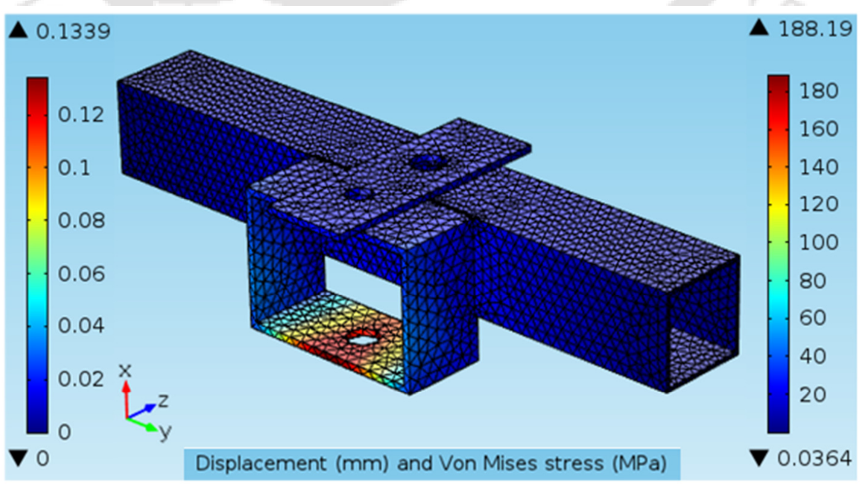


Fig. 2.8 Static loading condition FEA results for upper clamp

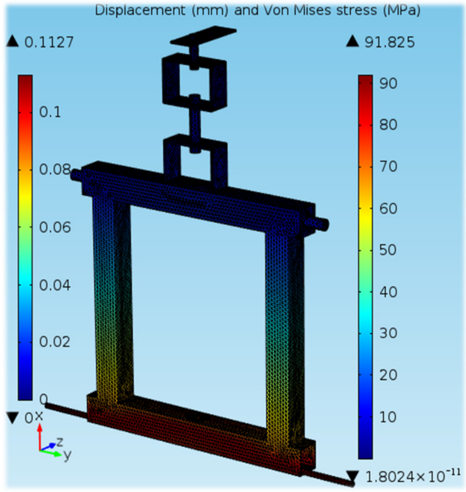


Fig. 2.9 Static loading condition FEA results for mid clamp

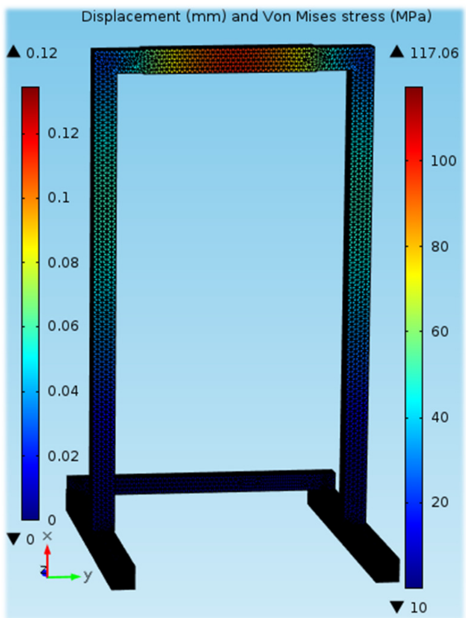


Fig. 2.10 Static loading condition FEA results for main frame

2.4 Product Development – Leg Strength Measuring Device

Mild steel square tube (25×25 mm) was used for the construction of main frame. The base frame was attached with mild steel solid round bar (d = 20 mm). The main frame was flexible to slide over base frame in vertical direction, facilitating the adjustment of height of the device. The minimum height of the device (from ground to foot rest) was 50 mm with maximum possible upward adjustment of 150 mm. The space between the top of both the frame and foot rest confined a load cell (specification is given in Appendix 9) attached by nut-bolt mechanism. An adjustable screw was provided between the pedal link and the platform to fix the pedal with lower frame. The pedal was mounted on a fixed horizontal level by screwing at appropriate position on the main frame. The magnitude of force was measured using the load cell attached between topmost main frame and foot rest frame. Height of the pedal could be adjusted with respect to the ground in two ways:

- ✓ Spacers of different height (10 mm, 20 mm and 30 mm) were used to adjust the pedal height.
- ✓ With the help of wire frame attached with the top of the main frame and one end of load cell holding bracket, thus enabling fine adjustments of platform height.

The physical prototype of isometric leg force measuring device is presented in Fig. 2.11. The device consisted of the following three main components as listed below:

1 Pedal, pedal frame and load cell
2 Lifting and lowering mechanism
3 Main frame

Fig. 2.11 Physical prototype of vertical isometric legs force measuring device

2.4.1 Calibration of leg strength measuring device

The purpose of calibration was to compare a known measurement (the standard) with the measurement obtained from the force measuring device developed. Typically, the accuracy of the measuring device under testing should be closest to the standard i.e. known weight. The load cell in this set-up was calibrated using dead weights. Dead weights of 0.5 to 10 kg were used as shown in Fig. 2.12. Normality of data was checked with skewness and kurtosis and Shapiro-Wilk's test. The analyses of normality showed that data were nearly normally distributed (Table 2.1).

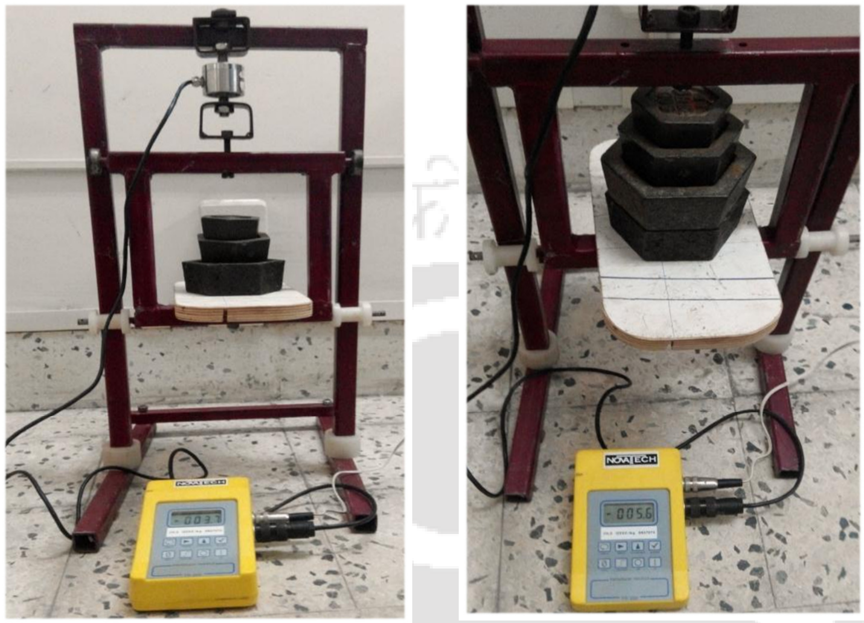


Fig. 2.12 Calibration of Instrument with known dead weight

Table 2.1 Tests of normality analyses for three measured values of isometric vertical force measuring device

Measurement	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Trial 01	0.079	20	0.200	0.961	20	0.566
Trial 02	0.082	20	0.200	0.959	20	0.530
Trial 03	0.082	20	0.200	0.959	20	0.532

Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, χ^2 (2) = 1.454, p =0.483. A one-way repeated measured analysis of variance (ANOVA) was conducted to evaluate the null hypothesis whether there was any change in, and due to, repeated measurements. The results of the ANOVA displayed no significant measurement effect (Wilks' Lambda = 0.938, F (1, 19) = 1.00, p>0.05). Thus, there was no significant response to reject the null hypothesis. Follow up paired comparisons indicated no significant difference between any pair (p>0.05), suggesting that there was no significant variation in values across repeated measurements. The internal consistency of the instruments was further tested through reliability analyses using Cronbach's Alpha, resulting in Cronbach's Alpha = 1.00 and intraclass correlation coefficient = 0.999 which were highly acceptable. The coefficient of determination was calculated to measure accuracy of the equipment for assessing the errors of measurement between the force applied and the force calculated by the equipment during the static measurements. The coefficient of determination (R^2) and the regression line in respect to the equality line were used to characterize the relationship between and the agreement of the measurements of equipment. The calibration curve of the load cell is given in Fig. 2.13 which showed excellent agreement between measured and predicted values ($R^2 = 0.999$).

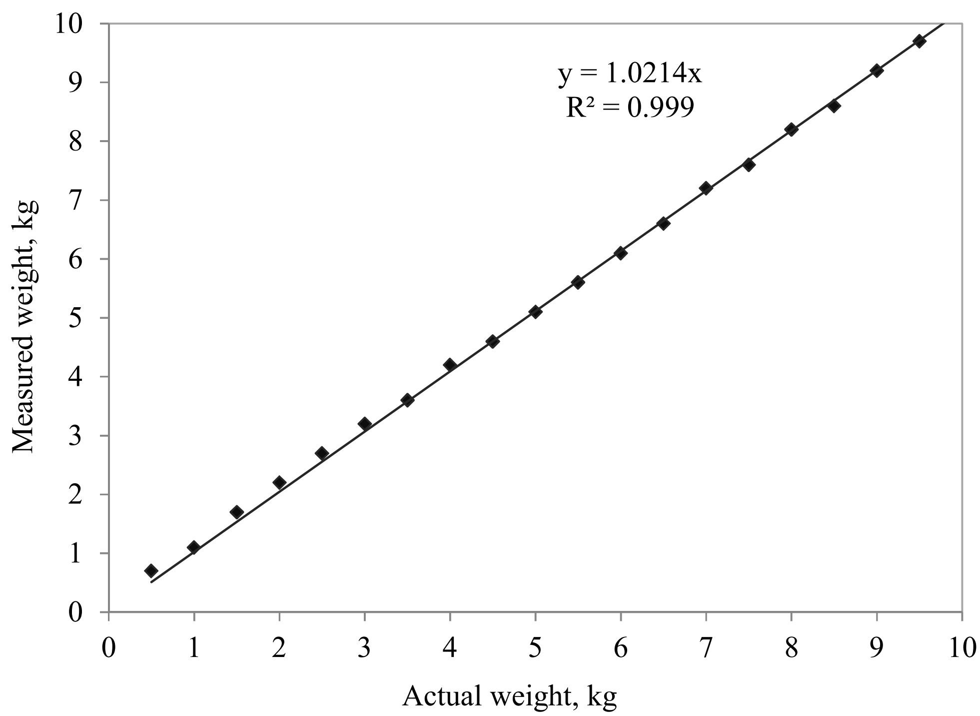


Fig. 2.13 Calibration curve of isometric leg force measuring device

Chapter 3

Development of Normative Anthropometric and Biomechanical Database for Assamese Farmers

Abstract – *The efficiency, productivity and well-being of farmers are significantly contingent of the tools / equipment they use. Thus ergonomic design of tools taking the anthropometric and biomechanical characteristics of the users into account is one of the important concerns to accomplish enhanced performance and efficiency along with greater comfort and safety. However, so far there was no published database for Assamese population (natives of 'Assam', a state from NER of India) of farmers, which could be used to design tools and equipment suitable for them. So an attempt was made to develop anthropometric and biomechanical database particular for the aforesaid population. Following a pilot study involving 40 participants (20 male and female each) to evaluate the reliability of anthropometric measurements, the field survey was conducted on 200 agricultural workers for a set of 27 body dimensions. Collected dataset was statistically analyzed using SPSS (v.22.0.0, IBM Inc, USA). A principal components analysis showed that out of 25 variables, 6 variables represented 6 principal components / factors. Linear regression analysis was also implemented to predict some pertinent body dimensions. Compiled database revealed significant difference ($p<0.05$), when compared with database from other parts of NER viz. Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura; and also with other zones of India viz., Northern, Southern, Eastern, Western, Central and Northeast. This deviation of database of Assamese population from other NER states as well as other zones contradicted blind adoption of agricultural equipment designed for other regions, implying severe occupational health risks.*

3.1 Introduction

Body dimensions are referred to as the standard 'anatomical positions' with the head in the Frankfort plane, unless otherwise specified in the measurement descriptions. For design purposes, the body is assumed to be bilaterally symmetrical. The understandings of measurement techniques and data representation methods are indispensible, especially while designing an anthropometric survey. Prior to such a survey, the important issues like accuracy, repeatability, reproducibility must be addressed through a pilot – without applying it might limit the use of anthropometric database, since in many cases the database is neither interchangeable nor compatible.

Anthropometric and biomechanical database are a much needed and worthwhile pursuit for design of user-friendly tools and equipment from the ergonomic viewpoint. It is generally acknowledged that, process of designing tools and equipment begins with a discussion on end-user limitations and capabilities. Therefore, various researchers have pointed out the importance of using relevant anthropometric and biomechanical database in tools and equipment design (Mehta et al., 2007; Patel et al., 2015). Various researchers also endorsed the importance of biomechanical database to ensure compatibility of tools and equipment for target users (Agrawal et al., 2009; 2010; Yadav et al., 2010; Tiwari et al., 2010; Gite et al., 2009; Dewangan et al., 2010;). Patel et al. (2013) reported significant variation in anthropometric database among different states of India, therefore emphasizing regional database for tools and equipment design.

Incompatibility between operators' physical capabilities (anthropometric and biomechanical) and task demands to operate tools / equipment often leads to poor performance, low productivity and safety problems. Although anthropometric data are generally being considered, an inadvertent negligence of using strength database for agricultural tools / equipment design reduces efficiency of operation, creates safety problems and discomfort for operators (Gite and Singh, 1997). Ergonomic design of tools and equipment is mediation between operator's physical capabilities and energy / force demands by tools and equipment (Dhimmar et al., 2011; Chandra et al., 2013). While designing farm tools and equipment, expected variability in human capability and limitation are used to indicate how much or what range of adjustability needs to be considered to accommodate the intended population of agricultural workers. Ergonomically designed machine should be usually conceived to accommodate the population lying between the 5^{th} and 95^{th} percentile (i.e. at least 90%) of the user population (Abeysekera and Shahnavaz, 1989).

3.2 Ergonomics / Human Factors in Tools and Equipment Design

Agriculture has become substantially automated across the past century. Many farmers are, however, unable to afford the automated farming for planting, weeding, harvesting, threshing etc. These operations are still performed manually, thus leading to compelled adoption of various awkward postures such as squatting, stooping, bending, twisting, kneeling etc. (Gite and Yadav, 1989; Fathallah et al., 2004). These awkward postures result in several occupational health concerns e.g. musculoskeletal ailments, postural syndromes further reasoning for operational difficulties and decreased productivity (Gite and Singh, 1997; Prasannakumar and Dewangan, 2003). Therefore, improving occupational health and efficiency, increasing output and productivity without compromising comfort and efficiency attest component-wise consideration of various human factor concerns like human / worker, tools / equipment and surrounding environment (Fig. 3.1).

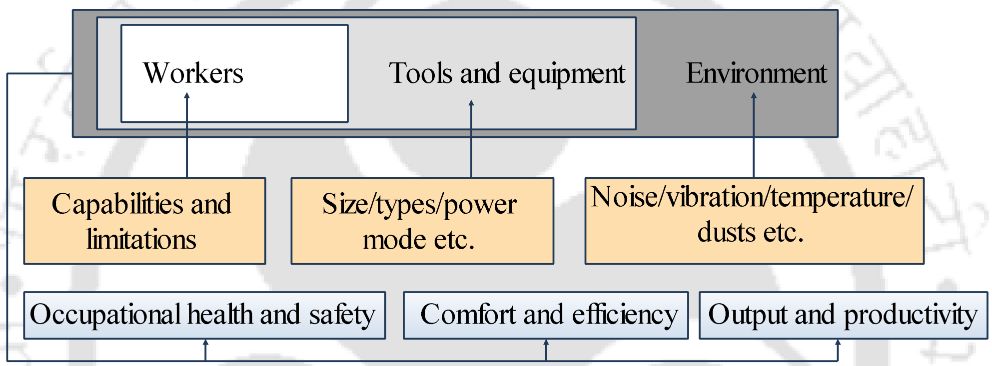


Fig. 3.1 Schematics representation of human factor concept

3.2.1 Anthropometric body measurement

Anthropometry is the aspect of physical ergonomics that is concerned with body measurements such as body size, shape, strength, mobility, flexibility and work capacity (Pheasant and Haslegrave, 2005). User-centric tools and equipment design for Indian farmers are the need-of-the-hour, where considering ergonomic aspects, mainly anthropometric and strength variability database is crucial (Patel et al., 2014). Although one can measure anthropometry in many different ways, static one-dimensional measurements such as height, weight, lengths, circumferences, etc. are most commonly used. For static one-dimensional measurements, an Integrated Composite Anthropometer (ICA) was developed by IIT Kharagpur (Tewari et al., 2007), as illustrated in Fig. 3.2.

Anthropometric studies have been conducted using ICA widely across the country viz., Jammu & Kashmir, Tamil Nadu, Orissa, Gujarat, Maharashtra, Meghalaya, Arunachal Pradesh and Madhya Pradesh (Gite et al., 2009). In developed countries, a large amount of anthropometric data is available for reference and use (Gite and Yadav, 1989) – like database of Aerospace Medical Research Laboratories (Dayton, USA), ERGODATA databank of Anthropology Laboratory of Paris University (France), National Aeronautics and Space Administration (NASA, USA), ANSUR database of male and female US Army personnel and National Health and Nutrition Examination Survey (NHANES, USA), etc.

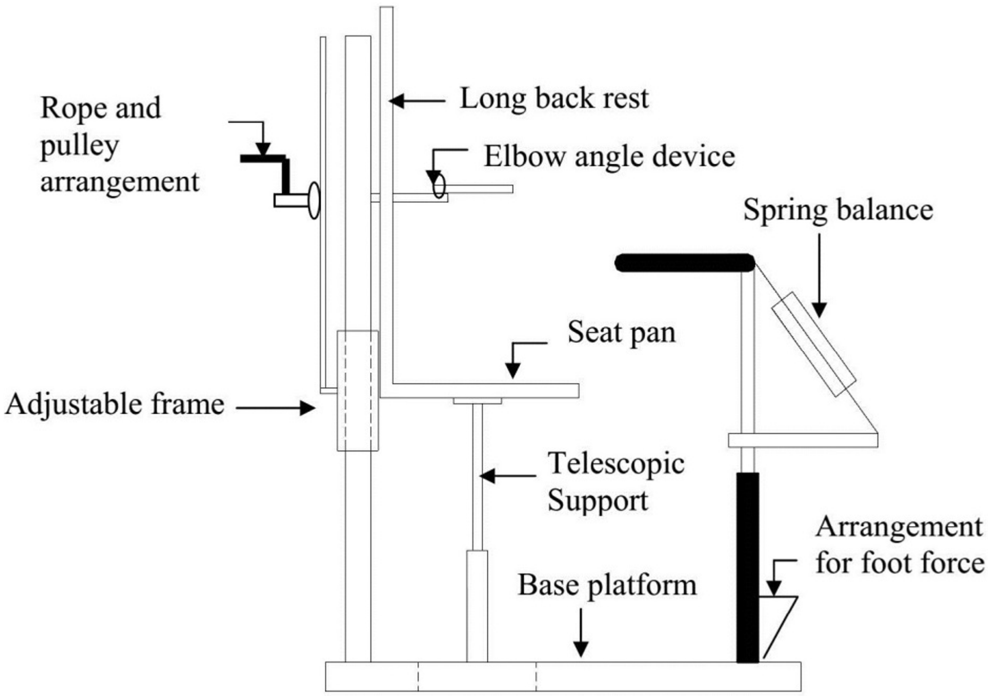


Fig. 3.2 Integrated Composite Anthropometer

In developing country like India, one important anthropometric database on Indian Army population (sex: male only, sample size: 11458, age: 20 – 40 years) was developed by Defence Research and Development Organization, Government of India (Zachariah et al. (2001). Presently it is being used only by Indian defence for their own requirements. Chakrabarti (1997) compiled anthropometric data (sex: male and female, sample size: 961, age: 20 years onwards) collected from different states of India in his book 'Indian anthropometric dimensions for ergonomic design practice' which is popularly being used allover India as ready reference for product and workstation design. None of these two Indian anthropometric databases mentioned above either deals with agricultural workers. Whereas available anthropometric database of Indian agricultural workers are discrete in nature with small sample size (Agrawal et al., 2010; Dewangan et al., 2005, 2010; Gite and Yadav, 1989; Kar et al., 2003; Mehta et al., 2008; Victor et al., 2002; Yadav et al., 1997). The most extensive study in India is the All India Coordinated Research Project (AICRP) on Ergonomics and Safety in Agriculture (ESA), a national level database on anthropometric and strength variables of agricultural workers. This survey database was compiled by Gite et al. (2009) and published by the Central Institute of Agricultural Engineering (Bhopal, India). However, this database *lacks information about agricultural workers* of Assam, an important state of the north-eastern India.

Most of the agricultural tools / machinery used in India is based on body dimensions of western population (Mehta et al., 2008; Dewangan et al., 2008, 2010). Since Western country has greater body dimensions as compared to Indian people (Agrawal et al., 2010), imported farm tools and equipment primarily designed considering their anthropometric database, would not be appropriate for Indian populations (Victor et al., 2002).

3.2.2 Application of ergonomics in tools and equipment design

Several studies have shown that agricultural tools and equipment design is not consistent with the user-specific anthropometric references (Dixit and Namgial, 2012; Dewangan et al., 2010). Agricultural workers deem to be at potential risk of suffering from negative effects of design mismatch in addition to health and safety concerns of existing non-ergonomic tools and equipment principally due to awkward working postures. Moreover, designers / manufacturers must consider the body and physical dimensions of users i.e. anthropometry and biomechanics to assure comfort, fit and usability. Comfortable working posture is considered as an important factor towards prevention of musculoskeletal problems among farmers. Comfort in operation of tools and farm equipment is influenced by the working environment, adjustment features of the tools and equipment, working method, task and above all, the farmer's anthropometric frame.

Dewangan et al., 2010 recommended various design dimensions for agricultural equipment, like grip diameter of 3.7 cm for hand tools and manually operated equipment; optimal handle height for an indigenous plough as 71.5 – 87.5 cm; handle height of 100 cm for a push-pull type weeder; handle length of 122.0 cm for direct paddy seeder; for tractors, seat height 30 – 41 cm, seat width 37 cm and seat depth 27 cm – all recommendations cited for male farmers of NER. Similarly for female farmers of NER, they recommended 10.8 cm length and 3.32 cm diameter for handle of hand tools i.e.

sickle handle and 101.93 – 118.44 cm as handle height of a weeder. Similarly Agrawal et al., 2010 reported anthropometric data of the farmers from Meghalaya and recommended minimum grip diameter of 3.7 cm for male and 3.3 cm for female farmers; handle height of 89.5 cm for male and 85.7 cm for female alongside 95.6 cm and 101.2 cm for male and female workers respectively for 5^{th} and 95^{th} percentile body dimensions to maintain elbow angle of 100^0. From the above discussion, it could be perceived that there were reasonable similarities in recommended values in some design dimensions for male and female agricultural workers such as grip diameter values. However some researchers also reported dissimilarity in recommended design dimensions for other regions of India like Agrawal et al. (2011), who suggested some design recommendations, based on case studies, such as hand height of weeder 94.7 – 102.8 cm to ensure comfortable holding by both male and female workers; grip diameter within the range of 3.2 – 4.0 cm for female and 3.6 – 4.2 cm for male workers; minimum handle grip length of 109 mm for male and 96 mm for female operated tools and strap length of 675 mm for knapsack sprayer for agricultural workers from Madhya Pradesh.

Regional anthropometric database for tools and equipment design should essentially be emphasized due to noteworthy variation in the anthropometric body dimension across different regions, which indicates that, tools and equipment designed according to anthropometrics of one region would never be suitable for another region (Liu et al., 1999). To address these problems, one needs to understand this significance of difference in design, development and mass production of tools and implements for the welfare of agricultural workers, thereby nation as a whole.

3.3 Pilot Studies

Pilot studies were conducted for anthropometric data measurement and vertical leg force measurement. Forty (40) healthy Assamese farmers, 20 male (50%) and 20 female (50%), participated in this study. Before starting the study, consent of participants was duly obtained by completing the 'consent form'. The whole data collection was performed in accordance with Helsinki protocol (WMAH, 2001). In order to avoid any bias during leg strength measurement, participants needed to be free from any previous history of musculoskeletal disorder; leg pain, injuries or surgery. The youngest participant was being 17 years old and the oldest, 62. The participants had 3 to 15 years of experience in performing various agricultural operations, with the mean equal to 7.90 ± 3.45 years (Mean ± SD). The subjects were informed about their role in this study, selecting only those who agreed to their participation by signing a written informed consent.

3.3.1 Pilot study 1 – Anthropometric data measurement

The pilot study was performed prior to the main study. The purpose of the pilot study was not only to establish reliability and validity of the anthropometric measurements, but also to establish a protocol for collection of the anthropometric data in farmers from the field. The reliability coefficient (R) value varies between 0 and 1, where an R of 0 indicates no reliability, while R value equal to 1 indicates perfect reliability. An R value equal or greater than 0.95 is considered acceptable. Ulijaszek and Kerr (1999) recommended a minimum of 10 subjects for assessment of within-observer and between-observer variability. Therefore, for pilot study, 20 male and 20 female agricultural workers are considered.

3.3.1.1 Objective

To measure selected body dimensions of Assamese agricultural workers, useful for design of tools and equipment such as a *pedal-operated paddy thresher*.

3.3.1.2 Equipment

1. Portable anthropometric kits
2. Handgrip dynamometer
3. Weighing scale
4. Grip cone
5. Vernier scale (slide calipers)

3.3.1.3 Experimental procedures

Anthropometric body dimensions considered for construction of database is shown in Table 3.1. The understanding of anthropometric landmarks (specific reference points on the body) is a must for accurate measurement of body dimensions and reduced random errors in course of repetitions. The anthropometric measurement techniques correspond to the guidelines of Hertzberg (1968) and NASA 1024 (1978). All the measurements were performed after requisite training for data collection, and measurements were considered accurate based on the technical error of measurement (TEM < 1%) and reliability coefficient (R > 0.95) (Mueller and Martorell, 1988; Hasheminejad et al., 2013). Proforma, illustration of landmarks and definitions are given in appendixes 1, 2 and 3.

Table 3.1 Anthropometric data considered for present study

Body dimensions	
11 Standing measurement	
Body weight	Knee height
Stature	Arm reach from wall
Acromial height	Shoulder grip length
Elbow height	Shoulder breadth
Olecranon height	Hip breadth
Trochanteric height	
9 Sitting measurement	
Height	Buttock-popliteal length
Acromial height	Foot length
Knee height	Instep length
Popliteal height	Foot breadth
Buttock-knee length	Functional leg length
5 Sitting/standing measurement	
Hand length	Hand breadth across metacarpal-III
Palm length	Maximum grip length
Hand breadth across thumb	

All measurements were taken with portable anthropometric kits (Fig. 3.3). Internal grip diameter was measured with the help of wooden cone used by researchers (viz. Dewangan et al., 2005; 2008; 2010) for the same purposes. In addition, a portable bathroom scale (error upto ± 0.1 kg) was used to take the body weight. All the anthropometric measurements (standing, sitting and sitting / standing) were collected from the right side of the subjects only, to conserve a methodological consistency. The procedures for measurement are detailed hereunder:

1. All the measurements were taken with the participants wearing minimal clothing and without shoes.
2. Vertical body weight was measured in kg using the mechanical bathroom weighing scale to the nearest of 0.1 kg.
3. Anthropometric body dimensions were measured using portable anthropometric kits to the nearest of 0.1 cm.
4. Various sitting dimensions were measured with the person on sitting posture.
5. All hand and foot related measurements were measured nearest to the 0.1 mm using a Vernier's scale on a slide calipers.
6. Handgrip strength was measured with the Jamar hand grip dynamometer (Sammons Preston Inc., Boling-brook, IL, USA).

7. The inside grip diameter was measured using a grip cone.

8. Steps 1 to 7 were performed for all the agricultural workers participated in the survey, including 130 male and 70 female.

Fig. 3.3 Anthropometric data measurement of agricultural workers

3.3.2 Statistical analysis

The data collected hereinabove were compiled and subjected to statistical analysis using Statistical Package for the Social Sciences (SPSS v.22.0.0, IBM Corporation, USA). The outlier detection analysis was performed for each data set to ensure that incorrect data had not been inadvertently entered. Distribution of each set of data was analyzed for normality using Kolmogorov-Smirnov test. Normality of data distribution was accepted only for $p \geq 0.05$. Further, the variable which satisfied this condition was inspected visually with normality plot at 95% confidence limit for each parameter as shown in Fig. 3.4 for stature values.

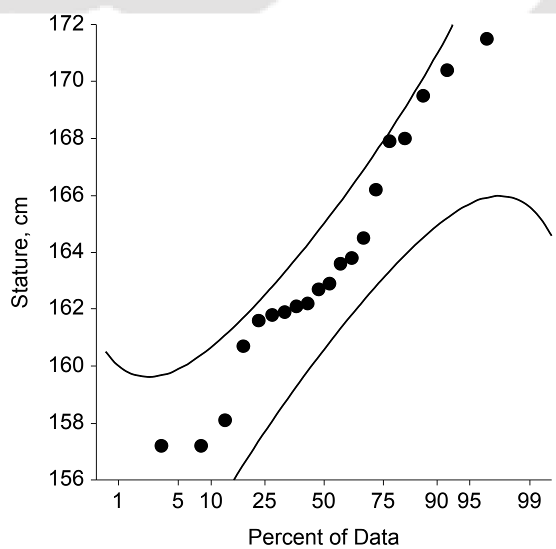


Fig. 3.4 Normal probability plot at 95% confidence limit for stature values

3.3.3 Results and Discussion

3.3.3.1 Subject characteristics

The physical characteristics of the agricultural workers who participated in the pilot studies were presented in Table 3.2.

Table 3.2 Physical characteristics of participated male and female agricultural workers

Particular	Male		Female	
	Mean ± SD	Range	Mean ± SD	Range
Age, year	37.5 ± 9.32	22 – 52	36.2 ± 9.79	19 – 48
Weight, kg	55.7 ± 3.83	52 – 67	52.8 ± 5.96	45 – 63
Stature, cm	163.13 ± 3.39	155.4 – 168.1	154.86 ± 4.11	147.1 – 164.5
Exp., year	12 ± 6.38	3 – 22	11.4 ± 4.03	4 – 18
BMI, kg/m^2	1.59 ± 0.05	1.51 – 1.74	1.5 ± 0.07	1.39 – 1.67
BSA, m^2	20.95 ± 1.53	18.76 – 24.64	22.08 ± 2.91	18.61 – 27.73

3.3.3.2 Reliability analysis

The results of reliability analysis with absolute TEM, relative TEM (%TEM) and reliability coefficient (R) for all 25 body dimensions measured in this study were tabulated in Table 3.3. Technical error of measurement (TEM) carries the same measurement units as the variable measured. It could be observed that coefficient of reliability for both intra- and inter-observer were found more than equal to 95%. It means that the measurements of anthropometric data are 95% error free. The variation in the TEM, %TEM and R values for intra- and inter-observer ranged between 0.04 – 0.48, 0.23 – 1.44, 0.961 – 0.999 and 0.05 – 0.64, 0.28 – 1.51, 0.952 – 0.998, respectively. Variability in measurement was considered acceptable for reliability coefficient (R) more than equal to 0.95 (Ulijaszek and Kerr, 1999).

From the Table 3.3, it was noted that higher reliability coefficient (R) was not consistently correlated with lower value of relative technical error of measurement. This could be due to the R being a function of the measure's CV. It is worth noting that reliability and accuracy in measurements are acceptable for some variables with higher relative TEM i.e. % TEM, which could be due to difficulty faced in locating accurate anatomic landmark, which might also be due to differential somatotypes, such as for maximum grip length. Therefore, TEM value for Maximum grip length was observed higher compared to other measurements. However, the result is within acceptable limit with reliability coefficient fairly above 0.95. The relative technical error of measurement was fairly close to 1 for all variables except the maximum hand grip for which TEM was >1.4%. Considering the criterion for assessing measurement reliability in measurement of anthropometric body dimensions, overall R coefficient was found to be within acceptable limits (which was above 95% for all measurements) suggested for anthropometric data collection (Mueller et al., 1988; Hasheminejad et al., 2013).

Table 3.3 Anthropometrist reliability for repeated measurements of male agricultural workers (n = 20)

Body Dimension	Intra-observer			Inter-observer		
	TEM	%TEM	R	TEM	%TEM	R
Weight, kg	0.2	0.34	0.999	0.3	0.57	0.998
Stature	4.8	0.29	0.987	6.4	0.39	0.974
Acromial height	3.1	0.23	0.995	6.4	0.47	0.977
Elbow height	4.8	0.47	0.985	5.9	0.58	0.976
Olecranon height	4.6	0.47	0.985	5.6	0.57	0.977
Trochanteric height	4.5	0.56	0.974	6.0	0.75	0.956
Knee height	3.1	0.69	0.975	2.2	0.49	0.987
Arm reach from wall	4.7	0.57	0.980	4.6	0.56	0.981
Shoulder grip length	3.5	0.50	0.987	4.7	0.67	0.976
Bideltoid breadth	2.7	0.65	0.988	4.1	0.96	0.974
Hip breadth	2.4	0.79	0.977	2.6	0.86	0.974
Sitting height	2.3	0.27	0.995	2.4	0.28	0.995
Sitting acromial height	2.1	0.36	0.993	2.0	0.35	0.994
Knee height sitting	2.7	0.55	0.977	2.6	0.53	0.977
Popliteal height sitting	2.4	0.58	0.993	2.8	0.68	0.990
Maximum grip length	1.6	1.44	0.979	1.7	1.51	0.977
Hand length	1.2	0.67	0.983	1.7	0.97	0.965
Palm length	0.4	0.43	0.982	0.7	0.67	0.966
Hand across thumb	0.4	0.45	0.992	0.5	0.51	0.989
Hand across metacarpal III	0.6	0.78	0.983	0.6	0.73	0.984
Buttock-knee length	2.2	0.40	0.993	2.4	0.45	0.992
Buttock-popliteal length	2.7	0.65	0.989	2.8	0.67	0.988
Foot length	1.4	0.59	0.971	1.7	0.70	0.959
Instep length	1.2	0.65	0.985	1.6	0.88	0.972
Foot breadth	0.9	0.93	0.961	1.0	1.04	0.952

TEM=technical error of measurement (square root of measurement error variance); %TEM=relative technical error of measurement (TEM/mean×100); R=coefficient of reliability $(1-(TEM/SD)^2)$ which represents the proportion of the variance free of measurement error.

There are inherent sources of error in the collection of anthropometric data. Possibly certain level of error could be reduced by grouping according to instrument used and ordering sequence of measurement i.e. stature and acromion height measurement instead of stature and shoulder breadth. Personal error could be possibly avoided by using single observer but anthropometric data measurement is a very tedious and hectic process, and therefore, in many instances measurement by single observer is not possible.

3.4 A Pilot Study 2 – Isometric Leg Strength Measurement

The position of knee joint i.e. knee angle is a key determinator of knee force exertion. The pilot study for measurement of vertical force exertion was conducted with the previously mentioned sample of 40 participants (considered for anthropometric measurements) for different knee joint angles i.e. 90°, 120° and 150° with both dominant and opposite legs in standing position. The leg strength is essential for operating pedal-operated paddy thresher. The thigh muscles contract and calf muscles extend while applying vertical force on the pedal with foot. During this process the leg extends and the knee angle increases. Therefore as a precaution of musculoskeletal problems, while designing farm tools and equipment, magnitude of force to be employed by the leg at the different knee angles needed to be measured (Agrawal, 2008; Mital and Kumar, 1998).

3.4.1 Objective

The pilot aimed to analyze the vertical exertion of isometric force at different knee joint angles i.e. 90°, 120° and 150° with both dominant and opposite legs in standing position.

3.4.2 Equipment

1. Portable anthropometric kits
2. Leg force measuring device
3. Weighing scale

3.4.3 Experimental design

This experiment was conducted for analyzing isometric legs force. The force applied was analyzed at knee-joint angles of 90°, 120° and 150°, with dominant and opposite legs (Fig. 3.5). The horizontal distance was adjusted by participants themselves as per their convenience during experiments of maximum strength test. Each participant underwent with three repeated trials for every strength measurement of each of above, said conditions. The trials were repeated until three readings were consistent within a range of 10%. This gave rise to 720 strength data (3 knee joint angles × 2 strength values of dominant and opposite legs × 3 replications) measured for all participants. The participants were restricted to performing heavy muscular activity before 2 – 4 hours to avoid a carryover effect at the time of experiments.

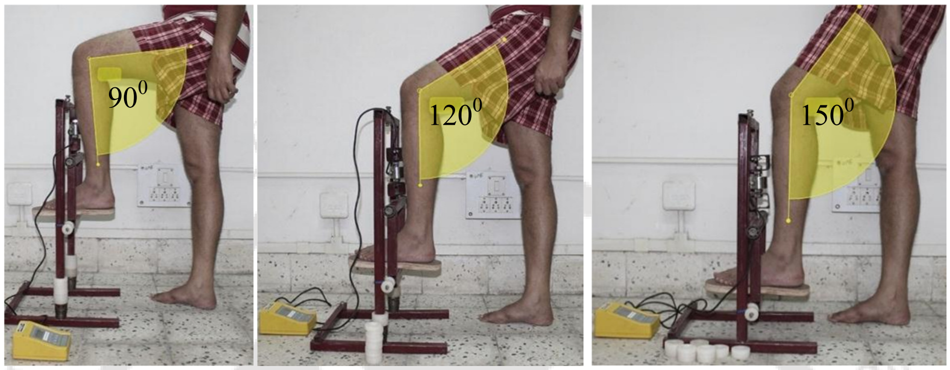


Fig. 3.5 Vertical isometric led strength measurement at different knee angles

3.4.4 Experimental procedure

Experiment was conducted in horizontal plane which having dry and rough surface to prevent slipping during strength data collection process. The experimental procedure was explained to participants and familiarized with the experimental setup before conducting the experiment. All participants were instructed to be with minimum clothing and without slipper / shoes. Participants were also encouraged to adjust their postures until they had achieved the stance that they believed would apply greatest force. For leg force measurement, participants stood erect having both feet flat on the floor with shoulder and forearm straight while relaxed, and the wrist without extension and ulnar deviation. Pedal height was set according to the knee angle of 120° and then subject was asked to put maximum pressure with the help of right leg and maintained for at least 3 seconds after which the score was recorded. Participants were encouraged verbally during the experiment so as to inspire them to apply their maximum force. All the three trial were recorded in the same manner. Every two consequent recordings were intervened by a 2-min rest; while the height of the experimental setup was adjusted as required. They were also given additional rest, if requested or they appeared tired. The results were recorded in kg. The maximal of all the three value was noted for each instance and used for analysis. The procedure for statistical analysis was followed as discussed in section 2.4.

3.4.5 Results and Discussion

The peak strength of right and left legs for knee joint angles of 90°, 120° and 150° for the male and female was tabulated as shown in Table 3.4. The peak strength of right leg for knee joint angles of 90°, 120° and 150° for the male participants was 26.68 ± 7.90 kg (Mean ± SD; range 15.50 – 42.60), 30.40 ± 6.83 kg (range 20.50 – 44.80), 25.21 ± 6.44 kg (range 14.30 – 38.40), and for female group was 21.12 ± 7.74 kg (range 10.00 – 38.70), 24.56 ± 7.63 kg (range 12.20 – 41.00), 19.69 ± 7.79 kg (range 9.90 – 35.90), respectively. Corresponding values for the left leg was for the male group was 19.80 ± 5.82 kg (range 9.30 – 28.90), 23.86 ± 5.29 kg (range 13.30 – 31.60), 19.30 ± 5.82 kg (range 7.70 – 29.30), and for female group was 17.26 ± 6.37 kg (range 7.10 – 29.40), 20.36 ± 6.58 kg (range 11.20 – 32.40), 16.77 ± 6.11 kg (range 7.40 – 27.40), respectively.

Table 3.4 Isometric strength data of agricultural workers leg muscular strength (n = 40)

Strength	Measure	Male (knee joint angle)			Female (knee joint angle)		
		90°	120°	150°	90°	120°	150°
Right leg	Mean	26.68	30.40	25.21	21.12	24.56	19.69
	Minimum	15.50	20.50	14.30	10.00	12.20	9.90
	Maximum	42.60	44.80	38.40	38.70	41.00	35.90
	Range	27.10	24.30	24.10	28.70	28.80	26.00
	SD	7.90	6.83	6.44	7.74	7.63	7.79
	COV, %	29.62	22.49	25.57	36.64	31.06	39.58
	SEM	1.77	1.53	1.44	1.73	1.71	1.74
	Lower limit#	23.22	27.40	22.38	17.73	21.22	16.27
	Upper limit#	30.14	33.39	28.03	24.51	27.90	23.10
Left leg	Mean	19.80	23.86	19.30	17.26	20.36	16.77
	Minimum	9.30	13.30	7.70	7.10	11.20	7.40
	Maximum	28.90	31.60	29.30	29.40	32.40	27.40
	Range	19.60	18.30	21.60	22.30	21.20	20.00
	SD	5.82	5.29	5.82	6.37	6.58	6.11
	COV, %	29.39	22.17	30.18	36.92	32.34	36.43
	SEM	1.30	1.18	1.30	1.42	1.47	1.37
	Lower limit#	17.25	21.54	16.75	14.46	17.47	14.09
	Upper limit#	22.35	26.17	21.85	20.05	23.24	19.45

Measurement unit - kg; SEM -standard error of the mean COV- coefficient of variation; # - 95% confidence interval for the mean

Box's test of equality of covariance matrices was conducted prior to the repeated measures ANOVA tests. In this study, repeated measure ANOVA was conducted to test for between-subject differences and within-subject differences. Repeated measures ANOVA for within-subject variance revealed significant differences in peak isometric strength values across knee-joint angle ($F_{1, 76}$ = 10.63, P < 0.01) as shown in Table 3.5. Further, univariate ANOVA for between-subject effects of knee-joint angle, legs and gender variations were also performed, as shown in Table 3.6. It could be observed that leg ($F_{1, 76}$ = 11.83, p<0.01) and gender ($F_{1, 76}$ = 8.28, p<0.01) showed significant differences. The differences between males and females were statistically significant. Further, the difference between the dominant and opposite leg was also found significant.

Table 3.5 Repeated measure ANOVA analysis for within subject effect of knee joint angle, legs and gender associations

Source	Sum of square	Mean Square	DF	F	Sig.	η^2	Observed Power
KJA	39.01	39.01	1	10.63	0.002	0.123	0.896
KJA × Leg	10.51	10.51	1	2.86	0.095	0.036	0.386
KJA × Gender	0.01	0.01	1	0.00	0.967	0.000	0.05
KJA × Leg × Gender	0.01	0.01	1	0.00	0.967	0.000	0.05
Error(KJA)	278.98	3.67	76				

KJA (Knee joint angle) - 90, 120 and 150; Leg - dominant and opposite; Gender - male and female; η^2 - Partial eta squared

Table 3.6 Repeated measure ANOVA analysis for between subject effect of knee joint angle, legs and gender associations

Source	Sum of Squares	Mean Square	DF	F	Sig.	η^2	Obs. Power
Intercept	116865.07	116865.07	1	886.01	0.000	0.921	1.00
Leg	1560.60	1560.60	1	11.83	0.001	0.135	0.924
Gender	1092.27	1092.27	1	8.28	0.005	0.098	0.811
Leg × Gender	117.60	117.60	1	0.89	0.348	0.012	0.154
Error	10024.47	131.90	76				

η^2- Partial eta squared; Leg- dominant and opposite; Gender- male and female

3.5 Experimental Development of Normative Database for Assamese Male and Female Agricultural Workers

3.5.1 Selection of sample size

Sample size estimation is the major statistical concern while designing anything, like tools and equipment. The larger the sample, the more likely it is to represent the total population. Statistical description of the user population remains unknown and cannot be observed unless the whole population is studied. Therefore, a representative sample should be obtained (drawn using random sampling technique) for a precise estimation of exactitude of the output of the whole population, and thus making the sample a true representative of the population. The present piece of work estimated the size of the representative sample according to the equation provided in ISO 15535:2003 (ISO 15535:2003 – General requirements for establishing anthropometric databases) for a 95% confidence interval for the 5th and 95th percentiles:

$$n \geq \left(3.006 \times \frac{CV}{\alpha}\right)^2$$

Where n is sample size, CV is the coefficient of variation, and α is the percentage of relative accuracy desired. In this study, 1.5% relative accuracy was desired for the 5th and 95th percentiles and an empirical value for CV of 3 – 4 was recommended (Pheasant and Haslegrave, 2005). Therefore, value of CV was considered to be 4. The result was about 65 for male and female each group. However, in this study 130 male and 70 female subjects were selected randomly from the available population of Assamese agricultural workers.

3.5.2 Selection of participants

Participants for this study were drawn randomly from fifteen different villages of Assam, drawing a minimum of 10 participants from each village depending on the size of population of villages. While identifying the villages, socio-economic structures, ethnic distribution of population and agricultural scenario were considered to ensure true representation of the population in the corresponding sample. Thus a sample of 200 agricultural workers (age range of 17-62 years, 130 male and 70 female, representing the Assamese agricultural workers' population) participated in the study. Most of them were among self-farming category or working on daily wages basis for performing various agriculture activities.

3.5.3 Procedures for anthropometric data measurement

As deliberated in the pilot study, 27 body dimensions relevant to the design of hand tools and equipment were considered for this study. The selected dimensions were divided into

3 groups, containing 11 body dimensions including weight in standing posture, 10 dimensions in sitting posture and 6 body dimensions in sitting / standing postures (Table 4.7). Due attention was given to corroborate with the standards and methodologies followed in pilot study.

Table 3.7 Anthropometric data considered for field survey

Anthropometric measurement	
11 Standing body dimensions measurement	
Weight, kg	
Stature	Knee height
Acromial height	Arm reach from wall
Elbow height	Shoulder grip length
Olecranon height	Shoulder breadth
Trochanteric height	Hip breadth
10 Sitting body dimensions measurement	
Height	Buttock-popliteal length
Acromial height	Foot length
Knee height	Instep length
Popliteal height	Foot breadth
Buttock-knee length	Functional leg length
6 Sitting/standing body dimensions measurement	
Grip diameter	Palm length
Maximum grip length	Hand breadth across thumb
Hand length	Hand breadth across metacarpal-III

3.5.4 Results and Discussion

3.5.4.1 Anthropometric data of male agricultural workers

Tests for normality of distribution for all anthropometric data showed them to be normally distributed except hand grip diameter (based on skewness, kurtosis and Kolmogorov-Smirnov test at the 5% level of significance). Descriptive statistics of the 27 dimensions measured for the agricultural workers database are summarized in Table 3.8. Descriptive statistics included mean, SD, CV (%), minima, 5th, median, 95th and maxima. For the participants, age, stature and body weight (Mean ± SD) are 37.3 ± 11.7 years, 162.75 ± 4.59 cm and 55.2 ± 7.0 kg respectively.

The values of CV for age (31.53%) and body weight (12.68%) were found to be relatively higher among the measurements, while dimensions like stature, hand length and foot length registered relatively lower CV values ranging between 2.82 – 3.98. In addition to the above, three anthropometric indices were also calculated – body mass index (BMI; kg/m^2), relative sitting height (RSH; ratio) and body surface area (BSA; m^2). The BMI is measured for human body shape based on an individual's mass and height, expressed as weight in kg divided by squared height in meter. According to WHO classification (2014) for BMI range, individuals are considered ***(a)*** underweight with BMI < 18.5; (***b)*** normal weight between 18.5 – 24.9; ***(c)*** overweight between 25.0 – 29.9; ***(d)*** moderately obese between 30.0 – 34.9 and ***(e)*** severely obese with BMI ≥ 40. The results of BMI calculation in Table 4.8 showed that average BMI value of 20.84 kg/m^2 was within the normal range of 18.5 – 24.9, as specified by WHO (2014).

3.5.4.2 Anthropometric variations among male agricultural workers in India

India is known to be a land of diversity in terms of landform, language, region, race, caste etc. with a larger population (having mixed population density) in the world, placed next to China. Literature has shown that to a great extent, gender, race, age, and geographical region are associated with differences in body dimensions (SAE International, 1998). There was very limited information (documented) regarding difference of body dimensions of agricultural workers in different parts of India. Therefore a comparison of body dimensions was attempted for male farm-workers from Assam with male farm-workers from (1) other northeastern states viz. Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura; and (2) different region of across India i.e. Northern, Southern, Eastern, Western and Central India.

In India, the most comprehensive resource and true representative national database for anthropometric measures of agricultural workers was published by the Central Institute of Agricultural Engineering, Bhopal, India (Gite et al., 2009). This reference publication was used for comparison of database in the present study (i.e. Assam versus other zones of India such as Northern India i.e. Punjab; Southern India i.e. Tamilnadu; Eastern India i.e. West Bengal; and Western India i.e. Gujarat). Similarly male anthropometric database available in Dewangan et al. (2005) was used as a reference for comparison of Assamese population versus various northeastern states such as Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura.

Table 3.8 Anthropometric database of Assamese male agricultural workers

Anthropometric dimensions	Mean ± SD	Minima	5th	95th	Maxima	CV (%)
Weight, kg	55.22 ± 7.00	41.00	43.69	66.74	72.00	12.68
Standing measurement (cm)						
Stature	162.75 ± 4.59	151.70	155.20	170.31	173.60	2.82
Acromial height	135.23 ± 4.38	125.20	128.02	142.44	145.30	3.24
Elbow height	100.68 ± 4.4	88.60	93.44	107.92	116.30	4.37
Olecranon height	98.36 ± 4.49	85.50	90.98	105.75	114.30	4.56
Trochanteric height	78.92 ± 4.08	68.20	72.21	85.64	95.50	5.17
Knee height	45.35 ± 2.35	38.50	41.48	49.22	53.80	5.19
Arm reach from wall	81.56 ± 3.74	70.70	75.40	87.72	96.20	4.59
Shoulder grip length	69.78 ± 3.67	59.20	63.73	75.82	82.90	5.26
Shoulder breadth	42.22 ± 2.02	35.10	38.90	45.54	49.50	4.78
Hip breadth	30.77 ± 1.61	25.20	28.12	33.43	38.50	5.25
Sitting measurement (cm)						
Height	84 ± 3.99	67.50	77.43	90.56	91.20	4.75
Acromial height	58.21 ± 3.41	45.40	52.61	63.82	67.30	5.85
Knee height	49.08 ± 2.31	39.90	45.28	52.89	56.90	4.71
Popliteal height	40.23 ± 2.49	31.00	36.14	44.32	49.00	6.18
Buttock-knee length	53.76 ± 2.2	45.20	50.14	57.38	59.20	4.10
Buttock-popliteal length	42.59 ± 2.54	36.60	38.42	46.77	50.60	5.96
Foot length	23.97 ± 0.82	21.20	22.62	25.33	25.80	3.43
Instep length	18.46 ± 0.93	14.70	16.92	19.99	20.90	5.05
Foot breadth(ball of the foot)	9.75 ± 0.59	7.30	8.78	10.72	11.40	6.06
Functional leg length	94.24 ± 4.03	82.30	87.61	100.87	107.30	4.28
Sitting/standing measurement (cm)						
Grip diameter (inside)	4.91 ± 0.46	3.80	4.15	5.67	5.80	9.42
Maximum grip length	11.36 ± 0.95	8.40	9.80	12.93	14.80	8.37
Hand length	17.47 ± 0.7	15.10	16.33	18.61	19.90	3.98
Palm length	10.1 ± 0.43	8.20	9.39	10.81	11.70	4.27
Hand breadth across thumb	9.69 ± 0.45	8.20	8.95	10.43	11.30	4.66
Hand breadth -metacarpal III	7.91 ± 0.48	6.20	7.13	8.69	9.70	6.03
Indices						
RSH	0.52 ± 0.02	0.44	0.48	0.56	0.58	4.62
BSA, m^2	1.58 ± 0.1	1.37	1.42	1.75	1.77	6.35
BMI, kg/m^2	20.84 ± 2.53	15.65	16.68	25.01	28.09	12.15

Results of Student's *t*-tests of anthropometric variables were revealed in Tables 3.9 and 3.10. Comparing the database of Assam with other northeastern regional database demonstrated that most of the Assamese body dimensions differ significantly from others ($p<0.05$). Further, Assamese database, when compared across the other zones of India, was found to have statistically significant differences in about 85% body dimensions ($p<0.01$ *and* $p<0.05$). These results suggested that, in course of the design process, it is essential to implicate accurate anthropometric information relevant to the prospective users. Design of the tools and equipment should be adjusted to the user population's dimensions and physical work capabilities; so as to avoid uncomfortable postures, that could in turn, lead to fatigue of operators and subsequent likelihood of work-related injuries. It was thus demonstrated that, it could be easy to envisage how anthropometric measurements of the same nation varied across different regions, likely to be so due to social, economic and environment variations. Therefore database of one region could not be used effectively for the other region while designing tools and equipment. However, due caution must be exercised while implying any anthropometric database for one population to experiment with a different population (Garneau and Parkinson, 2009).

From the above discussion, the significant difference in anthropometric dimensions of Assamese farm-workers and other regional populations from India implies that, tools and equipment design for one region should not be employed directly for any other region without modification, redesign or taking care of end-users' anthropometric norms (Dixit and Namgial, 2012; Patel et al., 2013). Some important factors contributing to the distribution of anthropometric characteristics among similar age groups could be geographical, socio-economic, cultural stratus and ethnicity. Lacking a regional anthropometric standard makes the product design process more challenging for designers / manufacturers. It is commonly assumed that human comfort, safety and productivity could be achieved through user-friendly design process, which in turn, would improve the worker's overall livelihood. Mostly in rural areas, designing tools and equipment are generally based on manufacturers' personal understanding and past experience, without concerning anthropometric consideration. For the same tool, like animal drawn MB plough, there is large variation in various models Gite (1991). Indigenous tools and equipment manufactured by local toolmaker, failed to address many of these human factor issues – likely due to lack of knowledge of ergonomics and end-user dimensions (Patel et al., 2013).

Table 3.9 Male anthropometric data of Mean, standard deviation (SD) and t-test result among different states of northeast region of India with present study

Particulars (cm)	Assam# (n = 130)	Ar. Pradesh (n = 40)	Manipur (n = 40)	Meghalaya (n = 40)	Mizoram (n = 40)	Nagaland (n = 40)	Tripura (n = 40)
	(Mean ± SD)	Mean (± SD)	Mean (± SD)	Mean (± SD)	Mean (± SD)	Mean (± SD)	Mean (± SD)
Stature	162.75 ± 4.59	163.91 ± 5.04	166.24 ± 4.10*	162.72 ± 5.11	164.90 ± 4.49*	164.48 ± 5.00	164.78 ± 3.69*
Acromial height	135.23 ± 4.38	133.63 ± 4.18*	137.65 ± 4.63*	132.62 ± 3.50*	133.32 ± 4.19*	135.50 ± 4.34	132.38 ± 4.21*
Elbow height	100.68 ± 4.40	101.53 ± 3.51	103.66 ± 3.59*	100.19 ± 3.55	101.74 ± 3.80	102.43 ± 3.24*	102.62 ± 3.91*
Olecranon height	98.36 ± 4.49	98.00 ± 3.24	100.02 ± 3.29*	97.43 ± 3.48	98.52 ± 3.31	99.43 ± 3.89	99.66 ± 3.20*
Trochanteric height	78.92 ± 4.08	81.23 ± 3.68*	84.07 ± 3.59*	79.89 ± 3.80	82.08 ± 3.42*	81.57 ± 3.21*	80.61 ± 3.10*
Knee height	45.35 ± 2.35	43.20 ± 2.35*	46.81 ± 2.11*	43.94 ± 2.55*	44.35 ± 2.80*	45.69 ± 2.31	45.96 ± 2.08
Shoulder breadth	42.22 ± 2.02	40.34 ± 3.09*	43.57 ± 3.49*	44.28 ± 3.43*	43.91 ± 3.63*	43.36 ± 3.35*	42.62 ± 3.62
Hip breadth	30.77 ± 1.61	29.92 ± 2.45*	30.93 ± 2.39	30.60 ± 2.13	30.65 ± 2.30	32.14 ± 1.94*	32.28 ± 1.90*
Sitting height	84.00 ± 3.99	84.21 ± 2.55	85.40 ± 3.10*	83.60 ± 2.80	84.72 ± 3.12	84.50 ± 3.06	84.65 ± 2.68
Sitting acromial height	58.21 ± 3.41	53.93 ± 2.94*	56.81 ± 2.64*	53.50 ± 2.6*	53.14 ± 2.63*	55.52 ± 3.02*	52.25 ± 2.45*
Popliteal height	40.23 ± 2.49	41.00 ± 2.88	41.59 ± 2.60*	40.71 ± 2.45	41.26 ± 2.29*	41.15 ± 2.69	41.23 ± 2.54*
Buttock popliteal length	42.59 ± 2.54	44.24 ± 2.35*	44.88 ± 2.60*	43.93 ± 2.50*	44.59 ± 2.38*	44.40 ± 2.43*	44.49 ± 2.59*
Grip diameter	4.91 ± 0.46	4.80 ± 0.30	4.71 ± 0.29*	4.77 ± 0.32*	4.67 ± 0.22*	4.80 ± 0.28	4.80 ± 0.29
Hand length	17.47 ± 0.70	18.22 ± 0.39*	17.98 ± 0.46*	18.00 ± 0.50*	17.65 ± 0.66	18.20 ± 0.10*	17.94 ± 0.45*
Palm length	10.10 ± 0.43	9.96 ± 0.31*	9.80 ± 0.33*	10.06 ± 0.49	9.79 ± 0.26*	10.15 ± 0.42	9.98 ± 0.33
Hand breadth - A	9.69 ± 0.45	9.69 ± 0.45	9.68 ± 0.35	9.85 ± 0.43*	9.67 ± 0.44	10.00 ± 0.60*	9.72 ± 0.45
Hand breadth - B	7.91 ± 0.48	8.41 ± 0.30*	8.34 ± 0.56*	8.77 ± 0.40*	8.50 ± 0.40*	9.05 ± 0.42*	8.12 ± 0.44*

A- across thumb; B - across metacarpal-III; n = corresponding sample size; * Significant at $p<0.05$; # except Assam, values for all other states are from Dewangan et al. (2010)

Table 3.10 Anthropometric database comparison between Assamese male agricultural workers versus different zones of India male agricultural workers

Body Dimensions	Northeast (Assam)	Northern India#	Southern India#	Eastern India#	Western India#	Central India#
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Weight, kg	55.22±7.0	66.1±9.5	56.1±9.7[NS]	51.4±7.9	55.3±8.5[NS]	50.8±6.6
Stature	1628±46	1698±74	1629±65[NS]	1627 ±64[NS]	1632±69[NS]	1640±65
Acromial height	1352±44	1418±73	1372±62	1341±58	1378±61	1367±62
Elbow height	1007±44	1074±59	1018±49	1013±47[NS]	1029±69	1040±48
Olecranon height	984±45	1042±55	988±47[NS]	988±46[NS]	1009±60	1009±47
Trochanteric height	789±41	812±47	869±51	758±44	839±53	855±46
Knee height	454±24	493±34	478±30	446±27	490±35	468±25
Arm reach from wall	816±37	878±48	863±51	835±41	834±48	825±41
Shoulder grip length	698±37	775±57	738±76	729±38	707±44	710±38
Shoulder breadth	422±20	462±25	414±32	392±26	432±31	413±23
Hip breadth	308±16	315±29	291±24	301±19	321±27	299±17
Height	840±40	809±46	810±36	852±46	781±83	842±38[NS]
Acromial height	582±34	557±35	572±31	587±38[NS]	561±79	561±31
Knee height	491±23	505±34	503±28	566±39	507±26	480±26
Popliteal height	402±25	441±27	415±25	410±37	422±24	402±22[NS]
Buttock-knee length	538±22	531±38	544±27	580±32	540±26[NS]	539±33[NS]
Buttock-popliteal length	426±25	447±30	460±23	464±32	451±31	414±32
Foot length	240±8	253±16	251±14	253±16	239±14[NS]	249±14
Instep length	185±9	199±13	189±12	181±14	180±12	185±12[NS]
Foot breadth	98±6	90±10	88±7	92±7	96±6	96±7
Functional leg length	942±40	1049±49	1014±54	957±47	930±39	996±46
Grip diameter (inside)	49±5	52±4	49±4[NS]	44±6	51±5	51±5
Maximum grip length	114±10	133±15	110±13	133±15	137±10	129±15
Hand length	175±7	179±16	181±10	176±9[NS]	177±10	185±10
Palm length	101±4	100±8[NS]	102±7	100±5	97±6	106±7
Hand breadth - A	97±5	99±7	99±8	92±6	101±6	99±6
Hand breadth - B	79±5	84±6	81±5	77±5	83±5	83±5

All Measurements are in mm unless specified; A- across thumb; B - across metacarpal-III; All body dimensions are statistically significant at $p<0.05$ except non significance marked with NS; # - Gite et al. (2009)

Further, database generated in the present study was compared with other developed and developing nationalities. The comparison revealed statistically significant difference ($p<0.05$, Table 3.11) in stature and sitting height of Assamese population with all other nationalities, however excluding sitting heights of Australian and Malaysian populations. Stature of Northeast India people was found significantly lower ($p < 0.01$) compared to others. Similar observation was also noted for the sitting height where Assamese people had lower sitting height compared to other countries except Bangladesh. Continuing with RSH, it could be seen from Table 3.11 that, Assamese people had a RSH of 0.52. This was similar to Singapore, Southern Thai, Turkish, USA and Brazilian populations and less than Portuguese, Swedish, Taiwanese and Iranian populations; yet however, more than rest of the comparison group.

Table 3.11 Values of mean and standard deviation (SD) for stature and sitting height dimensions of male population for different nationalities

Source	Nationalities	n	Stature	Sitting height	RSH
			Mean ± SD	Mean ± SD	
A	*India (Assam)*	*130*	*1628 ± 46*	*840 ± 40*	*0.52*
B	USA	110	1770 ± 72	920 ±37	0.52
C	Bangladesh	470	1677 ± 53	829 ±37	0.49
D	Brazil	94	1734 ± 63	896 ±34	0.52
E	Iran	105	1725 ± 58	912 ±26	0.53
F	Japan	107	1706 ± 54	NA	-
G	Malaysia	516	1686 ± 68	846 ±66^{NS}	0.50
H	Netherlands	107	1833 ± 74	950 ±38	0.52
I	Portuguese	492	1690 ± 76	920 ±37	0.54
J	Singapore	206	1740 ± 52	900 ±34	0.52
K	Thailand	100	1719 ± 52	902 ±34	0.52
L	Sweden	105	1792 ± 70	944 ±36	0.53
M	Taiwanese	735	1687 ± 60	903 ±32	0.54
N	Turkey	2263	1708 ± 81	892 ±46	0.52
O	Australia	33	1658 ± 79	843 ±56^{NS}	0.51
P	Philippine	843	1670 ± 80	848 ±58	0.51

Measurements are in mm; RSH-sitting height to stature, n- sample size; All anthropometric data statistically significant at $p<0.05$ except marked with NS; NA-data not available; *A - in present study (2015);* B, D, F, H - Ward (2011); C, G - Khadem et al. (2014); E - Mououdi (1997); I - Barroso et al. (2005); J - Chuan et al. (2010); K - Klamklay et al. (2008); L - Hanson et al. (2009); M - Wang et al. (1999); N - Ali and Arslan (2009); O - Kothiyal and Tettey (2000); P - Prado-Lu and Leilanie (2007)

Most of the agricultural tools / machinery used in India are based on anthropometric standards of western laypeople (Mehta et al., 2008; Dewangan et al., 2008, 2010). Thus, imported farm-machinery designed considering the Western anthropometric norms would not obviously be user-friendly for Indian sub-continental populations (Victor et al., 2002), since Western people have higher body dimensions as compared to Indians (Agrawal et al., 2010).

3.5.4.3 PCFA and regression analysis

Principal component analysis is an important statistical technique for multivariate analysis for dimension reduction to obtain linear transformations for a group of correlated variables (Karmakar et al., 2012). Principal component factor analysis (PCFA) with orthogonal rotation was performed to reduce inter-correlated variables into small groups of independent factors, as described by Sharma (1995). PCFA with Varimax rotation, originally proposed by Kaiser (1958), was performed initially on 25 variables for a sample of 130 male anthropometric body dimensions. All the dimensions were considered for analysis as communalities was found to be ≥0.5. Barlett's test of sphericity showed significant variance ($p<0.001$) which fulfilled the basic requirement of principal component factor analysis. Based on the eigenvalues more than ≥1, six factors were considered, which explained 71.21% of the variations in original quantitative traits as shown in Table 3.12.

All the factors loaded on at least two components which are having factor loading ≥0.5. The group highly-correlated dimension into factors (Principal Components) is shown in Table 3.13. Six variables representative of 6 principal components/factors (as each factor was denoted by one variable) were identified out of 25 variables. These 6 variables would construct the minimum data set which almost accounts for viability exhibited by 25 original variables. Anthropometric body dimension which is having highest factor loading into principal components is written in 'UPPER CASE' letter. All principal components which are having factor loading ≥ 0.5 has positive coefficient. In PCFA the first principal component captures the maximal variance (Jackson, 2005; Jolliffe, 2005). It can be seen that the factor loading 1 accounting for the largest portion of variations i.e. 37.68% and remaining factors accounts for nearly 33.53% of the total variance. Each factor could be defined according to the estimated factor loadings and communality results.

Table 3.12 Coefficients for factor loading matrix for the 6 extracted factors satisfying the Eigen value > 1 criterion for the anthropometric dimensions

Body dimensions	Fac01	Fac02	Fac03	Fac04	Fac05	Fac06	Comm.
Trochanteric height	0.839#	-0.100	0.064	0.032	-0.054	0.137	0.741$
Acromial height	0.836#	0.272	0.105	0.128	0.158	0.144	0.846$
Knee height	0.819#	-0.075	0.098	0.204	-0.068	-0.029	0.733$
Olecranon height	0.809#	0.221	-0.134	0.326	0.098	0.059	0.841$
Elbow height	0.808#	0.225	-0.125	0.323	0.102	0.076	0.839$
Stature	0.796#	0.288	0.235	0.029	0.185	0.122	0.822$
Knee height sitting	0.782#	-0.166	0.258	0.164	0.100	0.060	0.746$
Functional leg length	0.762#	-0.047	0.283	-0.127	0.245	0.289	0.823$
Buttock-knee length	0.743#	0.060	0.203	-0.154	0.283	0.227	0.752$
Buttock-popliteal length	0.716#	0.110	0.087	-0.237	0.186	0.163	0.650
Sitting popliteal height	0.603#	0.149	0.272	-0.069	0.023	-0.280	0.544
Arm reach from wall	0.540#	-0.088	0.318	0.298	0.107	0.287	0.584
Sitting height	0.093	0.900#	0.164	-0.037	-0.100	0.057	0.860$
Sitting acromial height	0.122	0.890#	-0.002	0.109	0.104	-0.111	0.842$
Maximum grip length	0.091	0.136	0.714#	-0.098	-0.161	0.227	0.623
Instep length	0.123	0.058	0.672#	0.421	0.076	-0.142	0.673
Foot length	0.307	0.023	0.538#	0.507#	0.174	0.134	0.690
Shoulder grip length	0.409	0.027	0.500#	-0.149	0.354	0.143	0.586
Hand breadth across metacarpal III	-0.049	0.019	-0.006	0.724#	0.095	-0.011	0.536
Foot breadth	0.297	-0.204	0.073	0.578#	0.079	0.377	0.617
Hand breadth across thumb	0.054	0.355	0.089	0.523#	-0.006	0.201	0.451
Shoulder breadth	0.217	0.172	0.118	0.095	0.819#	-0.141	0.790$
Hip breadth	0.121	-0.157	-0.093	0.151	0.806#	0.155	0.745$
Palm length	0.158	-0.024	0.077	0.128	0.011	0.855#	0.779$
Hand length	0.409	0.118	0.386	0.225	0.048	0.554#	0.689
Eigen value	9.419	2.148	2.110	1.598	1.407	1.120	-
TV (%)	37.678	8.593	8.440	6.392	5.630	4.479	-
CV (%)	37.678	46.271	54.711	61.103	66.733	71.211	-

Comm. – Communalities; $ Communalities > 0.7; TV-Total variance; CV - Cumulative variance; # Factor loading ≥ 0.5.

Table 3.13 List of factor wise dominant variables as a result of factor analysis

Component	Dimension
Fac01	***Trochanteric Height***, acromial height, knee height, olecranon height, stature, elbow height, sitting knee height, functional leg length, buttock-knee length, buttock-popliteal length, popliteal height, arm reach from wall
Fac02	***Sitting Height***, sitting acromial height
Fac03	***Maximum Grip Length***, instep length, foot length, shoulder grip length
Fac04	***Hand Breadth across Metacarpal-III***, foot length, foot breadth(ball of the foot), hand breadth across thumb
Fac05	***Shoulder Breadth (Bi-Deltoid)*****,** hip breadth
Fac06	***Palm Length***, hand length

Highest factor loading is denoted by '***Bold Italic***' in particular component

The first two largest components factor 1 and factor 2 factor loading were related to height and segmental length measurement. The second principal components factor 3 and factor 6 were related to hand and foot length measurement. The third principal components factor 4 and factor 5 were related to the width related dimensions. After principal components factor analysis, regression analysis was performed based on components derived from the PCFA. Since every principal component was a linear combination of all of the original variables, a more challenging problem was to select the variable for predictor (independent) from the long list of original variables. For the purpose of prediction, certain anthropometric variable which were difficult to measure, the enter method of regression analysis was performed. The significant predictor with correlation coefficient >0.7 was considered for regression equations (as in Kroemer et al., 1986). The acromial height, elbow height, olecranon height, sitting knee height, buttock knee length, sitting acromial height, trochanteric height, functional leg length, buttock popliteal length and popliteal height measurements were predicted. Table 3.14 presents the list of prediction equations for determining pertinent body dimensions, F-ratio, standard error of estimate (SEE) and correlation coefficient (Right) for each equation. The following five measurements were selected for the prediction of equation viz., stature (ST), knee height (KH), Sitting height (SH), buttock-knee length (BKL) and sitting knee height (SKH). The correlation coefficient and contribution of other measurements were not significant ($p<0.001$) in regression analysis. The best-fit least square simple and multiple linear regression techniques showed that certain body dimensions could be predicted to fair precision. The contribution of stature to predict acromial height was of highest significance (r = 0.88).

Anthropometric data collection is extremely time consuming, expensive and difficult, particularly when surveys attempt to be truly representative (Pheasant and Haslegrave, 2005). Factor analysis and multiple regression analysis could be very useful for generating missing data or to predict an anthropometric variable which is highly correlated with one or more other body dimensions. This approach in due course reduces the number of variables to be collected by field survey mandatorily.

Table 3.14 Linear regression equations for prediction of certain body dimensions

Variable predicted	Equations	F-ratio	SEE	r
Acromial height	0.836ST-0.822	424.81**	21.2	0.88
Elbow height	0.682ST-10.333	131.76**	31.0	0.71
Olecranon height	0.685ST-13.133	123.83**	32.1	0.70
Sitting knee height	0.711KH+16.839	139.97**	16.1	0.72
Buttock knee length	0.351ST-3.380	148.40**	15.0	0.73
Sitting acromial height	0.668SH+2.099	202.86**	21.3	0.78
Trochanteric height	0.797 KH+0.323 EH+10.263	69.85**	28.4	0.72
Functional leg length	1.135BKL+0.511SKH+8.121	137.74**	22.8	0.83
Buttock popliteal length	0.735BKL+0.145KH+0.027ST-7.792	56.86**	16.7	0.76
Popliteal height	0.873SKH-3.102	120.71**	20.9	0.70

All dimensions are in mm; ST - Stature; KH - Knee height; SH - Sitting height; EH - Elbow height; BKL - Buttock-knee length; SKH-Sitting knee height; SEE - Std. error of the estimate; r - Resulting correlation coefficient; **Significant ($p < 0.001$)

3.5.4.4 Female anthropometric data

Anthropometric body dimensions measured during the study and some important derived parameters such as RSH, BSA and BMI were analyzed for mean, standard deviation, minima, maxima, median, coefficient of variation, percentile ranges for female agricultural workers (Table 3.15).

Table 3.15 Anthropometric database of Assamese female agricultural workers

Body dimensions	Mean ± SD	Min	5^{th}	95^{th}	Max	CV (%)
Weight, kg	48.49 ± 7.72	36.00	35.79	61.18	73.00	15.91
Standing measurement (cm)						
Stature	153.1 ± 4.83	139.90	145.16	161.04	168.90	3.15
Acromial height	127.09 ± 4.77	115.90	119.23	134.94	141.90	3.76
Elbow height	95.5 ± 3.85	85.40	89.16	101.83	106.00	4.03
Olecranon height	92.47 ± 3.86	80.20	86.11	98.82	101.00	4.18
Trochanteric height	75.41 ± 3.94	65.10	68.94	81.88	88.20	5.22
Knee height	41.61 ± 2.77	35.20	37.05	46.17	48.60	6.66
Arm reach from wall	75.16 ± 3.95	64.90	68.66	81.66	84.60	5.26
Shoulder grip length	65.57 ± 2.83	59.90	60.91	70.23	74.80	4.32
Shoulder breadth	38.11 ± 2.95	31.60	33.26	42.97	44.90	7.74
Hip breadth	30.16 ± 2.03	24.10	26.83	33.49	34.90	6.72
Sitting measurement (cm)						
Height	80.49 ± 3.11	74.10	75.37	85.61	86.70	3.87
Acromial height	54.45 ± 2.97	45.30	49.57	59.33	60.20	5.45
Knee height	44.68 ± 2.52	39.70	40.54	48.83	51.30	5.64
Popliteal height	37.03 ± 2.84	31.90	32.36	41.70	43.60	7.66
Buttock-knee length	50.51 ± 2.07	45.80	47.11	53.91	54.80	4.10
Buttock-popliteal length	40.82 ± 3.11	33.70	35.70	45.94	47.00	7.63
Foot length	22.27 ± 0.98	19.40	20.66	23.88	24.40	4.39
Instep length	16.69 ± 0.86	13.80	15.28	18.11	18.70	5.14
Foot breadth	8.76 ± 0.53	7.40	7.90	9.63	10.20	6.01
Functional leg length	90.2 ± 3.35	81.20	84.70	95.71	97.20	3.71
Sitting/standing measurement (cm)						
Grip diameter (inside)	4.61 ± 0.54	3.80	3.72	5.49	5.80	11.64
Maximum grip length	10.49 ± 0.84	7.90	9.11	11.88	12.30	8.03
Hand length	16.4 ± 0.81	14.80	15.07	17.73	18.70	4.93
Palm length	9.32 ± 0.45	7.40	8.59	10.05	10.70	4.78
Hand breadth across thumb	8.83 ± 0.41	7.20	8.16	9.50	9.90	4.64
Hand breadth -metacarpal III	6.82 ± 0.53	5.90	5.96	7.69	8.80	7.70
Indices						
RSH	0.53 ± 0.03	0.45	0.48	0.58	0.62	5.87
BSA, m^2	1.43 ± 0.12	1.21	1.24	1.62	1.73	8.07
BMI, kg/m^2	20.64 ± 2.85	16.60	15.95	25.32	30.23	13.81

The weight and stature (Mean ± SD) for female agricultural workers were found 48.49 ± 7.72 kg and 153.1 ± 4.83 cm respectively, whereas 95th percentile values of weight and stature of female agricultural workers were 61.18 kg and 161.0 cm, respectively. The CV% of some dimensions like hand grip strength, leg strength, age, weight, knee height, shoulder breadth, hip breadth, popliteal height, buttock-popliteal length, foot breadth (ball of the foot), grip diameter (inside), maximum grip length, hand breadth across metacarpal III were found relatively high (Range: 6 – 36%). So far as SEM results concern, it was observed that age and body weight had the highest SEM values (0.81 – 1.27) compared to other dimensions.

3.5.4.5 Comparison of anthropometric database between male and female Assamese agricultural workers

Anthropometric database of male and female Assamese agricultural workers were compared. Table 3.16 showed significant differences between male and female dimensions in terms of hand grip strength (Right) ($t=11.61$, $p<0.001$), hand grip strength (Left) ($t=11.07$, $p<0.001$), leg strength (Right) ($t=6.66$, $p<0.001$), leg strength (Left) ($t=5.71$, $p<0.001$), weight ($t=6.25$, $p<0.001$), stature ($t=13.92$, $p<0.001$), acromial height ($t=12.15$, $p<0.001$), elbow height ($t=8.29$, $p<0.001$), olecranon height ($t=9.28$, $p<0.001$), trochanteric height ($t=5.87$, $p<0.001$), knee height ($t=10.07$, $p<0.001$), arm reach from wall ($t=11.32$, $p<0.001$), shoulder grip length ($t=9.02$, $p<0.001$), shoulder breadth (bi-deltoid)($t=10.42$, $p<0.001$), hip breadth ($t=2.17$, $p=0.03$), height ($t=6.88$, $p<0.001$), acromial height ($t=7.77$, $p<0.001$), knee height ($t=12.44$, $p<0.001$), popliteal height ($t=8.25$, $p<0.001$), buttock-knee length ($t=10.17$, $p<0.001$), buttock-popliteal length ($t=4.08$, $p<0.001$), foot length ($t=13.05$, $p<0.001$), instep length ($t=13.18$, $p<0.001$), foot breadth (ball of the foot)($t=11.72$, $p<0.001$), functional leg length ($t=7.16$, $p<0.001$), grip diameter (inside) ($t=4.14$, $p<0.001$), maximum grip length ($t=6.43$, $p<0.001$), hand length ($t=9.75$, $p<0.001$), palm length ($t=12.04$, $p<0.001$), hand breadth across thumb ($t=13.29$, $p<0.001$) and hand breadth across metacarpal – III ($t=14.76$, $p<0.001$).

It was observed that in almost all the measurements except hip breadth ($p<0.01$), the male agricultural workers registered a significantly higher score compared to their female counterpart. The significant difference in these measurements clearly directed that gender should be duly considered while designing tools and equipment for the Assamese population of farmers.

Table 3.16 Mean, standard deviation (Mean ± SD) and t-test results for anthropometric dimensions of males and females of Assamese agricultural workers

Anthropometric dimensions	Male (Mean ± SD)	Female (Mean ± SD)	CI_L	CI_U
Weight, kg	55.22 ± 7.00	48.49 ± 7.72	4.61	8.92
Standing measurement (cm)				
Stature	162.75 ± 4.59	153.1 ± 4.83	8.28	11.04
Acromial height	135.23 ± 4.38	127.09 ± 4.77	6.82	9.50
Elbow height	100.68 ± 4.4	95.5 ± 3.85	3.95	6.37
Olecranon height	98.36 ± 4.49	92.47 ± 3.86	4.64	7.09
Trochanteric height	78.92 ± 4.08	75.41 ± 3.94	2.33	4.68
Knee height	45.35 ± 2.35	41.61 ± 2.77	3.01	4.51
Arm reach from wall	81.56 ± 3.74	75.16 ± 3.95	5.28	7.54
Shoulder grip length	69.78 ± 3.67	65.57 ± 2.83	3.29	5.20
Shoulder breadth	42.22 ± 2.02	38.11 ± 2.95	3.33	4.81
HIP BREADTH	30.77 ± 1.61	30.16 ± 2.03	0.05	1.13
Sitting measurement (cm)				
Height	84 ± 3.99	80.49 ± 3.11	2.50	4.59
Acromial height	58.21 ± 3.41	54.45 ± 2.97	2.81	4.68
Knee height	49.08 ± 2.31	44.68 ± 2.52	3.70	5.12
Popliteal height	40.23 ± 2.49	37.03 ± 2.84	2.43	4.00
Buttock-knee length	53.76 ± 2.2	50.51 ± 2.07	2.62	3.87
Buttock-popliteal length	42.59 ± 2.54	40.82 ± 3.11	0.91	2.57
Foot length	23.97 ± 0.82	22.27 ± 0.98	1.44	1.97
Instep length	18.46 ± 0.93	16.69 ± 0.86	1.51	2.03
Foot breadth(ball of the foot)	9.75 ± 0.59	8.76 ± 0.53	0.82	1.15
Functional leg length	94.24 ± 4.03	90.2 ± 3.35	2.93	5.09
Sitting/standing measurement (cm)				
Grip diameter (inside)	4.91 ± 0.46	4.61 ± 0.54	0.16	0.45
Maximum grip length	11.36 ± 0.95	10.49 ± 0.84	0.60	1.13
Hand length	17.47 ± 0.7	16.4 ± 0.81	0.85	1.30
Palm length	10.1 ± 0.43	9.32 ± 0.45	0.65	0.91
Hand breadth across thumb	9.69 ± 0.45	8.83 ± 0.41	0.73	0.98
Hand breadth -metacarpal III	7.91 ± 0.48	6.82 ± 0.53	0.94	1.24

95% CI- confidence interval; L- lower; U – Upper; All dimensions were statistically significant at $p<0.001$, except hip breadth, which was significant at $p<0.05$

3.6 Experimental Procedures for Handgrip Measurement

The subjects were informed about purpose and their role in this study before they agreed to participate therein. Before commencing the test, consent form and self-responded short questionnaire related to previous history of neurological disorder, inflammatory joint diseases, injury to upper limb etc. (which could significantly affect handgrip strength) were obtained. Hand dominance was determined by knowing the preferred hand used for eating and dominant coordination. Since all the participants were found to be right handed, the right hand was considered as dominant hand and left hand as opposite hand. Handgrip strength measurement was taken with the Jamar handgrip dynamometer (Sammons Preston Inc., Boling-brook, IL, USA). Handgrip dynamometry is a robust and perhaps the most reliable measurement of maximal isometric muscular strength (Sullivan et al., 1988; Bohannon, 1986). These dynamometers consisted of five gripping positions and a dial representing strength in terms of force exerted. The strength reading can be viewed as kg (maximum 90, to nearest 0.5 kg) or pounds (lb; maximum 200, to nearest 2.5 lb). The highest reading on the dial was noted from peak-hold needle, which was reset for every recording.

Handgrip strength was measured in standing position for both dominant and opposite hands. Each subject stood erect with his / her arms hanging straight downwards, trunk and wrist in neutral positions to provide maximum grip strength. For each hand three readings were obtained. A ~3 min rest intervened between two subsequent trials for each subject in order to avoid muscle fatigue. Each subject performed grip tests on both the hands on the same day. The dynamometer handle was set at the second grip position and adjusted when required for comfortable of holding. The upper and lower parts of dynamometer handle ideally rested on first metacarpal (heel of palm) and middle of four fingers respectively, as shown in Fig. 3.6. Each participant was instructed to hold the handle of the dynamometer straight and squeeze with the right hand (dominant) first and then left hand (opposite) exerting maximum isometric strength for a period of 3-5 s without any significant movement of other body parts (Fig. 3.7). As the subjects began to squeeze, verbal encouragements (little more; you can do it more; and finally, Relax!) were given to attain a maximum effort. With the same instructions, second and third trials were repeated for each hand in an alternating pattern. The results were recorded in kg and the highest of the three strength measurement readings for each of right and left hand were used for analysis.

Fig. 3.6 Handgrip strength measurement technique

Fig. 3.7 Measurement of handgrip force for male and female agricultural workers

3.6.1 Results and Discussion

3.6.1.1 Hand grip strength

The descriptive statistics including mean, minima, maxima, SD, COV(%), SEM, 95% confidence lower and upper limits, 5^{th} and 95^{th} percentile values of handgrip isometric strength (N) for male and female agricultural workers were tabulated in Table 3.17. The handgrip strength readings (Mean ± SD) for right (dominant) and left (opposite) hands were 30.11 ± 7.06 kg and 26.59 ± 6.84 kg for males, whereas for females, they were

19.75 ± 5.38 kg and 15.96 ± 5.74 kg, respectively. The coefficients of variation of grip strengths for dominant and opposite hands were found to be higher for female participants compared to male participants.

Table 3.17 Comparisons of dominant hand and opposite hand strength (kg) of male and female agricultural workers (n=200)

Parameters	Dominant hand		Opposite hand	
	Male	Female	Male	Female
Minima	13.20	9.40	11.70	6.30
Lower limit#	28.89	18.50	25.41	14.61
Mean	30.11	19.75	26.59	15.96
St. deviation	7.06	5.38	6.84	5.74
Upper limit#	31.33	21.00	27.77	17.31
SEM	0.62	0.64	0.60	0.69
Maxima	50.20	34.10	45.00	29.40
5^{th} percentile	18.50	10.90	15.33	6.52
95^{th} percentile	41.72	28.61	37.84	25.40
COV (%)	23.44	27.25	25.74	35.97

SEM - standard error of the mean; COV -coefficient of variation; # - 95% confidence interval for the mean

3.6.1.2 Effect of hand grip strength for male and female among different age groups

Handgrip strength depends upon various factors such as gender, age, physical fitness, environment, hand preference of the individual etc. Various researchers reported age-related decline of muscular strength (Lindle et al., 1997; Beckett et al., 1996; Pieterse et al., 2002). Some positive correlation of grip strength with height and weight is also reported (Newman et al., 1984). The handgrip strength for three age groups viz., < 30 years, 30 – 40 years and > 40 years of present research were plotted on a bar graph as shown in Fig. 3.8. It was observed that, there were significant variations of grip strength across the age groups and genders. Handgrip strength was found to decrease with age for dominant and opposite hands in both male and female. However, grip strength of the dominant hand registered significantly higher scores than the opposite hand, irrespective of age and sex as a criterion. As like observed normally, males proved to be stronger than females, registering significantly higher grip strength values among all the age groups. For males of age groups <30 years, 30-40 years and >40 years, dominant and opposite handgrip strength were 32.43 kg and 28.01 kg; 30.38 kg and 27.34 kg; 27.76 kg, and

24.69 kg; while for females, the readings in the same order were 20.8 kg and 18.1 kg; 19.29 kg and 15.74 kg; 18.93 kg and 13.64 kg respectively; with significant differences between male and female scores (p<0.05). The above outcomes implicated the age dependent grip strength variation across genders with a trend of progressive decline in the same with aging. When compared to females, for the youngest group (<30 years), the males exhibited 9.91 kg and 11.63 kg greater strength for dominant and opposite hands respectively; while for the middle age group (30-40 years), the males showed 11.09 kg and 11.6 kg better strength for dominant and opposite hands respectively, and for the oldest group (>40 years), the male grips were found to be more strong by 8.83 kg and 11.05 kg for dominant and opposite hands respectively.

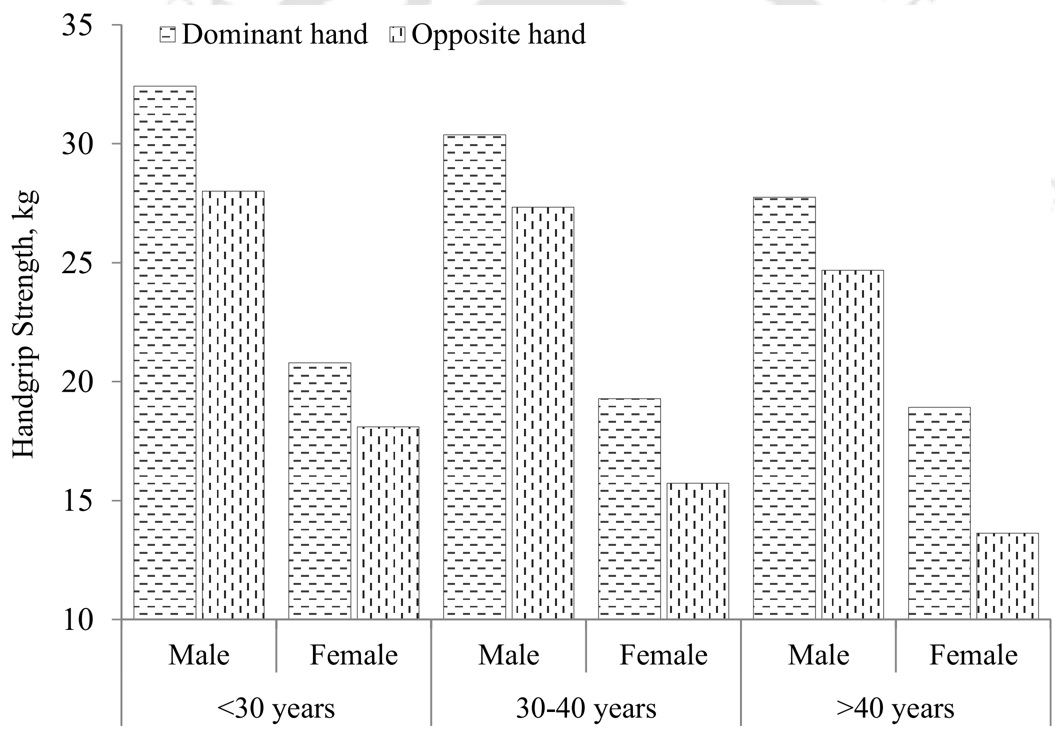


Fig. 3.8 Strength for dominant and opposite hands for male and female workers of different age groups

3.6.1.3 Comparison of grip strength with other regions / zones of India

The Student's t-test was performed to determine the significant of differences between mean values of handgrip strength of agricultural workers from Assam and from other regions of India viz., Jammu and Kashmir (J&K), Madhya Pradesh (MP), Maharashtra (MH), Orissa (OR) and Tamil Nadu (TN) states. The results pronounced that, the handgrip strength database of dominant and opposite hands of Assamese population deviated significantly (p<0.01) in all the cases, except for Maharashtrian female agricultural workers, as shown in Table 3.18. These significant differences in strength of agricultural workers from Assam (both male and female) and other parts of India clearly designate that the tools and equipment design should be region-specific.

Table 3.18 Comparison of handgrip strength data of agricultural workers of present study (i.e. Assam state) with data from other zones of India

Handgrip Strength	Gender	Northeastern India¤ (Mean ± SD)	Other zones of India # (Mean ± SD)				
			Northern India	Southern India	Eastern India	Western India	Central India
Dominant hand	Male	295 ± 69	313 ± 52**	412 ± 87**	336 ± 82**	326 ± 66**	404 ± 110**
	Female	194 ± 53	140 ± 33**	275 ± 70**	225 ± 69**	*180 ± 44*	242 ± 88**
Opposite hand	Male	261 ± 67	294 ± 51**	388 ± 106**	326 ± 79**	313 ± 65**	377 ± 110**
	Female	157 ± 56	120 ± 29**	274 ± 73**	207 ± 57**	167 ± 42**	211 ± 89**

Measurement unit = newton (N); ¤ – present study i.e. Assamese population; # – Gite et al., 2009; North India – Jammu & Kashmir; Southern India – Tamilnadu; Eastern India – Orissa; Western India – Maharashtra; Northeastern India – Assam (present study); Central India – Madhya Pradesh; ** – statistically significant at $p<0.01$

3.6.1.4 Cumulative percentage distribution of handgrip force

The cumulative percentage distribution of handgrip strength for male and female dominant and opposite hands respectively was shown in Fig. 3.9. From the graph, it was observed that 90% of the cumulative right and left handgrip strengths of females corresponded to about 32% and 35% of right and left handgrip strengths of their male counter parts respectively. The mean values of right (34.1 kg) and left (29.4 kg) grip strength of females were about ⅔ of right (50.2 kg) and left (45.0 kg) grip strength of male workers. Patel et al. (2014) also compared sixteen strength parameters including dominant and opposite hands grip strength of pooled Indian database with regional database from various states viz., Gujarat, Jammu and Kashmir, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Meghalaya and Arunachal Pradesh. They reported that, average muscular strength of a female is significantly lower than their male counterparts (in general ⅔ of male) across all states. Therefore, knowledge about basic understanding of human abilities, limitations, and other characteristics which are relevant to tools and equipment design are utmost important.

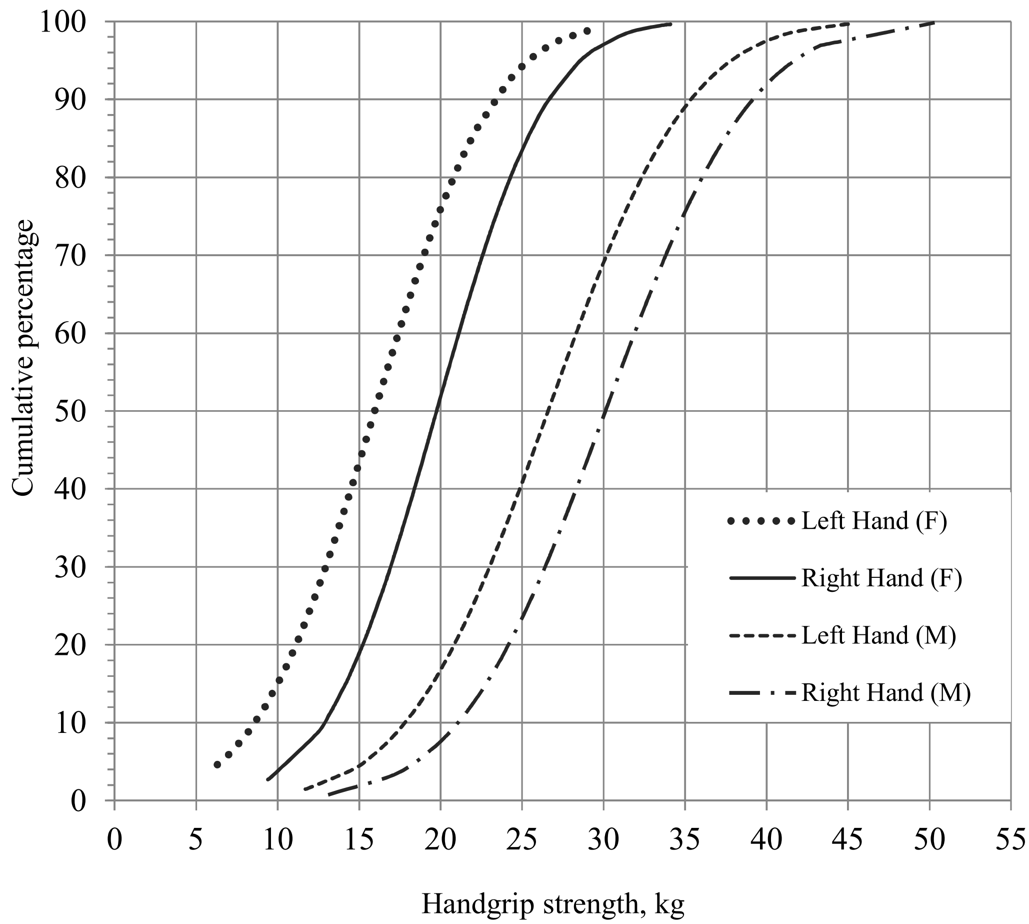


Fig. 3.9 Cumulative percentage distribution of handgrip force for male (M) and female (F) workers (From top female left handgrip, female right handgrip, male left handgrip and male right handgrip)

3.7 Experimental Procedures for Leg Strength Measurement

Following the pilot study, field experiment was conducted for collection and compilation of database of Assamese agricultural workers. Procedures followed herein for isometric leg force measurement have been described vividly in pilot study earlier. The demographic characteristics of subjects were discussed in previous section (Anthropometric measurement). For isometric leg strength data collection in the field set-up as shown in Fig. 3.10, 120^{o} knee angle was considered optimal for exertion of maximal force; because 120^{o} knee angle was found to have maximal execution of leg strength, based on results of pilot study.

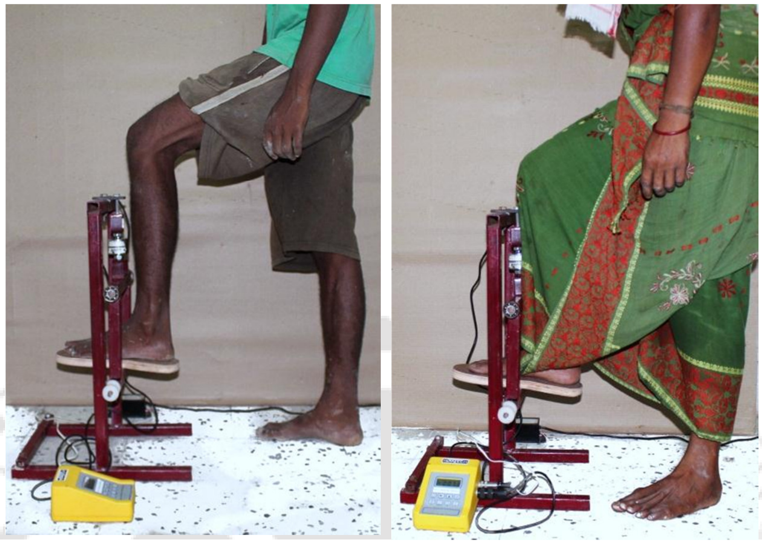


Fig. 3.10 Isometric vertical leg strength measurement for male and female workers

3.7.1 Results and Discussion

3.7.1.1 Isometric leg strength

The descriptive statistics including mean, minima, maxima, SD, COV(%), SEM, 95% confidence lower and upper limits, 5th and 95th percentile values of the male and female farm-workers were presented in Table 3.19.

Table 3.19 Comparisons of dominant and non-dominant leg muscle strengths of male and female agricultural workers (n = 200)

Parameters	Right leg		Left leg	
	Male	Female	Male	Female
Minima	12.40	8.20	9.70	8.70
Lower limit#	31.12	22.44	24.63	17.95
Mean	32.43	24.48	26.02	19.54
St. deviation	7.68	8.71	8.07	6.80
Upper limit#	33.74	26.52	27.41	21.13
SEM	0.67	1.04	0.71	0.81
Maxima	50.70	43.20	46.30	36.20
5th percentile	19.79	10.15	12.74	8.35
95th percentile	45.06	38.81	39.29	30.74
COV (%)	23.68	35.58	31.02	34.82

Measurement unit - kg; SEM -standard error of the mean; COV- coefficient of variation; # - 95% confidence interval for the mean

The leg strength values (Mean ± SD) for right and left legs were 32.43 ± 7.68 kg and 260.76 ± 8.07 kg for male farmers respectively whereas, for female farmers, they amounted to be 24.48 ± 8.71 kg and 19.54 ± 6.80 kg respectively. The coefficient of variation for right and left legs was found to be higher for female participants compared to male participants, similar to that shown in earlier instances.

3.7.1.2 Leg strength of male and female among different age groups

The isometric leg strength database of three age groups for male and female agricultural workers has shown in Fig. 3.11. The strength for right and left legs (kg; Mean ± SD) was found to be 35.70 ± 7.22 and 29.27 ± 6.73; 32.28 ± 6.91 and 25.94 ± 8.08; 29.54 ± 7.61 and 23.10 ± 8.21 for male workers of age groups of <30 years, 30-40 years and >40 years respectively. Similarly for female workers, leg strength for right and left legs (kg; Mean ± SD) were found to be 27.43 ± 8.56 and 21.40 ± 6.63; 23.57 ± 8.09 and 19.83 ± 7.21; 21.81 ± 8.71 and 17.12 ± 6.16 for <30 years, 30-40 years and >40 years respectively. Progressive with aging, muscle strength both legs in male and female reduce, as could be observed from the graph.

The results of independent samples Student's *t*-test showed that, there was significant difference in leg strength values for both legs ($p<0.05$) between male and female farmers across various age groups. Further, the combined leg strength database of male and female farmers across the age groups showed that, capability of right leg was significantly higher ($p<0.05$) than the left. The difference in leg strength between male and female participants was probably due to greater build of muscle mass in male (Westcott, 2003; Patel et al. 2014). Literature supported this fact well that, male muscular strength is commonly more than their female equivalents (Agrawal et al., 2009; Gite et al., 2009; Tiwari et al., 2010). Further, muscular force of the right leg is mostly more than the left.

It was observed from the Fig. 3.12 that, average muscular strength of female farm-workers expressed as % average strength of male farm-workers oscillated between 73 – 78%, such variation in leg strength for male versus female being 75.49% and 75.10% for right and left legs, in the present experimentation.

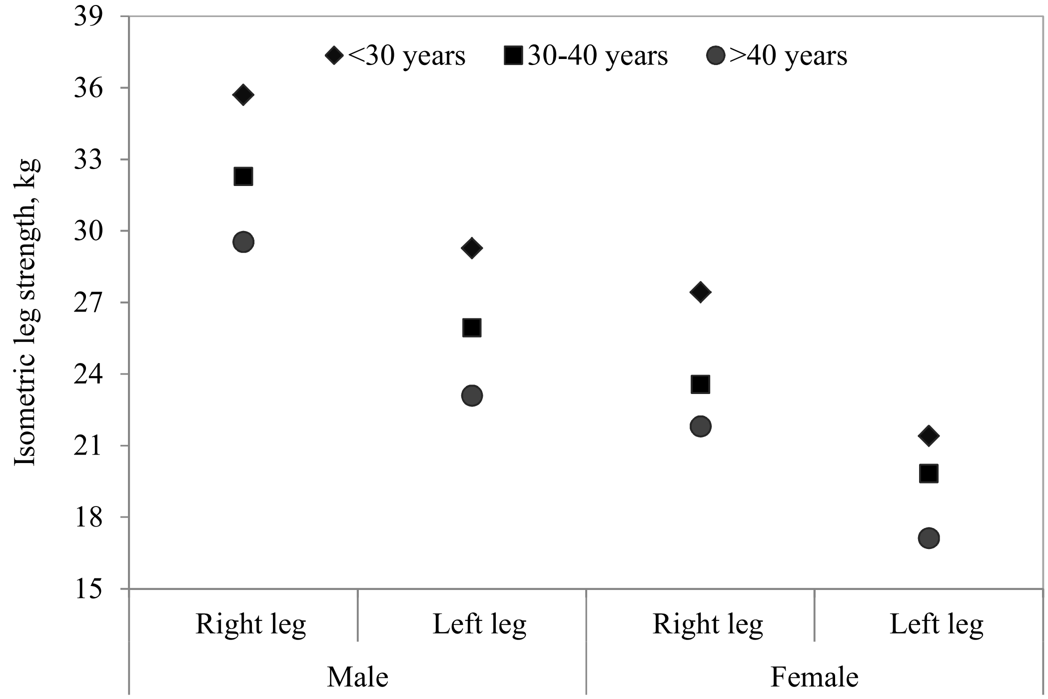


Fig. 3.11 Mean value of leg strengths for male and female, presented in age groups wise

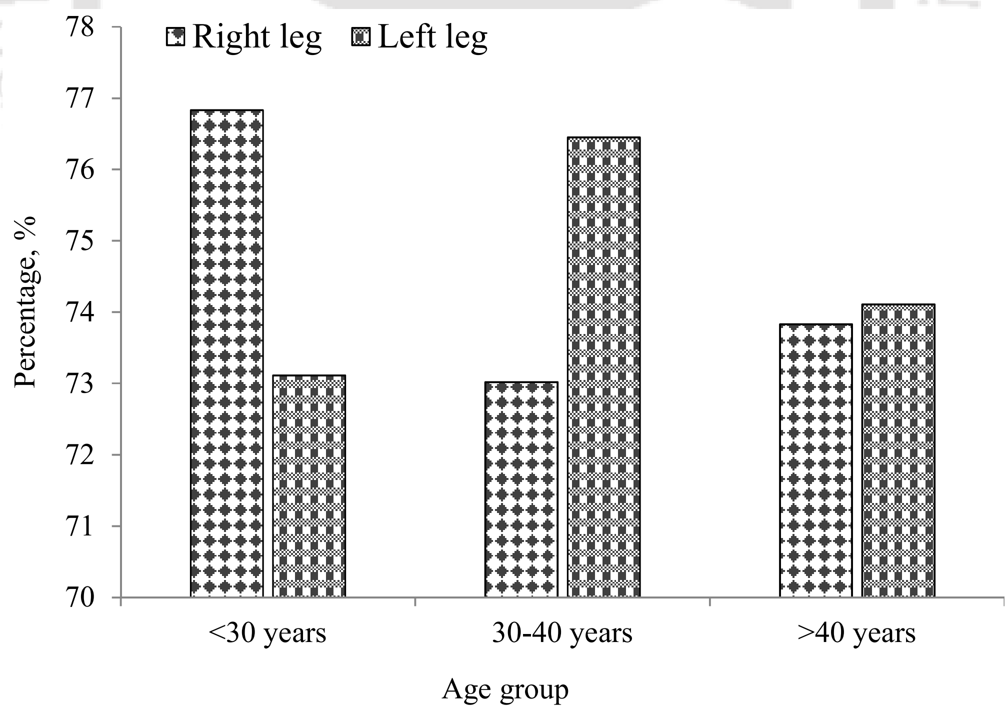


Fig. 3.12 Average muscular strength of female expressed as percentage of average strength data of male agricultural workers (From left: first column is for dominant leg and second column for opposite leg)

3.7.1.3 Distribution pattern of leg strength

As expected conventionally to be, at 95% probability, common zones or 'overlaps' for male and female leg strength values demonstrated inability to accommodate a wider array of muscular strength values of both male and female as shown in Fig. 3.13.

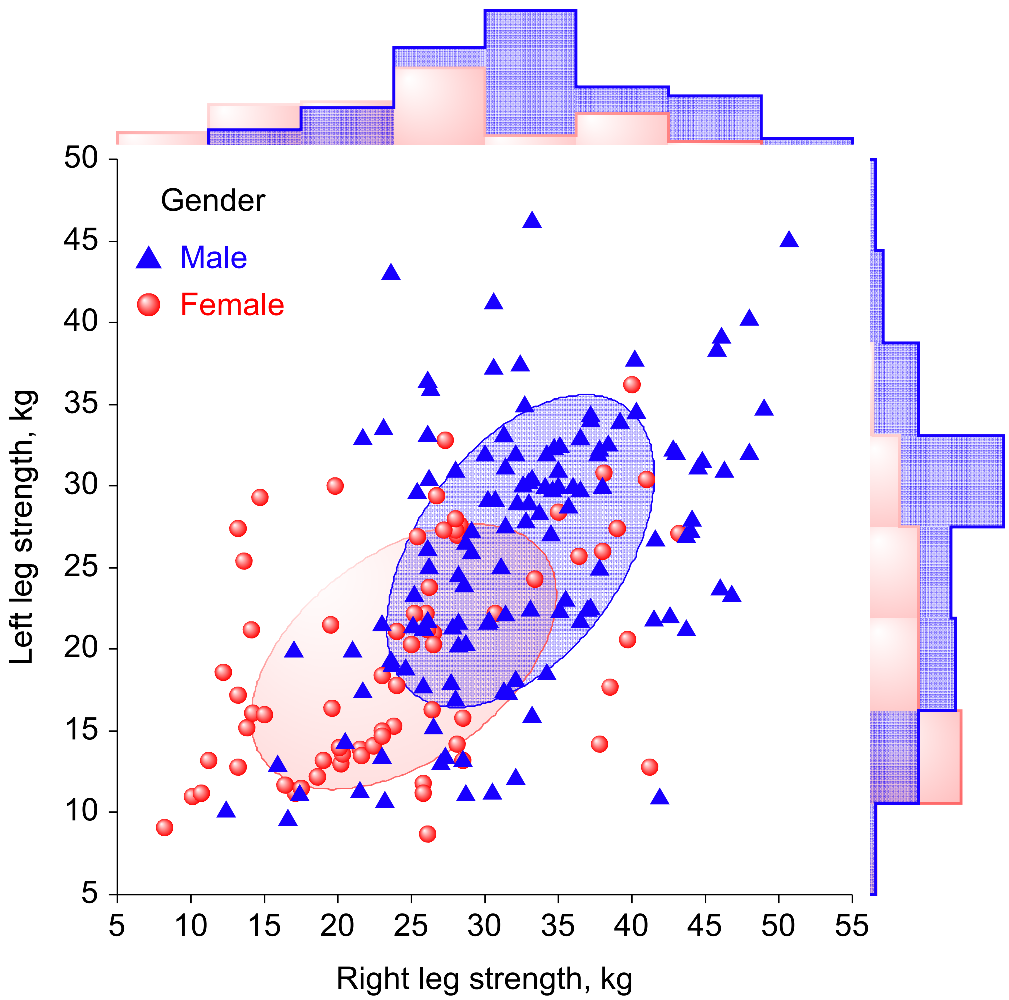


Fig. 3.13 Histogram and probability plots of leg strength

Therefore, any agricultural activity of repetitive nature executed commonly by both males and females should be so designed that, the force requirement would not exceed 30% of the 5th percentile of maximum strength capacity of female farmers. This would in turn ensure force requirement within safe limits. Force exertion may rise up to 50% as long as the effort is not prolonged for more than five minutes (Agrawal et al., 2009; Gite et al., 2009; Tiwari et al., 2010). Therefore, recommended value for leg strength for male and female agricultural workers of Assam should be 5th percentile of female data which were 11.47 kg for right leg and 8.34 kg for left. However, for the tools and equipment to be used exclusively by male agricultural workers, recommended values for strength should be 5th percentile value of male workers which were 19.33 kg for dominant and 13.78 kg for opposite legs respectively. In some work situations, where tools and equipment are designed as per 5th percentile mean values of male strength data and female workers are supposed to use the same occasionally, then sufficient rest pause must be provided for the female user to avoid any kind of musculoskeletal problems.

3.7.1.4 Cumulative percentage distribution of leg strength

The cumulative percentage distribution of isometric leg strength for male and female right and left legs respectively is shown in Fig. 3.14.

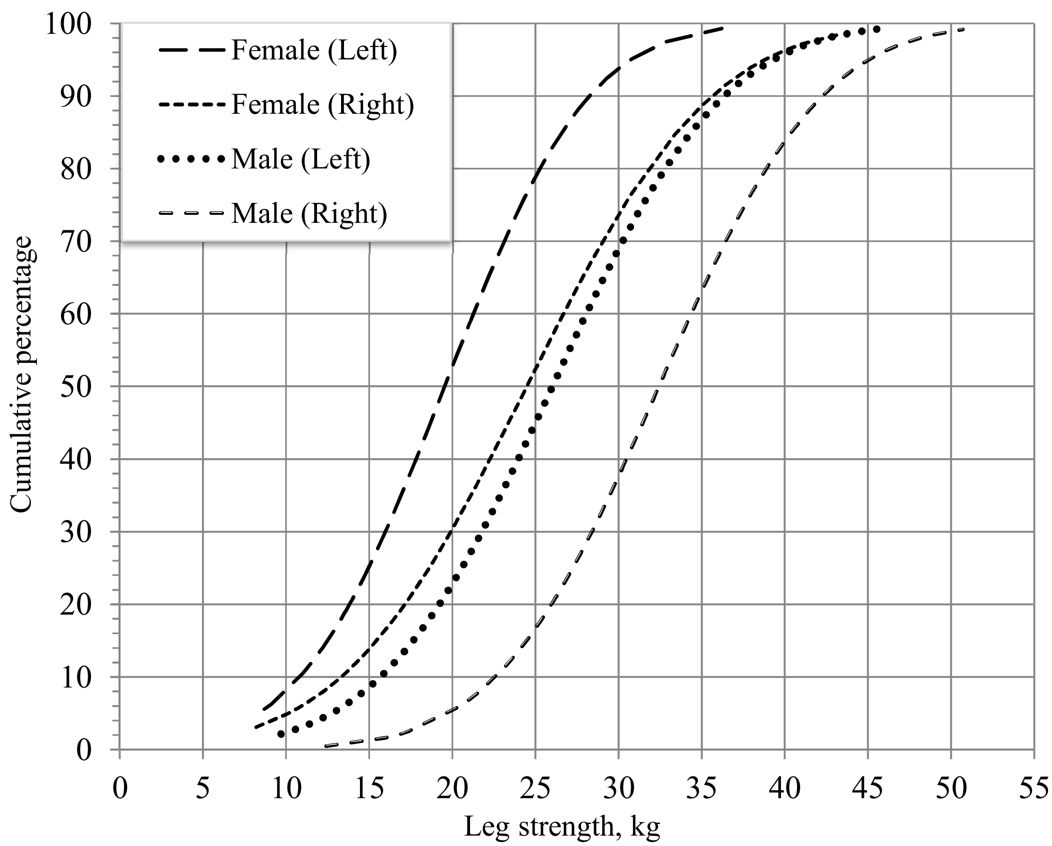


Fig. 3.14 Cumulative percentage distribution of isometric leg strength for male and female workers (From top female left leg, female right leg, male left leg and male right leg)

From the graph it is observed that cumulative percentage of 90% right and left leg strengths of male and female were about 42.6 kg and 36.5 kg; 35.5 kg and 28.4 kg respectively. For design or design modification of tools and equipment, to be operated by males and females both, operating force requirement should not exceed 30% of the 5th percentile value of maximum strength capacity of female workers to ensure wider coverage. However, minimum effort requirement should not be such low that, even for a moderately strong person it becomes difficult to control. The over-flexibility to accommodate the wider range of population may exacerbate the existing design problems. In such circumstances, design should focus on separate criteria for male and female workers.

Chapter 4

Ergonomic Design Modification, Testing and Evaluation of Pedal Operated Paddy Thresher

Abstract – *In NER, paddy threshing is mostly carried out by traditional methods (such as bullock treading, hand beating, foot crushing etc.) which requires enormous physical exertion. These discomfited situations expose workers to several risk factors. Existing pedal-operated paddy threshers are not suitable for this region due to constraints like heavy weight and lack of portability. To address these issues, the present research ideated the design of a pedal operated paddy thresher suitable for NER farmers, in particular for the Assamese farmers, following rigorous evaluation of the design in virtual 3D environment. Following identification of the needs and the intended users, some of the vital design features like appropriate clearance, protection from paddy dust, compact size, portability and operational safety were considered for conceptual fabrication of the 3D CAD model. Various human factor aspects of 3D-CAD model of pedal thresher were evaluated and rectified in DELMIA software using manikins (representing anthropometric data of the Assamese population) to ensure anthropometric and biomechanical compatibility of targeted users. Following virtual ergonomic evaluation of the thresher, physical prototype was fabricated. The developed model of paddy thresher was scrutinized in laboratory, followed by in real field scenario. Surface EMG was performed in the lab, while in the field experiments, observation-based methods / techniques like RULA were exercised, in addition to direct measurement, like heart rate and muscles fatigue, followed by subjective assessment such as NASA-TLX and body pain discomfort rating to identify the psychosocial stress during operation. The results showed that, in comparison to the existing thresher, the developed paddy thresher was more efficient in reducing drudgery, increasing comfort and thus enhancing overall productivity.*

4.1 Introduction

With the development of farm mechanization, improved farm implements and machinery came into use for various farm operations with the aim to increase productivity of land with rationalization of labor through timely operations, efficient use of inputs, improvement in duality of produce, resulting in reduced drudgery of farmer. In the developed countries, however, harvesting and threshing of rice has almost entirely mechanized and this has resulted in remarkable reserve of time and labor. Furthermore, the increased income of the farmers from higher paddy yields has provided additional encouragement for mechanization. However, cultivation in hilly terrains is still carried out with traditional hand tools or bullock drawn wooden implements. The NER is still in the early stages of evolution as far as mechanization is concerned. Mechanization in northeast states has not taken up the required shape possibly due to terrain, cultivation practices and economic condition of farmers as well as weak promotional efforts from the governmental and private organizations. Moreover in NER, non-availability of improved farm tools and implements along with their repairing facilities are also one of the major constraints in growth of mechanization.

The five stages of farm mechanization commonly cited are: primitive stage, elementary mechanization, animal traction, initial motorization and final automation. Hill agriculture demands lightweight machines, which are small in size and easy to transport. It should be operable even in narrow terraces and deep valley lands, where bigger equipment cannot reach. The lightweight power tiller can be very useful for hill farming, as it can be used for plowing, puddling, weeding, harvesting, threshing operations with the help of suitable attachments. Manually handled machines like wheel hoe, multipurpose weeders, seed drills and pedal paddy thresher has better scope in hilly areas. Thus attempts should be made to promote usage of mechanical and electrical powers for various operations by increasing their availability in NER, in order to ensure cost economy and timeliness of various operations. Several engine- or power-operated paddy threshers have been designed and developed in the past, but they have not been successful in the hilly areas because of cost, weight, and electric power requirement problems. Even though many designs are popular in different parts of the country, design suitable for NER has not yet been established.

4.2 Paddy Threshing – Post-Harvest Processing Means

Paddy cultivation involves a sequence of processes starting from seedbed preparation to post harvest processing. All the processes are divided into major five segments like farming, harvesting, threshing, winnowing and milling. Paddy threshing involves three quite distinct operations viz. separating the grain from the panicle, sorting the grain from the straw and winnowing the chaff from the grain. All these operations are quite time consuming, demanding surmount of energy.

Power operated paddy thresher has been widely adopted by farmers in northern states like Punjab, Haryana and Uttar Pradesh, while manual hold-on type pedal threshers still prevail in traditional rice growing areas of eastern and southern India. Current population of pedal operated threshers in India approximates to nearly one million. This very type of thresher is also popular in other developing countries like Bangladesh, Bhutan, Korea and some African countries. Paddy threshing can be done by various means but most commonly used methods include animal treading, tractor treading and power threshers, as shown in Fig. 4.1.

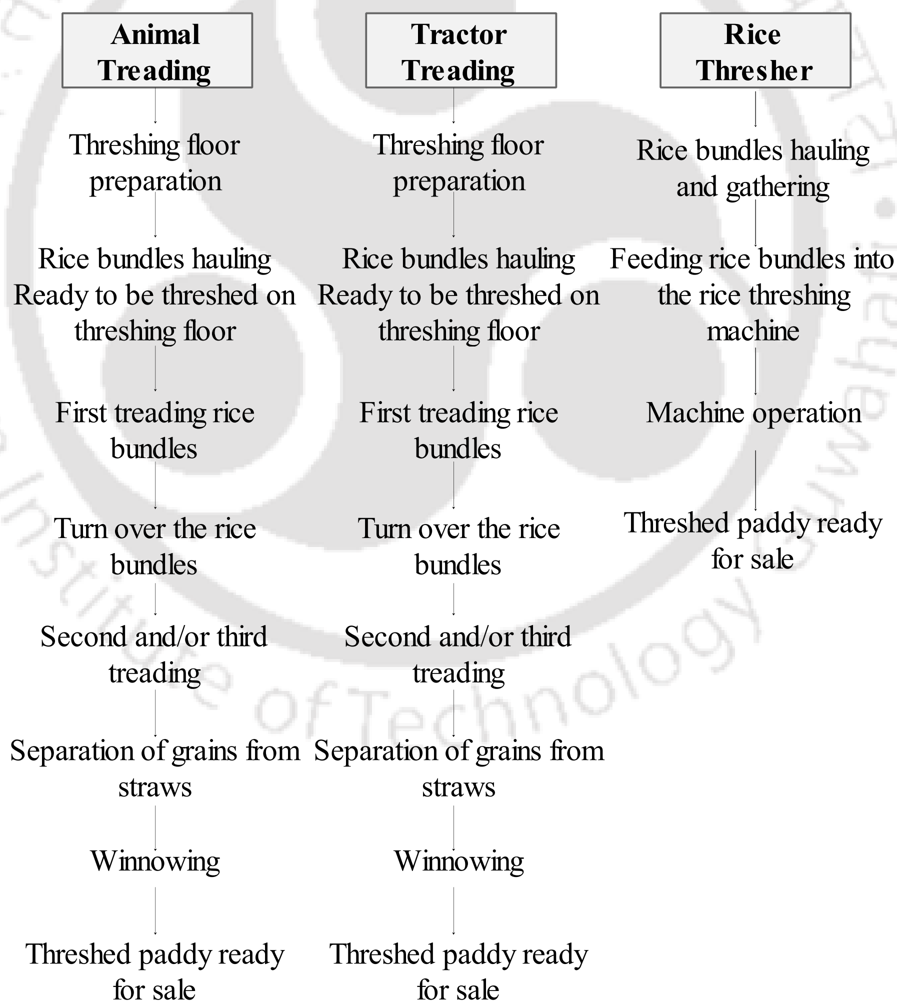
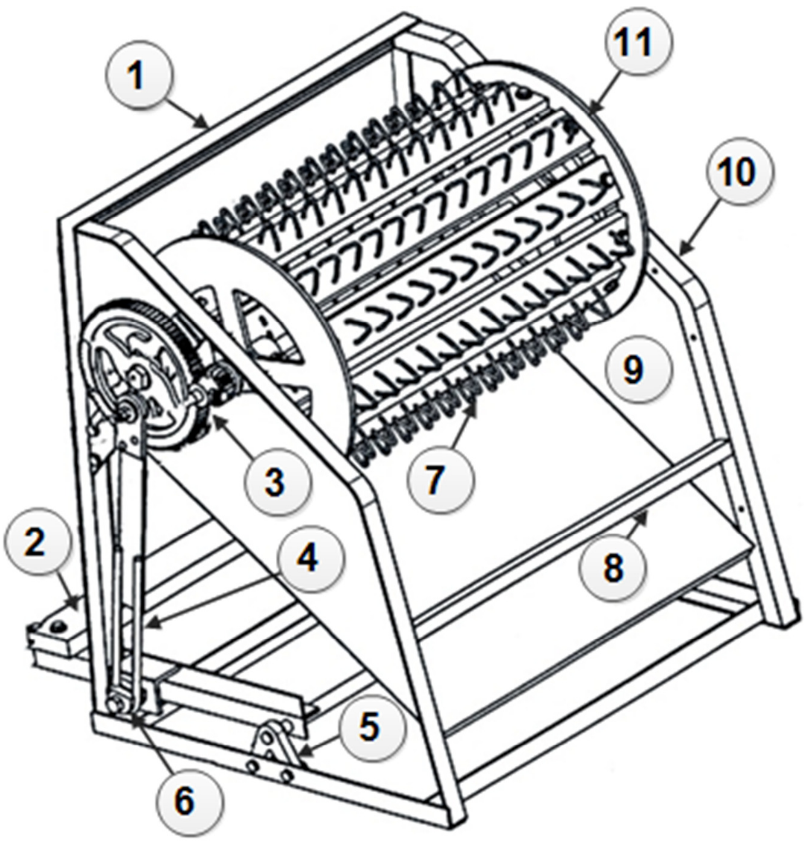


Fig. 4.1 Stages of rice threshing by various methods

On an average an individual can thresh upto 15-22 kg/h of grain by hand-beating or upto 110-140 kg/h by animal treading. In either method, sound grains are separated using a winnower operated by human, a power unit or dropping the mix against the medium high natural wind. Thus, the separation of sound grain and its manual bagging require additional labor, making the entire process tedious, time-consuming, and labor-intensive. Satapathy and Sahay (1998) reported that, more than 20 percent of gross energy is utilized in threshing activity. Therefore, mechanical means support the farmers to thresh more grains within a shorter spell and at the same time, reduce the transportation owed loss. These multipurpose threshers chop the paddy chaff into small bits and render them unfit for use as cattle feed. Mr. Mohammed Fazlul Haque from Assam invented a paddy thresher machine (Fig. 4.2) where whole paddy stalk can be obtained instead of chopped pieces thus nutritional value is conserved in the whole stalk and fed to cattle or sold.

Fig. 4.2 Power operated paddy thresher invented by a farmer in Assam

In some parts of Assam, Meghalaya and Arunachal Pradesh, pedal operated paddy thresher is in use, supplied by neighboring states viz. West Bengal and Orissa. Typical appearance of pedal operated paddy thresher is shown in Fig. 4.3. Pedal operated paddy threshers are commonly of manual hold-on type. The main parts of thresher includes crank gear, pinion gear, crank axle, crank pin, cylinder shaft, cylinder mounting, connecting rod, pedal, pedal shaft, threshing drum and wire loops. Its design and features have undergone many changes across different locations. The general failure of existing pedal threshers is likely due to their operational difficulty and heavy weight. The NER topogeography is somewhat different from other parts of the country. Therefore, transportation of heavy equipment in hilly areas is quite difficult.



1 - Rear grain shield and back supporting frame; 2 - Pedal; 3 - Crank and pinion gear; 4 - Connecting rod; 5 - Pedal shaft; 6 - Rocker assembly; 7 - Spike tooth; 8 - Tie member; 9 - Side grain shield; 10 - Side supporting frame; 11 - Threshing cylinder.

Fig. 4.3 Typical appearance of pedal operated paddy thresher

4.3 Computer-Aided Design and Digital Human Modeling

Computer-Aided Design (CAD) and Digital Human Modeling (DHM) technologies are specialized CAD software platform for virtual representation of human endowing unique opportunities to integrate human factors proactively in product design and research. Challenges of enhancing agricultural productivity through improvement of agricultural tools / machineries and better user compatibility can be assured by adoption of CAD and

DHM. Extensive literature review revealed that conventional design methodologies are gradually converted to modern techniques in diverse fields. Basic approaches in problem solving during development of agricultural equipment could be divided in two categories (Fig. 4.4). The *conventional approach* allows the engineer to design and conduct repetitive field experiments to determine the best combination of independent variables needed to obtain the required output. Problem associated with this approach is that, designers can only guess how operator would interact with the product. Moreover, it is time consuming, more costly and sometimes further modification is almost impossible. The second approach is *computer-aided design*, considered the best one – where equipment designer and manufacturer can effectively interact with the product model directly in 3D CAD environment, rather than conventional on-paper 2D interactions during the process of conceptual modeling (Kamboj et al., 2012). This offers freedom for any design modification at any stage in the product design development phase prior to production.

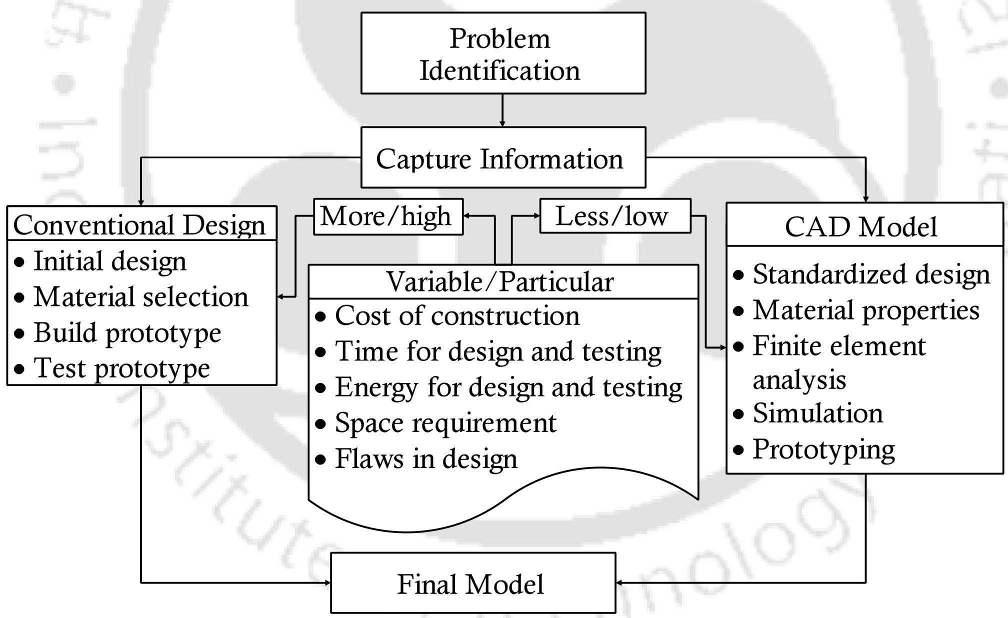


Fig. 4.4 Computer aided vs. conventional designing process

4.3.1 DHM in product design and development

DHM provides a computer-generated 3D environment for product design and simulation. At present, DHM has widespread applications in various applied fields and industries, including agriculture for design of tools / equipment, machines and off-road vehicles (Patel et al., 2013a); with use in human performance assessment and optimizing product design for optimal user-system integration (Dooley, 2012; Antonucci et al., 2013). Earlier, design of farm equipment used to bypass formal ergonomic considerations, resulting in subsequent occurrence of several potential anomalies to the end-user i.e. farmers. With the advancing technology, a greater number of features are being incorporated for analysis and simulations on projected designs (Antonucci et al., 2013). These new expansions offer uninterrupted human factors considerations to perform ergonomic analysis of the products. A combination of CAD and DHM encourages many novel approaches in modeling and simulation. These help to carry out ergonomic evaluations of human-machine interactions (Fig. 4.5) to make more safe, efficient, comfortable and productive work environment for every segment of the population (Paul and Lee, 2011).

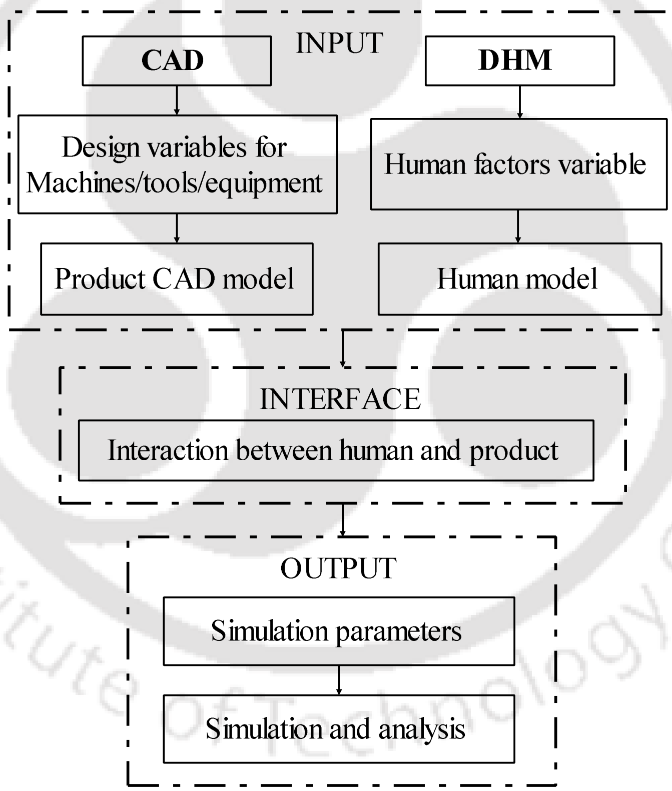


Fig. 4.5 CAD and DHM interface in product evaluation

Virtual simulation facilitates evaluation of potential advantages and disadvantages of the design conformations, thus being widely used to reduce costs, time to market, and thus to replace the need for costly physical prototypes (Wu et al., 2012). DHM provide visualizations of anthropometry and biomechanics, such as body posture, reach envelope, field of view, clearances, load on lumbar spine segments etc., which serve as basic inputs for design analysis and engineering decision making.

4.3.2 Applications of computer-aided design in agricultural engineering

Mechanization of various tools and technique used for production, transportation and processing of agricultural products is a need for sustainable development of agriculture (Pretty, 1995). It is well perceived that using CAD based design approaches will extrapolate the advancement of agriculture thereby boosting rural economy, improving the competitive farm ability, and finally raising the farmer's economy. To date, conventional agricultural design is gradually transformed into modern digitized design tools (Shuming, 2004). Application of CAD has made design of farm machineries intuitive, flexible yet convenient. Various researchers have already been harvested with the CAD advantages (Fig. 4.6).

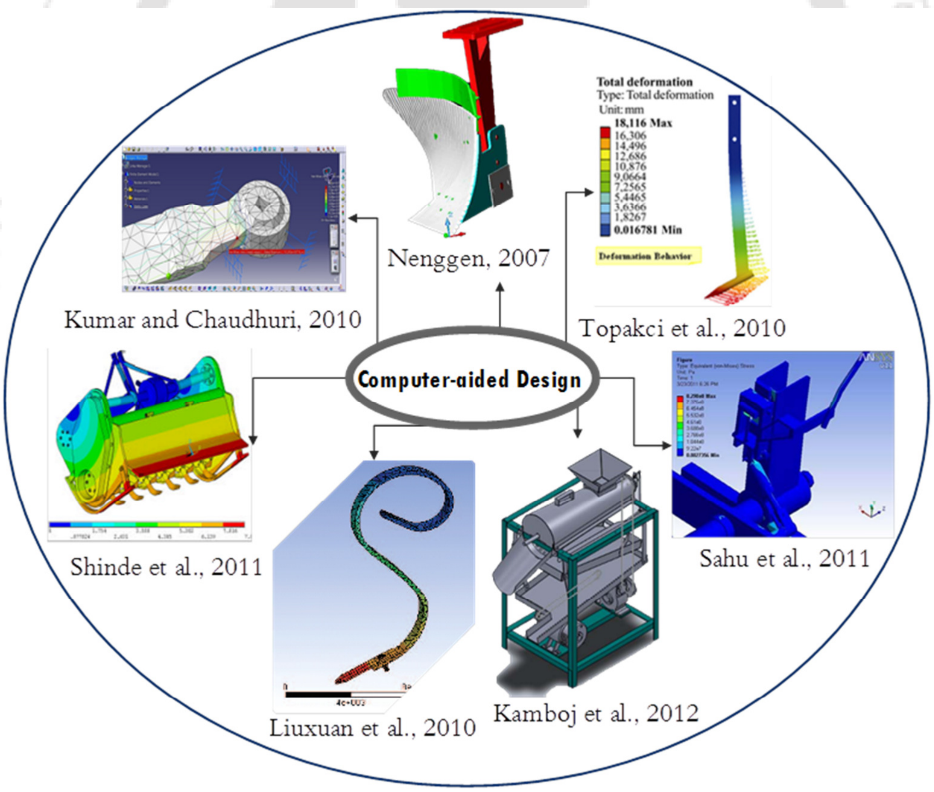


Fig. 4.6 Application of computer-aided design in agriculture sector

Analyses of various design considerations like stress, fatigue, weight, durability, damage and safety factors assist designer to determine the paramount promising fabrication design prior to finalize the prototype (Shrivastava and Jha, 2011). Today's CAD software is truly beneficial for modelling, rendering, simulation and mechanical analysis; but mostly these are not capable of evaluating human factor issues. For incorporation of ergonomic principles in product / process and workplace design, role of DHM software appears to be inevitable (Patel et al., 2013).

4.3.3 Applications of digital human modeling in agricultural sector

With developing consciousness about safety and ergonomic issues in line of advancing computational techniques, DHM is effectively addressing (and solving) human factor issues in early stage of product life cycle (Beeney and Charland, 2012). DHM is special component in CAD for developing 2D or 3D digital manikin (virtual representation of human) using anthropometric and biomechanical database of intended / targeted user population for successful ergonomic evaluation of product fitted in the workplace. There are numerous databases all over the world for different populations. Selection and recommendation of apt anthropometric and biomechanical database are context-specific, and therefore depend on the intended user group using the product / workstation. Use of percentile anthropometric and biomechanical dataset from identified database is a common practice in this regard. DHMs tools help in building complete digital humans (realistic reproduction of body measurement with incorporation of biomechanical features), which is subsequently interfaced with CAD models of product and workplaces in digitally rendered environments to explore the ergonomic consequences viz. human size-scaling, posture analysis, motion analysis, reach analysis, vision analysis etc. (Patel et al., 2013).

Today, engineering design is in the midst of a paradigm shift, where with the help of DHM, researchers have preliminary focus on interfacing the human with system to achieve better system-to-human compatibility. DHM have a comparatively late entry into agricultural engineering set-up. Most of the available literature reported applications of DHM in off-road vehicles only, specifically for tractor cab. DHM allows designers to build tractor cabs suitable for operators of varying body dimensions. It provides the designers with a biomechanically correct CAD representation of the human body i.e. manikin, that can be animated to simulate driver postures and behavior (Patel et al., 2013). Now, the question which comes to mind is – how would these technologies prove to be beneficial? This can be illustrated with the example of ergonomic evaluation of structure and function of a 3D tractor cab model (Fig. 4.7).

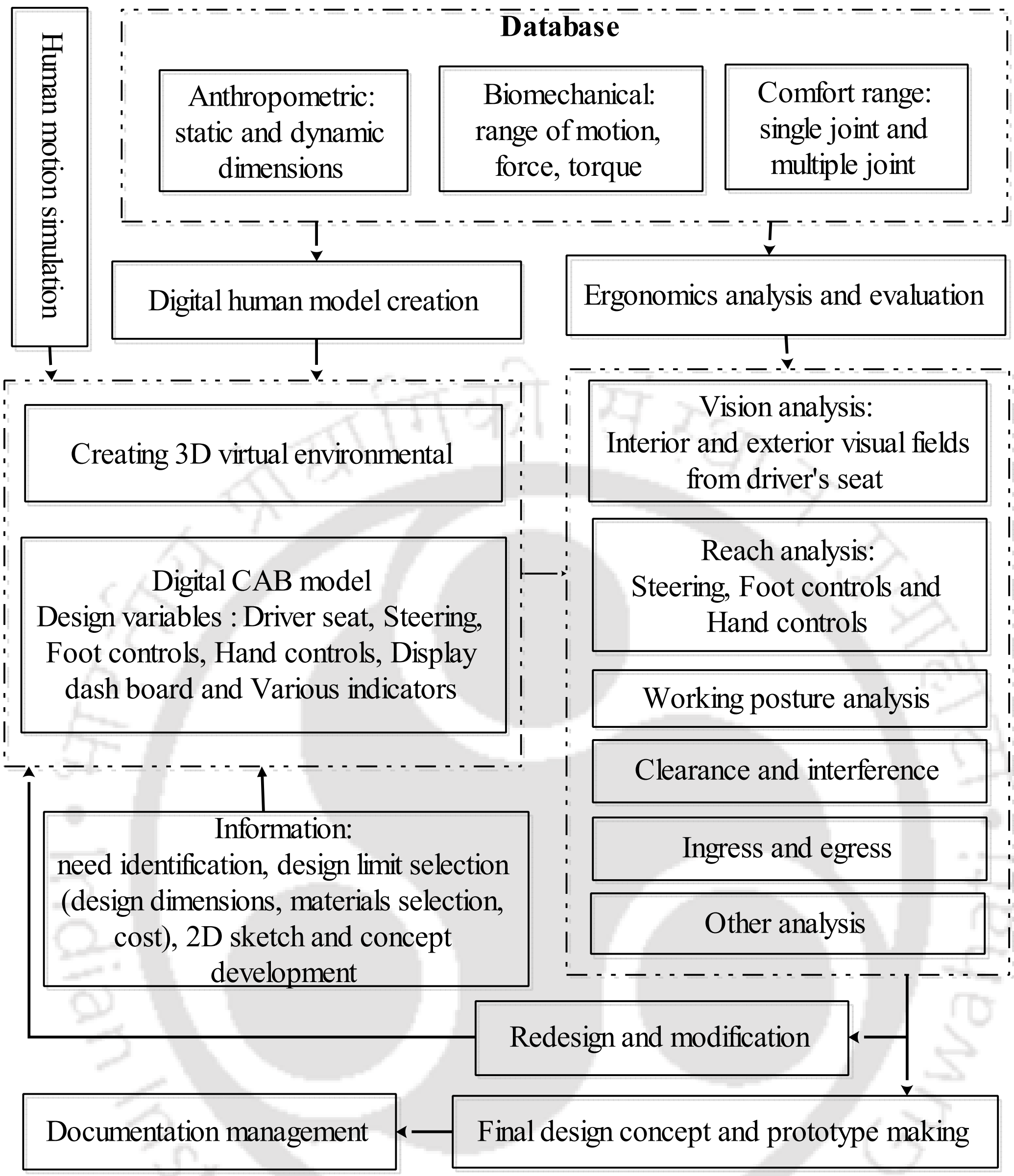


Fig. 4.7 Schematic representation for ergonomic evaluation of 3D tractor cab model with digital human modeling

Although, hand tools and equipment powered by human are commonly used for performing various agricultural operations, no available literatures revealed any DHM tool perceived for design and simulation of manually handled hand tools and equipment. Various applications of DHM ergonomics for design, analysis and simulation of farming machineries in 3D virtual environment (Wu et al., 2012; Ying et al., 2010; Fathallah et al., 2009; Lundstrom et al., 2008; Chang et al., 2010; Xiao-yan et al., 2010; Hsiao et al., 2005; Deisinger et al., 2000) are shown in Fig. 4.8.

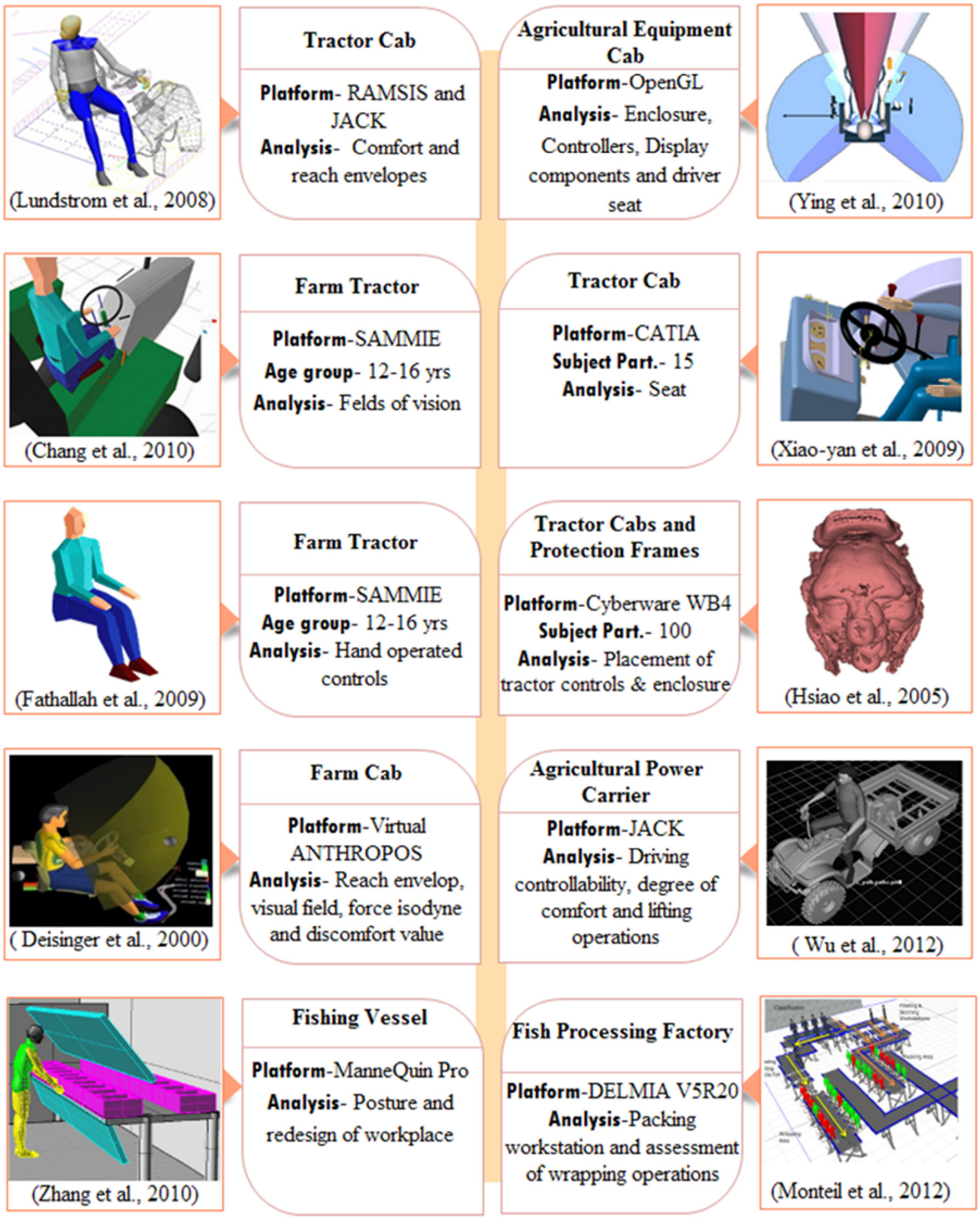


Fig. 4.8 Pictorial representation of DHM applications in agriculture

4.4 Pilot Study – Pedal Operated Paddy Thresher

Two factual surveys were conducted with manufacturers and users of the available pedal-operated paddy threshers to address two specific intentions –

1) Explore material, dimensional and other requirements for the paddy thresher
2) Musculoskeletal issues and risks of operating the pedal operated paddy thresher

Pedal-operated paddy thresher is locally manufactured by small scale industries. A survey related to its design parameters and physiological aspects of operation was conducted to collect relevant facts and figures (survey Proforma is given in Appendix 4). Musculoskeletal risks of operation were obtained from the farmers of three states of NER namely, Assam, Arunachal Pradesh and Meghalaya. The questionnaires were prepared separately for each survey.

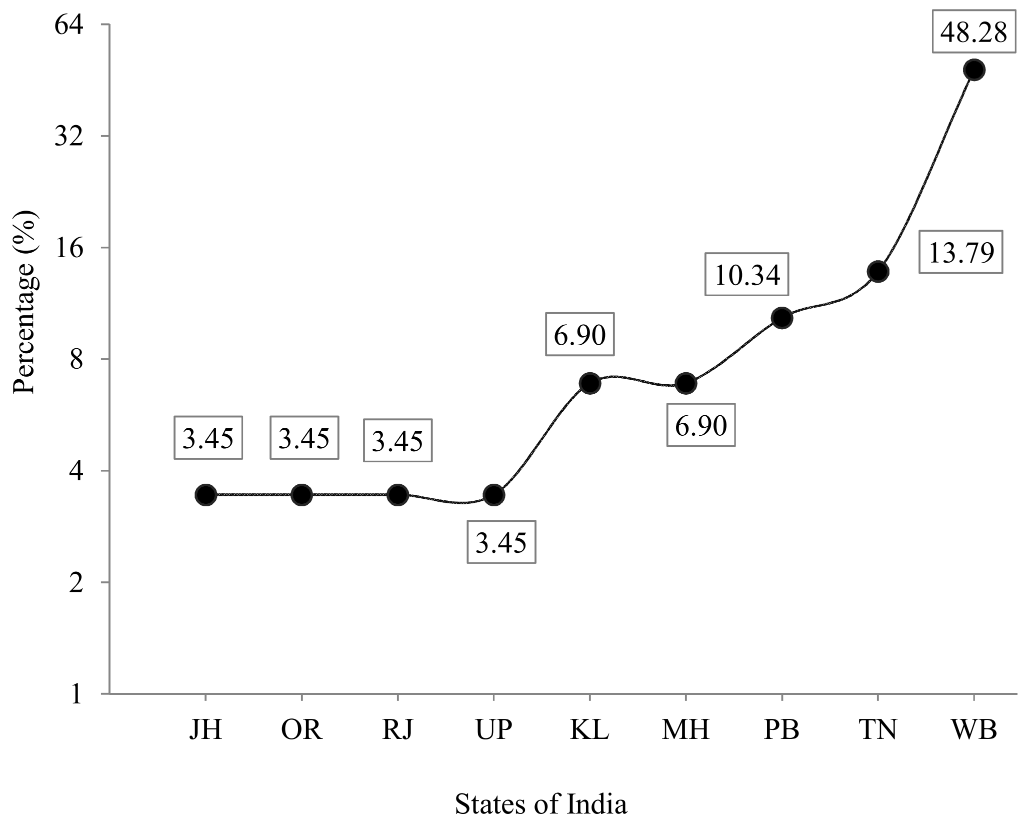
The Indian manufacturers of paddy thresher are mostly from West Bengal, together with however, also from Jharkhand, Odisha, Rajasthan, Tamil Nadu, Punjab, Maharashtra, Uttar Pradesh and Haryana; but none was found to be from the NER. A systematic survey was conducted to acquire technical design inputs pertinent to the paddy thresher from different manufacturers through website, telephonic conversation and *e*-mail. Twenty nine manufacturers responded willingly providing with detailed technical figures regarding design and manufacture of pedal-operated paddy thresher. Adoption of the stipulations of the Indian Standard IS**:** 3327 regarding the material, dimensional and other requirements for the pedal-operated paddy thresher is mandatory while manufacturing any such thresher.

The Proforma for musculoskeletal concerns of operation was sent to ICAR Research Complex of Meghalaya and Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Arunachal Pradesh. The survey in Assam was carried out by personal interview. Surprisingly, most of the Assamese farmers did not have even seen any pedal operated paddy thresher prior to this survey. Across entire Assam, only a fewer number of threshers were seen, fitted with electric motor and used on rental bases.

4.4.1 Results and Discussion

4.4.1.1 Availability of pedal operated paddy thresher

Result of the survey on pedal operated paddy thresher, shown in Fig. 4.9, revealed that about 48% manufacturers belonged to West Bengal, while no manufacture was found from the NER. Majority of the manufactures did not appoint any dealer for advertising and selling the thresher. They used to supply the equipment to the farmers directly, based on their requirement. Most of manufacturers had in-house production and assembly, whereas some of them procured the spares / components from other states and assembled in-house. Manually powered and engine driven threshers are available. The average capacity of manufacturing threshers normally ranges between 500 – 800 units yearly, with no warranty on the product / spare. The manufacturers even do not use any pamphlets or hoardings for sales promotion. This industry thus hosts a low-yield low-profit business. The state Agro Industries Corporations also buy threshers from them, but for demonstration purposes in the farmer field only. All threshers are normally sold on cash in 100% advance payment basis.



(States of India: JH – Jharkhand, OR – Orissa, RJ – Rajasthan, UP – Uttar Pradesh, KL – Kerala, MH – Maharashtra, PB – Punjab, TN – Tamilnadu, WB – West Bengal)

Fig. 4.9 Percentage of pedal thresher suppliers participated in survey

All the threshers operated on human power use four bar linkage mechanism. There was large variability in design dimensions of various components of threshers. The design dimensions of some main components are listed in the Table 4.1 appended below.

Table 4.1 Design dimensions of pedal operated threshers manufactured in India

Particulars	Specification
Overall dimensions and specifications	
Length, cm	60-121
Width, cm	71-145
Height, cm	72-85
Side frames	Mild steel angle
Front Grain Shield	Mild steel sheet
Rear Grain Shield	Mild steel sheet
Weight, kg	40-90
Operating parameters	
Power requirement	1-2 person minimum
Drum speed, rpm	300-550
Power mechanism	Crank-follower four bar linkage
Gear ration	3:1-5:1
Material of construction for gear	Cast iron
Threshing drum specifications	
Length, cm	48-125
Diameter, cm	30-43
Material	Cost iron
Fingertip height, cm	5.5-7.5
No of fingers per meter length	18-22
Distance between the tip, cm	4.8 to 7.5
Finger type	loop
Mounting method	Staggered
Pedaling parameters	
Minimum height above ground, cm	5-7
Maximum height above ground, cm	19-24
Pedaling strike per min	60-90
Material of construction	Wooden/Mild steel

4.4.1.2 Musculoskeletal concerns with pedal operated paddy thresher

A total of 46 participants responded for the questioners related to musculoskeletal problems in operating pedal operated paddy thresher. The data received from ICAR Research Complex of Meghalaya, Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Arunachal Pradesh and personal interview of Assamese farmers were analyzed. The lower legs ailment evidently dominated (95.65%) among the farmers using pedal operated paddy thresher over their upper legs (73.91%), lower back (52.17%), foots (28.26%), upper arms (19.57%), lower arms (15.22%), shoulders (6.52%) and neck respectively (Fig. 4.10). This showed that some of the body parts like calf, thigh muscle, lower back and ankle region got highest discomfort due to continuous pedaling with greater amount of force exerted on the pedal. The upper thigh and calf muscle soreness due to elongated application of larger force was also reported in some cases.

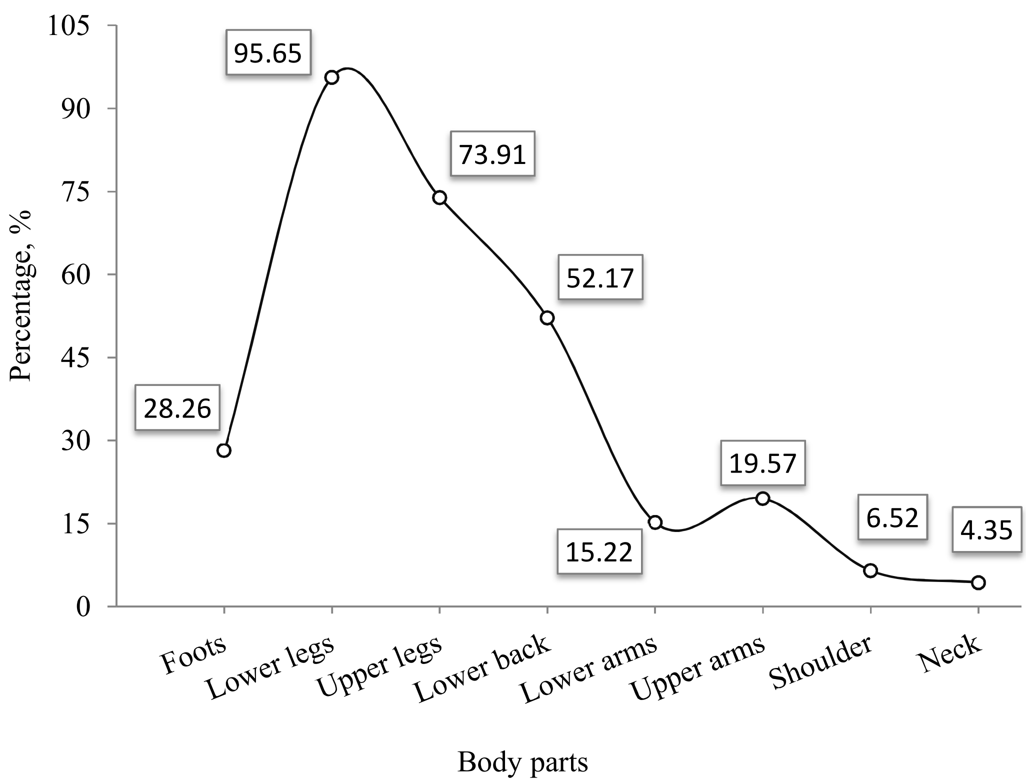


Fig. 4.10 Percentage of Agricultural workers reported MSD in different parts of the body during paddy threshing with existing pedal thresher

It appeared from the above result that, higher prevalence of musculoskeletal disorders reported could be associated with the higher physical demand for the pedaling operation of the paddy thresher; or might be due to the variable dimensions and capacity of thresher leading to mismatch with the body dimensions.

4.5 Virtual Product Development

Ergonomic design of agricultural tools and equipment using CAD-DHM dictate the designer for improved comfort, safety and productivity. Undoubtedly these tools have enough potential to improvise the product development challenges, thus exercising control over the entire process of virtual design and analysis of product before its physical launch. These techniques allow changes in the virtual design stage, thus reducing the chance of ergonomic problems in development stage before creating the actual prototype. This provides one with the key benefits like shorter design time, reduced redundant changes, lower manufacturing costs, better quality, increased output, enhanced safety leading to heightened morale.

This research focused on the design and evaluation of an ergonomic paddy thresher with due consideration to anthropometric database of Assamese farmers' population. The thresher was redesigned in a way to suit a wider range (5^{th} - 95^{th} percentile) of operators. 3D CAD model of the machine was created and analyzed in virtual environment with the help of DHM to test its efficiency and usefulness. Here, it is worthy to mention that the concept model of the thresher also considered other features (apart from anthropometric compatibility) like (a) grain shield for reducing spread of dusts/ husks and thus respiratory protection; (b) 'chain gear' mechanism instead of 'four bar linkage' mechanism, to simplify power transmission system; (c) adjustable pedal height with variable range of movement to satisfy the user with varying lower limbs' heights; (d) attachable wheels for translocation of the thresher within short distance; (e) substantial reduction in overall weight of the thresher by modifying the design and selecting lighter materials; (f) easy assemble/ dissemble of components (i.e. cylinder, grain shield, frame and power transmission mechanism etc.) for comfortable carriage at different terrains and during transportation.

4.5.1 Digital prototype of pedal thresher

Mechanical design feature of DELMIA (V5R19) digital human modeling software was used to generate CAD model of the existing and proposed threshers. The existing thresher model dimensions were measured. The various dimensions of the proposed model were finalized for generating 3D model. The CAD model was developed for individual parts and each part of the pedal thresher was assembled thereafter for the preparation of 3D model.

All the design dimensions of pedal operated paddy thresher were finalized and 2D diagram was constructed. Using this 2D diagram, 3D solid model was constructed with

CATIA. The isometric view of the developed 3D solid thresher model is shown in Fig. 4.11.

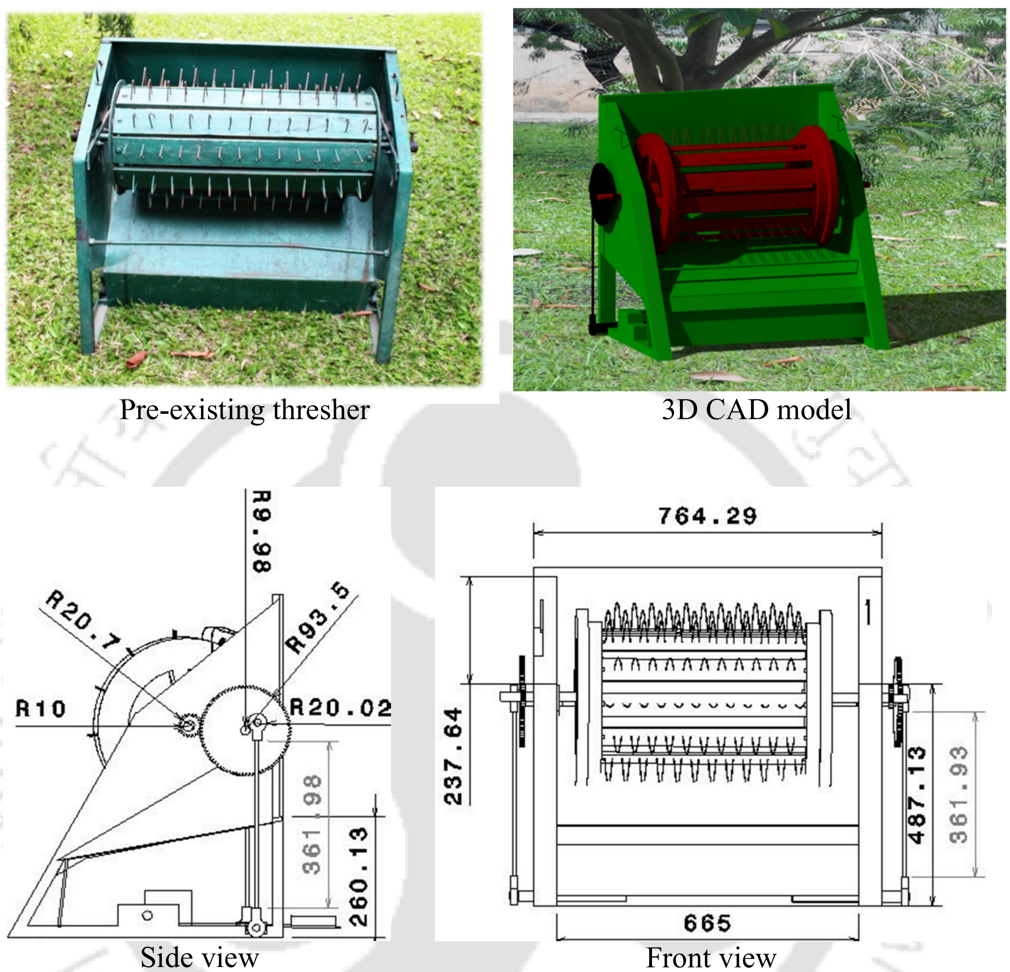


Fig. 4.11 pre-existing thresher and its 3D CAD model with detailed dimensions
(All dimensions are in mm; Scale 1:10)

4.5.2 Finite element analysis

The 3D solid model of developed thresher was transferred for generative structural analysis in COMSOL Multiphysics software for stress analysis of the model. The material used for development of thresher was mild steel. The yield stress value of mild steel is 250 MPa. Finite element analysis was performed to check whether this design would withstand the desired load under working condition. The elemental and material properties were applied from material library of the software. The loads and boundary conditions were applied during analysis. A force (F) of 300 N was applied at the center of the frame from both sides. The bottom of the frame was restrained. After application of the loads the generative structural analysis was carried out with the help of COMSOL. The critical sections on the frame were located with the help of *Von Mises* Stress contour. It could be observed from the Fig 4.14 that, *Von Mises* stress was maximum at the middle of the frame where force was applied, approximated to 35 MPa – less than the yield stress value of mild steel. So the design was considered safe. In fact, maximum value of Von Mises stress exerted on the material should be less than its yield strength. Further, deflection due to dynamic load on the frame was also calculated and found to be very less (~0.22 mm) as shown in Fig. 4.15. Based on the findings of the result, the design dimensions were accepted to be within safe range.

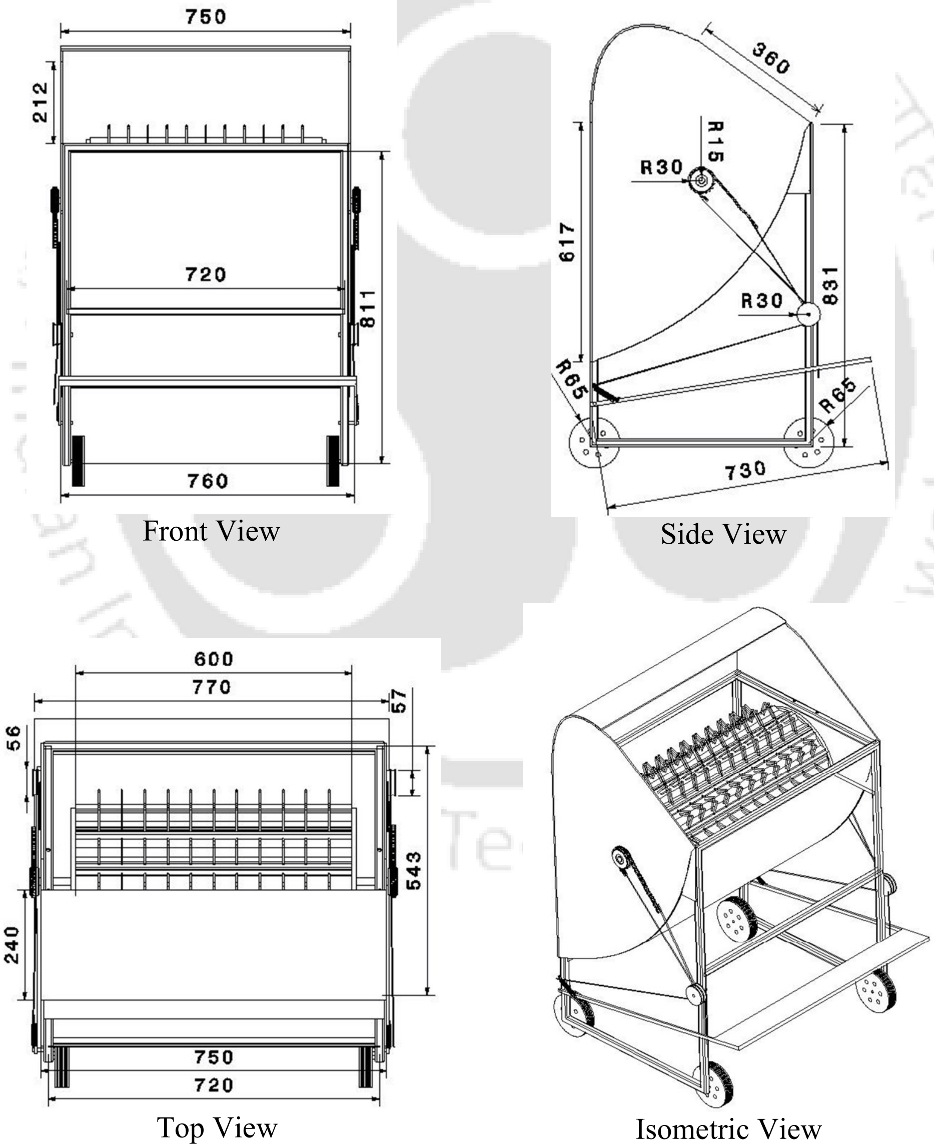


Fig. 4.12 Detailed dimensions of developed pedal thresher (All dimensions are in mm; Scale 1:10)

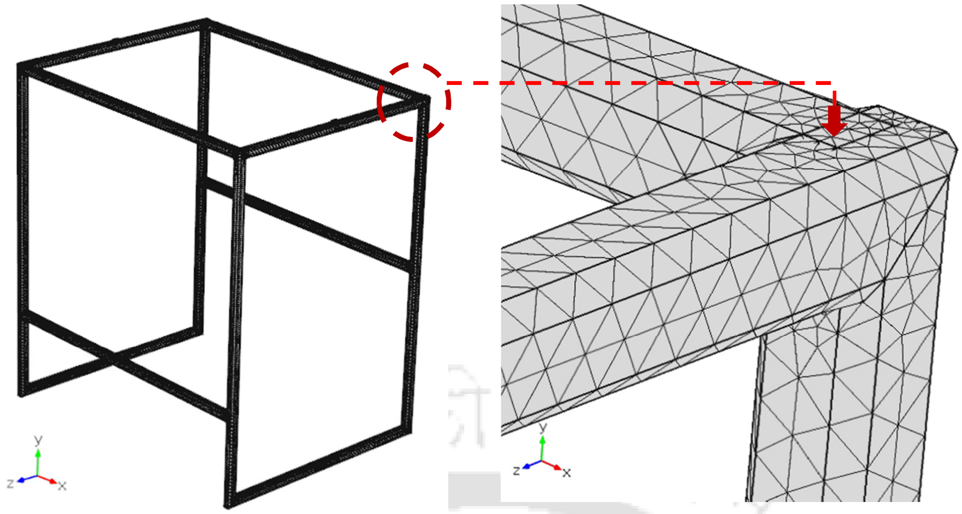


Fig. 4.13 CAD model/meshed model for main frame of developed thresher

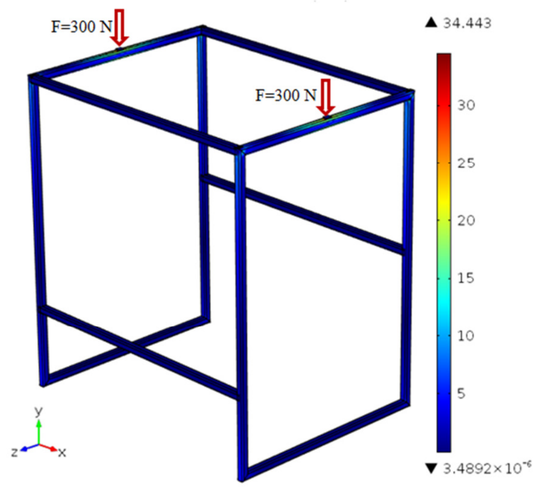


Fig. 4.14 Von-Mises stress (MPa) analysis for main frame of developed thresher

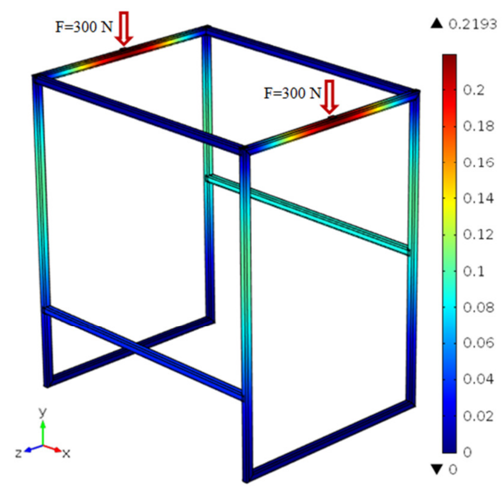


Fig. 4.15 Total displacement (mm) analysis for main frame of developed thresher

4.5.3 Creation of digital human models and rendering of comfort posture

Anthropometric database is quintessential for ergonomic design of any product to ensure workers' productivity and occupational safety. Anthropometric data of Assamese population was compiled and referred to for ergonomic design and subsequent evaluation of CAD model of the conceptualized paddy thresher. The digital human manikins were built to accommodate the target range of Assamese farmer populations in the present study, using anthropometric database for each selected representative in DHM simulation system. A total of six digital human models (5^{th}, 50^{th} and 95^{th} percentile for both male and female) were created to represent smallest, average and largest dimension of target population respectively, and then simulated for ergonomic design and evaluation (Fig. 4.16). Comfort postures were rendered over the digital human manikins.

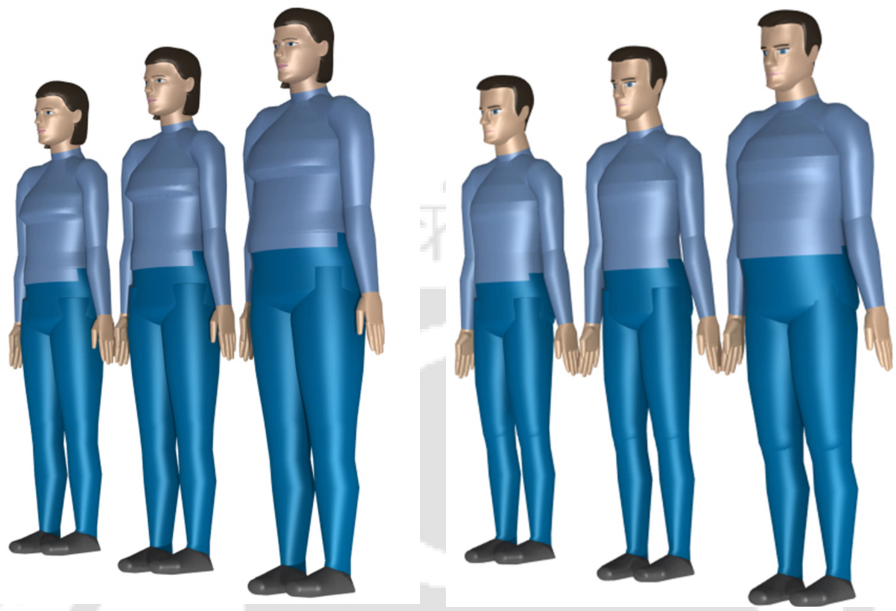


Fig. 4.16 5th, 50th and 95th percentiles male and female custom-built digital manikins

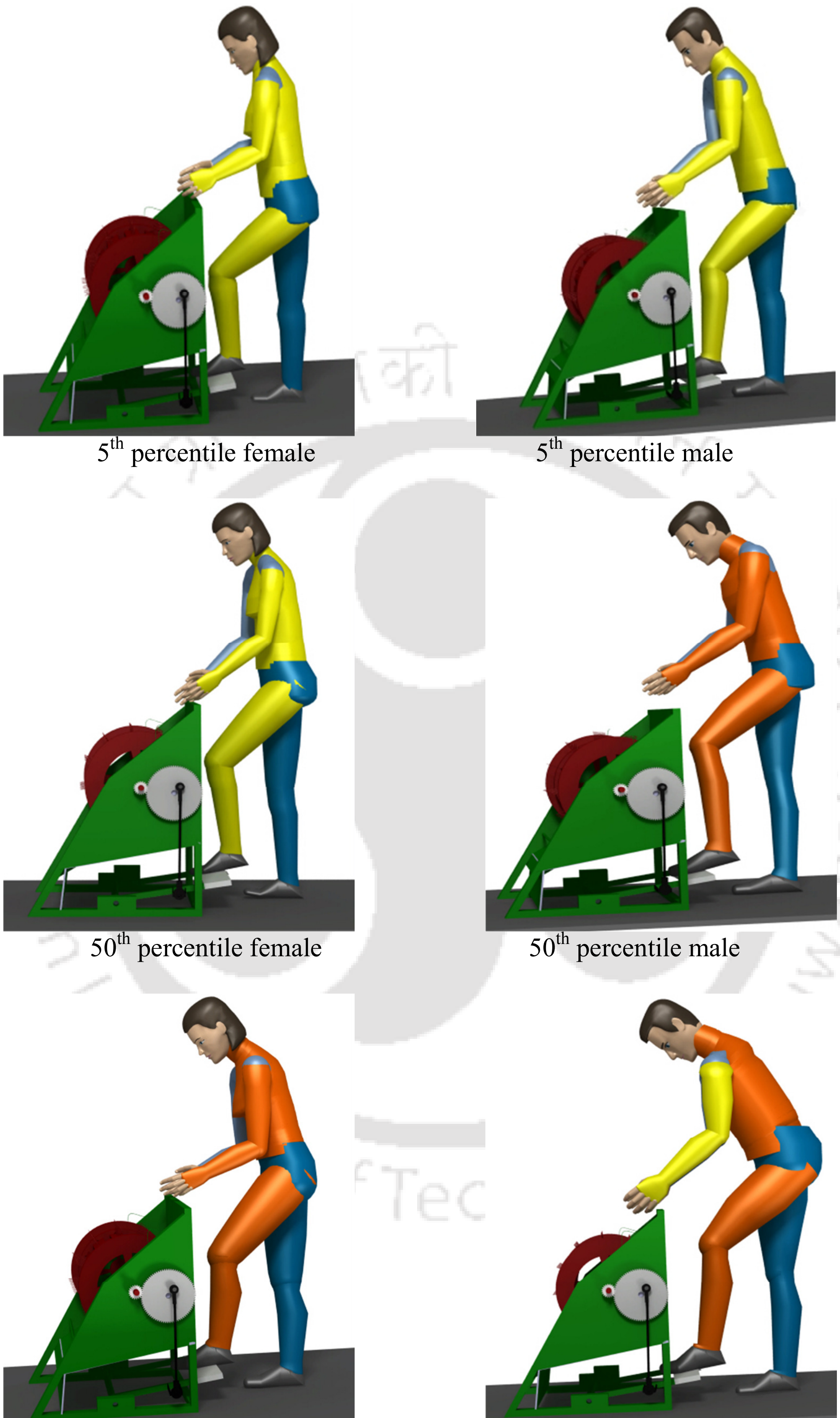
4.5.4 Interfacing digital human models with the virtual paddy thresher

Precise interfacing between digital human models of Assamese farmers and CAD model of paddy thresher featuring selected working postures were achieved using ergonomic design and analysis feature in DELMIA. Work activities of modified and existing paddy threshers were evaluated using DHM representing 5th, 50th, and 95th percentiles male and female agricultural workers to pinpoint the postural load.

4.5.5 Working posture assessment and biomechanical analysis

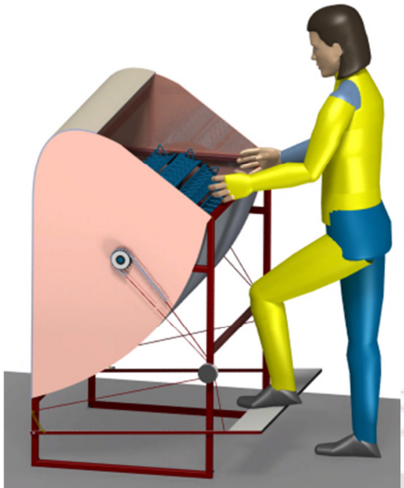
Mechanical load on lumbar spine is considered as a contributing factor to many of the low back anomalies (Chaffin and Andersson, 1984). Compressive forces on L4 – L5 lumbar spines, due to mass of body plus load acting on hand and trunk, have a safe / cut off limit of 3433 N with the maximum permissible limit of 6376 N, as recommended by National Institute of Occupational Health (Leyland, 2008). A safe limit of 500 N with 1000 N as maximal permissible limit was suggested by University of Waterloo ergonomic research group towards joint shear (Leyland, 2008). Compression force evaluated for existing and developed paddy threshers.

The model of the existing pedal thresher was found anthropometrically compatible for only 5th, 50th percentiles female and 5th percentile male manikins (Fig. 4.17). Whereas, newly developed thresher was found compatible to for all manikins (5th, 50th and 95th percentile male and female) used for evaluation (Fig. 4.18). This indicates that the design concept of the new thresher would accommodate wide range of the targeted user (agricultural workers of Assam) starting from 5th percentile female (representative of smaller body dimensions) to 95th percentile male (representative of higher body dimensions). For the developed thresher, L4–L5 Compression force of 5th, 50th and 95th percentile male were 873 N, 1057 N and 1790 N respectively, whereas for existing thresher, it recorded 882 N, 1261 N and 1828 N respectively. Similarly for female, readings were 858 N, 861 N and 1065 N for developed and 885 N, 920 N and 1116 N for existing thresher respectively. The absolute values of the L4–L5 compressions were found to be lesser for developed thresher, compared to the existing one. Postural comfort analyses in virtual environment revealed that the developed model was advanced over the existing one.

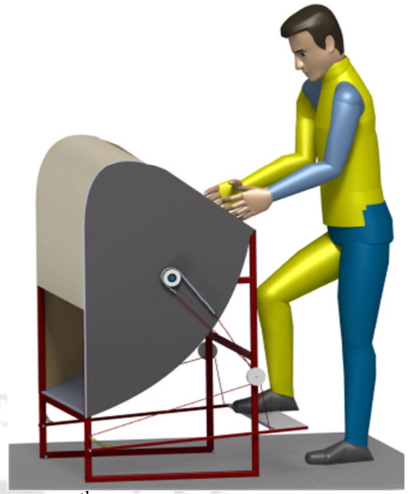


5th percentile female
5th percentile male
50th percentile female
50th percentile male
95th percentile female
95th percentile male

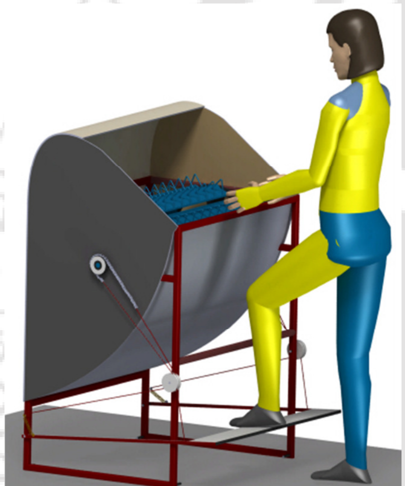
Fig.4.17 Posture analysis while using 5th, 50th and 95th female and male manikins for existing pedal operated paddy thresher



5^{th} percentile female

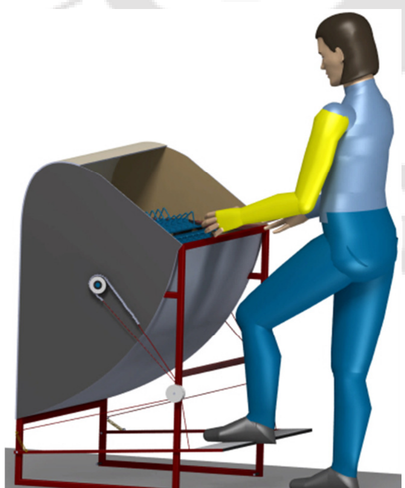


5^{th} percentile male



50^{th} percentile female

50^{th} percentile male



95^{th} percentile female

95^{th} percentile male

Fig.4.18 Posture analysis while using 5^{th}, 50^{th} and 95^{th} female and male manikins for developed pedal operated paddy thresher

4.6 Physical Fabrication of Thresher

Pedal paddy threshers are the widest used ones in the rice growing countries like India, Bangladesh, Bhutan, Korea and some African countries (Agrawal et al., 2013). Manual beating is common in all paddy-growing areas across the country (Datt, 2003), particularly in cases of marginal land holdings. In NER, 85% of the population are rural habitants (87% for Assam), where employment is rural and essentially agricultural. Due to the low production and thus low income, farmers cannot afford costly high-capacity paddy threshers. In view of the prevailing socio-economic conditions of farmers in NER, high-end threshers are inappropriate and even sophisticated. Considering efficiency and cost, rice grown in less than 1 hectare is not suitable for mechanical threshing, particularly in small fragmented land holdings (Hussain, 1982). Further, transportation of heavy machines in hilly areas is very difficult. Most of the farmers in these areas prefer to own machines that can be transported single handed or jointly by two. Several engine- or power-operated paddy threshers have been designed and developed in the past, but they have not been successful in the hilly areas because of cost, weight, and above all, power or fuel requirement issues.

Recognizing the requirement and functionality of virtual prototype in the present research, the physical prototype was developed. The literature review, result of questionnaire surveys, evaluation of virtual prototype and a critical understanding of the limitations of the existing pedal operated paddy thresher, led to the fabrication of physical prototype of paddy thresher. Named as 'developed thresher', it underwent rigorous testing of compatibility and efficiency, along with labour economy, compared to the existing model from ergonomics and safety perspectives. Thus, the ergonomically designed and anthropometrically erected paddy thresher was deliberated to fulfill some basic design criteria as given below:

- ✓ Paddy threshing would be done with lesser effort.
- ✓ Physiological cost to the operator would be within acceptable limits.
- ✓ It would be lightweight and easily transportable by two persons.
- ✓ Thresher would have design simplicity, easy for single-handed operation and low maintenance.
- ✓ The total grain output would be more than 40 kg/h to make it economically viable, in contrast with the average individual threshing capacity of 20-25 kg/h by manual beating method.

- ✓ Since electricity may not be available everywhere, there would be attached means to operate the thresher using alternate resources of energy in field itself.
- ✓ The thresher would be a low cost one with all spares available in local market.

Centered with the above design criteria, the following design features were worked out for fabrication of pedal operated paddy thresher considering the anthropometric and biomechanical database of Assamese agricultural workers.

Foot pedal Size

The pedal board was made from wooden plank with dimensions being 25 mm thick, 107 mm wide (foot breadth of 95th percentile male farmer) and 700 mm long (suitable for size of the cylinder).

Pedal stroke length

The force requirement for movement of threshing drum depends on the range of pedal movement. The pedal force applied was found maximum at the knee angle of 120^{0}. Agrawal (2008) documented maximum vertical leg force with foot at a height of 0.16 times the stature. The present research recorded 5th and 95th percentile value of stature of female and male agricultural workers to be 145.2 and 170.3 cm respectively, thereby calculating the foot height for maximum leg force to be 23.2 and 27.3 cm respectively. The developed thresher also featured adjustable stroke length to accommodate 5th and 95th percentile agricultural workers.

Cylinder speed and pedal speed

The pedal stroke of 60 – 75 cpm is commonly used to obtain a speed between 290 – 330 rpm. The physiological parameters also depend on number of strokes per min. Therefore, 60 cpm was selected and provided necessary chain mechanism to maintain 300 rpm of threshing cylinder speed.

Threshing cylinder length

The length of the threshing cylinder depends upon the number of operators. In the present study, threshing cylinder length was determined using anthropometric database of Assamese population. The 95th percentile value of the male shoulder width (i.e. 45.54 cm) was considered. Assuming the clearance on each side being 5 cm, width of threshing cylinder was calculated to be 56 cm.

Threshing cylinder height

The optimal height for holding paddy bundle depends on the geometry adopted by the operator. For maximal work efficiency, recommended elbow flexion angle ranges between 85^0-110^0 (Grandjean, 1988). Considering optimal elbow flexion at 85^0 and elbow height of 5^{th} percentile women as 89.16 cm, the optimum height for holding paddy bundle was calculated to be 92.39 cm. Similarly with elbow flexion at 110° and 107.92 cm as elbow height of 95^{th} percentile male farmer, the optimal height for holding paddy bundle would be 95.27 cm. Therefore, optimal height of threshing cylinder was averaged to 94 cm, rendering usability to both male and female farmers.

Threshing cylinder weight

The minimal weight of threshing cylinder is vital for the desired moment of inertia. The weight of existing threshing cylinder was reduced in the new design to 10.5 kg.

Specifications of threshing finger

The minimum recommended diameter of threshing finger as per BIS standard (IS: 3327-1982) is 3 mm with 25 – 32 mm distance between the ends of each tooth and 50 – 75 mm distance between the tip of the two adjacent teeth, while the threshing teeth shall project out 50 mm above the surface of the slats. Therefore the threshing finger diameter, distance between the ends of each teeth, distance between the tip of the two adjacent teeth and threshing teeth projection was 5 mm, 32 mm, 52 mm and 56 mm respectively.

Grain shield

In the existing pedal operated paddy threshers, there is no provision to collect the threshed grains. Therefore, grains spread over a wide area during threshing operation, incurring additional physical effort to bag them. To address this problem, threshing shield was provided in developed thresher covering all sides except grain feeding and grain outlet ends.

Weight of thresher

The thresher should be lightweight so as to make it suitable for any terrain agriculture i.e., it could be easily movable uphill or operable at a low span land. The total weight of the existing thresher was 45 kg while the developed thresher weighed only 23.5 kg.

Selection of power mechanism

Locally available resources are used for selection and functioning of power transmission system so that to make it viable in rural areas. Power transmission through pedaling action, bicycle gear and chain were selected as shown in Fig. 4.19. The working length of chain was decided based on vertical movement of pedal. From both ends of chain 5 cm margin was provided in actual pedal stroke length.

Fig. 4.19 Bicycle gear and chain selected for power transmission in developed thresher

Portability arrangement during transportation

In the existing pedal operated paddy threshers, no provision has been made to dismantle the major components, which make it very difficult to carry from one place to another. Further, no provision is there for attachment of wheels for transport. The developed thresher was equipped with all these provisions (Figs 4.20 and 4.21), so that it could be transported uphill and down land, wherever trashing activity would be required.

Fig. 4.20 Different views of CAD and developed prototype of pedal threshers

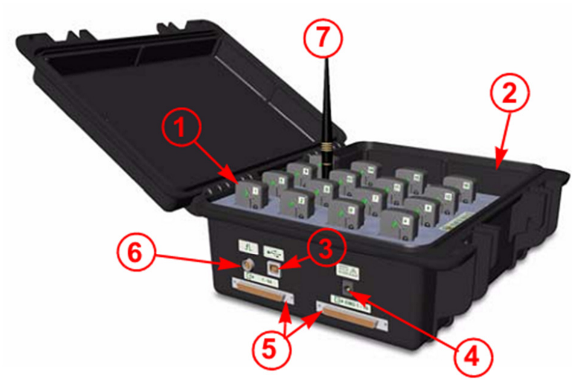
Fig. 4.21 Dismantling views of developed portable paddy thresher

4.7 Laboratory Testing – Surface Electromyography

Surface electromyography (sEMG) records bioelectric signals generated by neuromuscular activity with the help of surface electrodes (also known as topical or cutaneous electrodes). EMG has broad areas of application like gait and posture analysis, risk prevention, product certification, biomechanics, motion analysis, ergonomic design etc. EMG data recorded using surface electrodes is drawing increasing importance in ergonomic evaluation of various physical tasks. Measurement of muscular activities while performing various agricultural tasks is imperative in analyzing user centric design of agricultural tools and equipment to match capabilities and limitations of target users. Comfort, safety and productivity can be achieved only if design of tools and equipment are based on physiological and perceptual characteristics of the user. The ergonomic analysis using EMG provides the experimenter with valuable, quantitative measures of the load on a pertinent muscle at given work postures.

4.7.1 EMG system specifications

Electromyogram of selected muscles were recorded with Trigno™ Wireless EMG Systems (DAC Filter Bandwidth DC − 500 Hz, 160 dB/Dec, baseline noise <0.5 mV RMS; specification is given in Appendix 7) as shown in Fig. 4.22.



1 – Wireless Sensor; 2 – Base Station; 3 – USB Port; 4 – Power Jack/Power Supply; 5 – Analog Output Connectors; 6 – Trigger Port; 7 – Antenna

Fig. 4.22 Delsys Trigno™ Wireless EMG Systems

Trigno consists of 16 wireless EMG sensors and a base receiving unit. EMG data were digitized using a 16 bit analog to digital (AD) Converter, using a ± 5 V range, and recorded using EMG Works-Acquisition™ software (Delsys™, Boston, MA), using a sampling rate of 2000 Hz with an overall gain of 300 for each EMG channel. Raw EMG signals offer valuable information and need analog / digital processing to remove artifacts. In this experiment, raw EMG signals were first filtered using band pass filtered to reduce noise with low pass (350 Hz) and high pass (50 Hz), and rectified; these data were considered to consist primarily of EMG signal for further analysis.

4.7.2 Electrod placement on the skin

The placement of electrods at appropriate location i.e parallel to the muscle fibers, is one of the most important factors for optimal signal acquisition. The arrow of electrode placed in the center of the muscle belly (away from tendons at the edge of the muscle) should be parallel to the muscle fibers underneath the sensor. Fig. 4.23 showed possible additional locations of electrodes placement such as innervation zone (top electrode), the myotendonous junction (bottom electrode) and the lateral edge of the muscle (middle right electrode) and their respective EMG signal strengths.

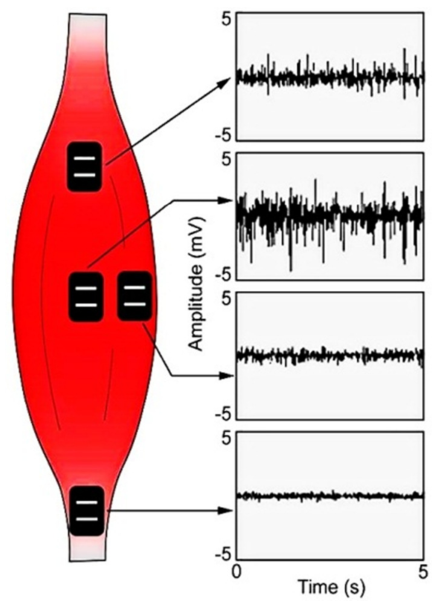
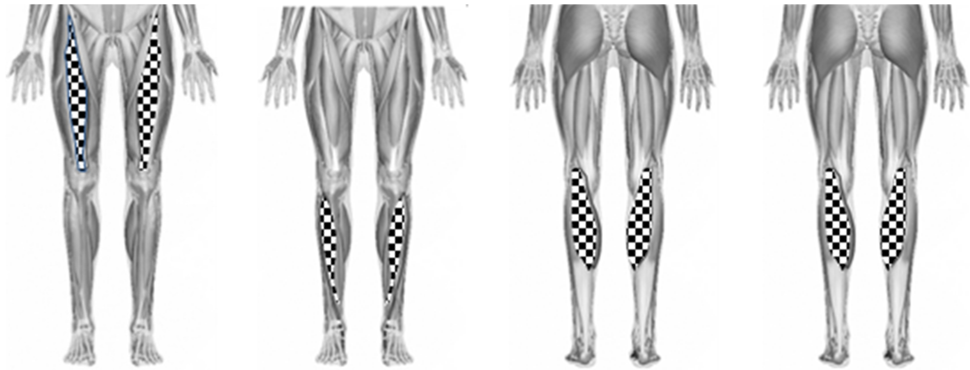


Fig. 4.23 Effect of electrode location in amplitude spectrum of the EMG signal

The sEMG signals of four identified muscles viz., Rectus Femoris (RF), Tibialis Anterior (TA), Gastrocnemius (GN), and Biceps Femoris (BF) were measured by electromyography (Delsys Trigno Wireless System, Natlick, Massachusetts, USA) of both legs as shown in Fig. 4.24.



(a) Rectus Femoris (b) Tibialis Anterior (c) Gastrocnemius (d) Biceps Femoris

Fig. 4.24 Muscles considered for EMG measurement

4.7.3 Participants

Twenty five males participated voluntarily in this experiment after being informed about the procedure and risks associated with the protocol. They were screened and excluded from the study if reported to have any recent muscular, joint or bone complaints that could interfere with the EMG signals. The subjects were explained about the experiment and their role therein; and their consents of participation obtained before the measurements. Body surface area (BSA) was calculated from the participant's height and weight by the formula of DuBois and DuBois (1916) using Eq. (1). Further, body mass index (BMI) was computed using weight and height parameters by the Eq. (2). According to BMI range classification (WHO, 2014), individuals are considered underweight when their BMI<18.5, normal range those between BMI 18.5-24.9, overweight those between BMI 25-29.9, moderate obesity those between BMI 30-34.9, severely obesity those between BMI 35-39.9 and very severe obesity when their BMI 40 and above.

$$BSA\ (m^2) = 0.007184 \times (\text{Height, cm})^{0.725} \times (\text{Weight, kg})^{0.425} \quad (1)$$

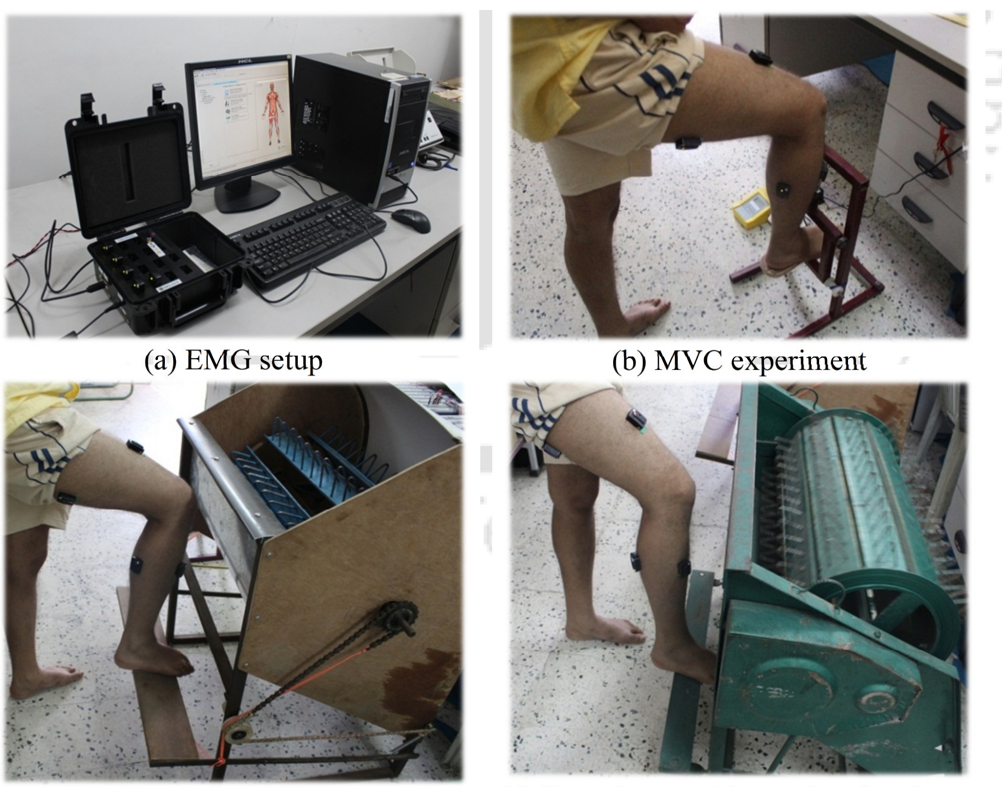
$$BMI = (weight, kg)/((height, m)^2) \quad (2)$$

4.7.4 Data collection procedure

Four different surface electrodes (10 mm by 1 mm electrode bars with an inter-electrode distance of 10 mm) were placed using standard placement procedures (Konrad, 2005), one on each selected muscles such as Rectus Femoris, Tibialis Anterior, Gastrocnemius and Biceps Femoris. Before placement of electrodes on selected muscles, the skin area and the EMG sensors are cleansed with isopropyl alcohol to reduce bioelectric and environmental impedance. The wireless 4-slot electrodes were attached to the skin using the both sided adhesive skin interface (Delsys Inc., Natlick, Massachusetts, USA) as shown in Fig. 4.25. Usage of the interface endorses a better conductivity between the sensor bars and the skin, minimizing motion artifacts and the ill-effects of line interference.

Fig. 4.25 Trigno Sensors 4 – slot with adhesive skin interfaces

The whole experiment was conducted in two phases. The first phase of experiment recorded the maximum voluntary contraction (MVC), while the second monitored EMG during pedaling of existing vs. developed model of paddy threshers as shown in Fig. 4.26.



(a) EMG setup (b) MVC experiment

(c) Experiment with developed thresher (d) Experiment with existing thresher

Fig. 4.26 Test apparatus used to measure muscle activations during simulation of developed and existing paddy threshers

Maximum voluntary isometric effort was performed to normalize the muscle activation level to the percent of maximum voluntary contraction (MVC). Since EMG signal depends on various factors such as electrode placement, sensor characteristics, electrode-skin interface, muscle crosstalk etc., one of the conventional methods to minimize the effects of these factors is to normalize the muscle activities using the MVC tests. In this experiment, EMG of the four selected muscles was obtained during the maximal voluntary contractions. All participants were instructed to exert their maximum possible leg extensor force within 5 seconds, then to hold their maximum effort for about 2 seconds and finally to lower the force slowly to zero. Each participant completed three trials intervened by 3-min intervals to avoid muscle fatigue, and the best reading was used for record and statistical analyses. Strong verbal encouragement motivated the participants during EMG recording.

Second phase of EMG data was acquired during pedaling operation of existing and developed paddy threshers. All participants were instructed to operate thresher for 30 seconds. Each participant replicate the whole experiment in three trials with 3 min intervals, and for each of the selected muscle, the best reading was considered for record and analysis. All EMG signals were amplified at designated gains to optimize resolution, full wave rectified, integrated over the duration of the MVC and transmitted telemetrically to a computer. The EMGworks® Software (Delsys Inc., USA) was used to process the signals. The measured MVC for each muscle group across all tests was considered to represent 100% for that muscle group. The muscle load was then expressed as %MVC for each muscle. After the MVC values were calculated, the results for pedaling operation of paddy threshers were analyzed separately.

4.7.5 Data analysis

The testing of both the threshers was conducted on the same day and time with same volunteer in order to avoid the within-subject and spatio-temporal variability. For calculation of MVC, 10 s epoch of consistent EMG was considered. The complete set of EMG data for each subjects were tabulated in Microsoft Excel and subsequently subjected to statistical analysis for interpretation using the Statistical Package for the Social Sciences (SPSS v.22.0.0, IBM Corporation, USA). Normality of data was checked with skewness and kurtosis, Shapiro-Wilk's test and the quantile-quantile plot (Q-Q plot). The results showed that the data was not distributed normally. Therefore, non-parametric paired test i.e. Wilcoxon signed ranks test was performed to compared force requirement between developed and existing model of paddy threshers.

4.7.6 Results and Discussion

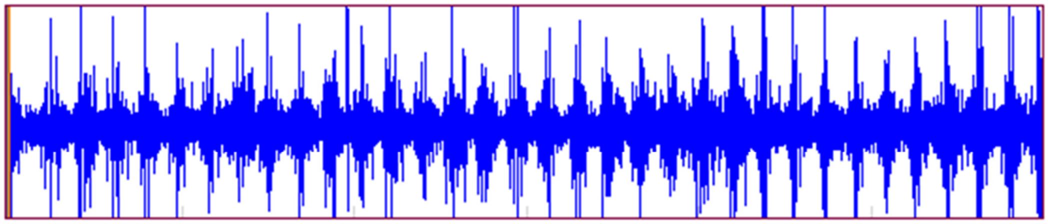
For each subject with minimal clothing and no shoes, body weight was measured to the nearest 0.1 kg using a standard bathroom weighing balance, and height, to the nearest 0.1 cm by portable anthropometric rods. Age, stature and weight of the subjects ranged between 24 – 35 years, 161 – 172 cm and 58 – 76 kg respectively. Physical characteristics of the participants are summarized in Table 4.2. Twenty three subjects were in 'normal' range of BMI (18.5 to 24.99) except two overweight ones.

Table 4.2 Physical Characteristics of participant (n = 25)

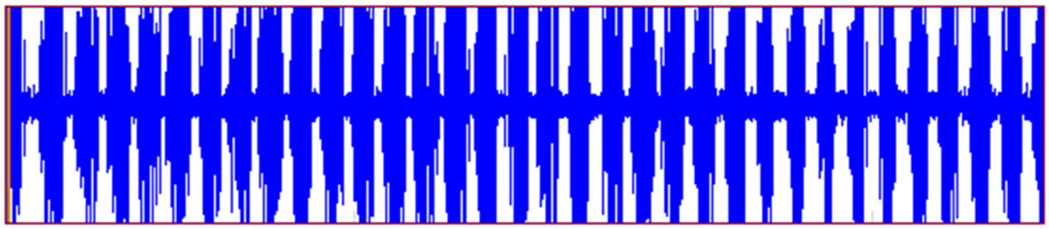
Characteristic	Mean ± SD
Age, year	29.52 ± 3.68
Stature, cm	166.64 ± 2.93
Weight, kg	65.68 ± 4.85
BSA, m^2	1.74 ± 0.06
BMI, kg/m^2	23.66 ±1.75

4.7.6.1 Raw EMG Data of Selected Muscles

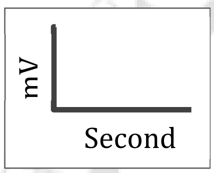
The raw EMG of designated muscles namely Gastrocnemius, Tibialis Anterior, Bicep Femoris and Rectus Femoris muscles were shown in Figs. 4.27 and 4.28. The muscles had different levels of activity which was observed, based on change in EMG signals. Out of the four selected muscles, maximum involvement was found for Gastrocnemius muscle followed by gradually decreasing involvement of Rectus Femoris, Tibialis Anterior and lastly Bicep Femoris. In the present research, field survey data (related to body parts discomfort while operating pedal operated paddy thresher) also showed similar trend of observations like hereinabove – maximum number of participants precisely reported for calf muscles exhaustion, which could possibly be due to proactive involvement of Gastrocnemius muscle in pedaling activity.



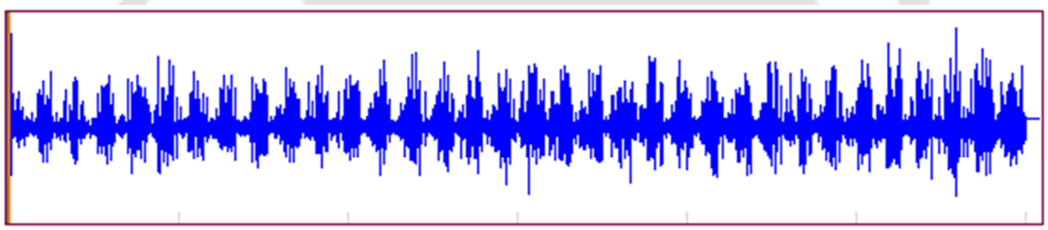
(1) Developed thresher



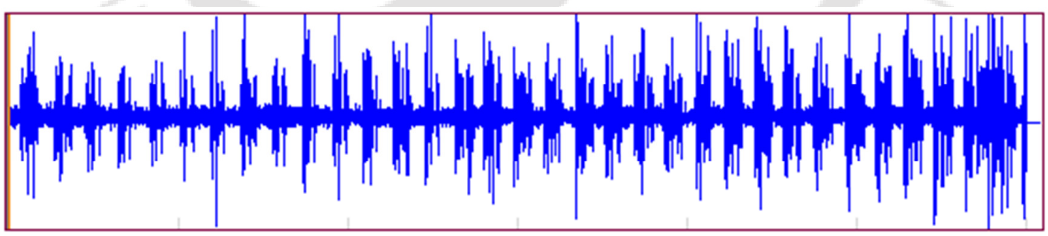
(2) Existing thresher



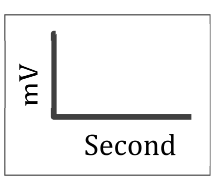
(A) Gastrocnemius



(1) Developed thresher



(2) Existing thresher



(B) Tibialis Anterior

Fig. 4.27 Representative raw electromyogram (EMG) data from (A) Gastrocnemius and (B) Tibialis Anterior muscles from a single subject during threshing operation

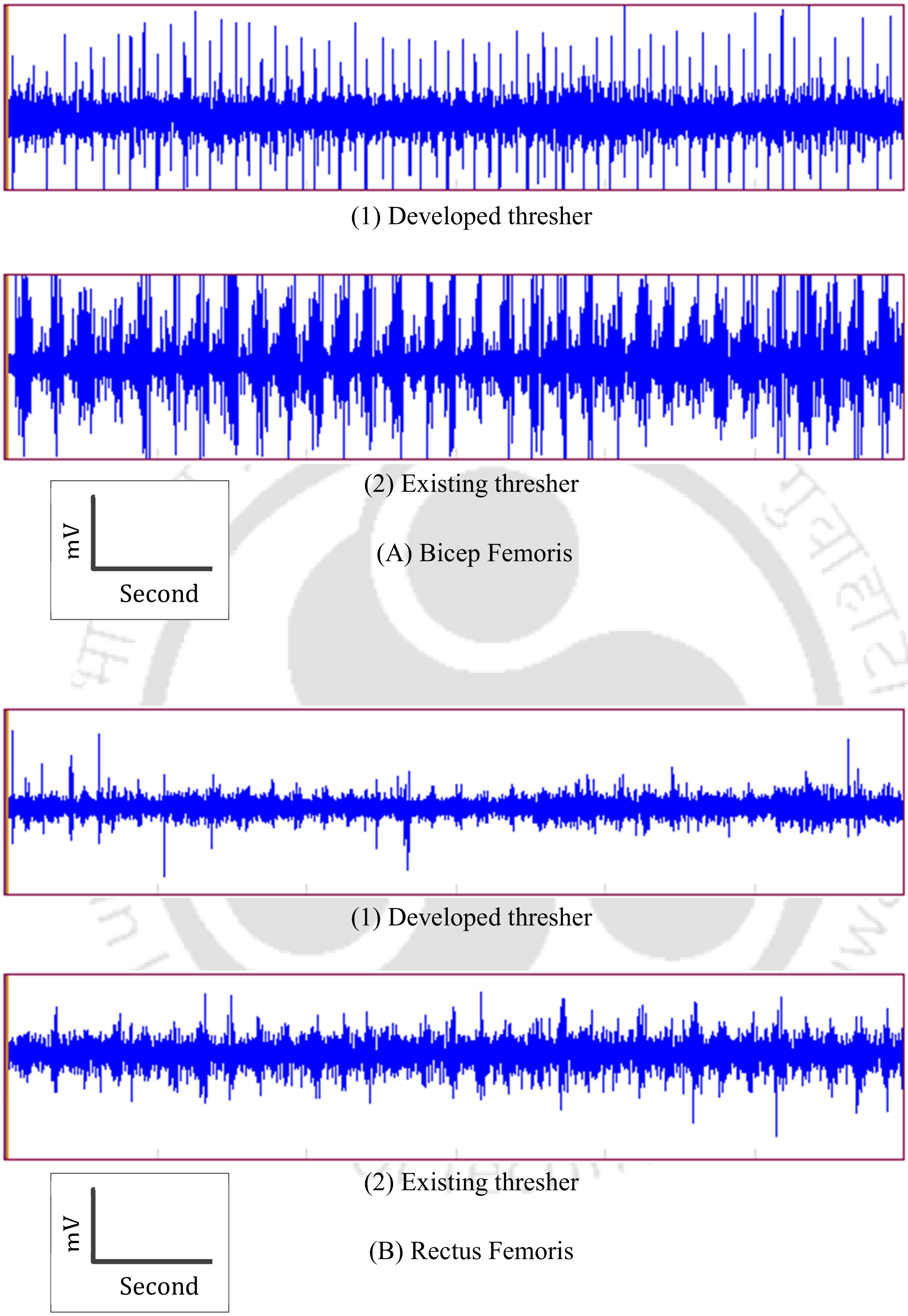


Fig. 4.28 Representative raw electromyogram (EMG) data from (A) Bicep Femoris and (B) Rectus Femoris muscles from a single subject during threshing operation

4.7.6.2 EMG (%MVC) for selected muscles

This experiment aimed to compare the muscle strength required for operating existing and developed paddy threshers. For the developed thresher, mean EMG (mV, expressed as % equivalent of mean MVC) of right leg muscles viz., Rectus Femoris, Tibialis Anterior, Biceps Femoris and Gastrocnemius was 18.68, 17.92, 15.09 and 28.77 %, whereas for existing thresher, it recorded 27.98, 24.36, 16.73 and 41.56% similarly (Fig. 4.29). The strength required for developed was lower than the existing thresher by 33%, 26%, 10% and 31% for Rectus Femoris, Tibialis Anterior, Biceps Femoris and Gastrocnemius muscles respectively. Further, Wilcoxon signed-rank test showed that all four muscles elicit a statistically significant change Rectus Femoris ($Z = -2.946$, $p<0.01$), Tibialis Anterior ($Z = -3.081$, $p<0.01$), Biceps Femoris ($Z = -2.193$, $p<0.05$) and Gastrocnemius ($Z = - 3.212$, $p=0.001$) in muscles strength levels while operating developed and existing pedal threshers.

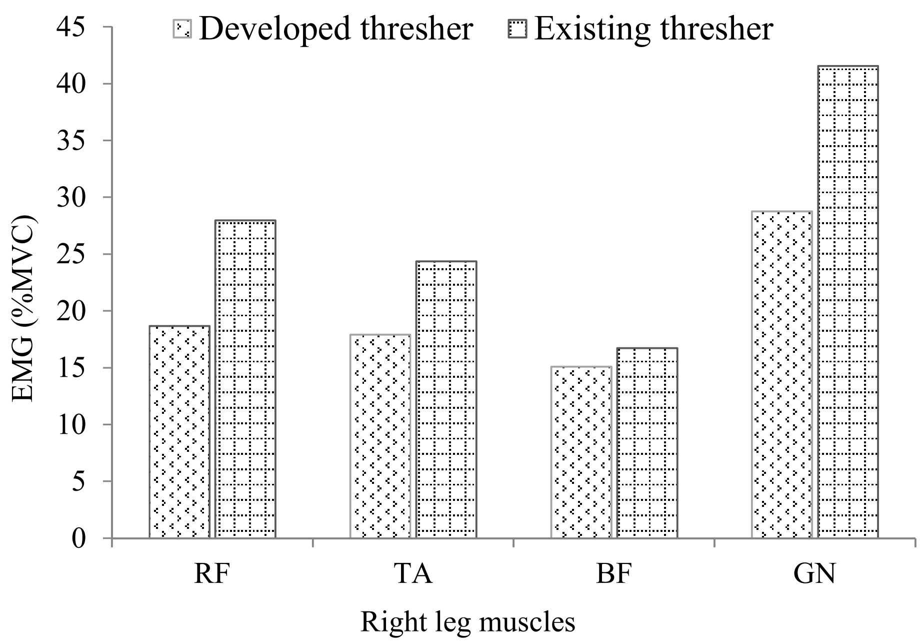


Fig. 4.29 The RMS %MVC graph plot for right leg muscles (Rectus Femoris-RF; Tibialis Anterior-TA; Biceps Femoris-BF and Gastrocnemius-GN) with developed and existing paddy threshers

Similarly, the mean value of EMG (%MVC) for left leg muscles was also recorded. For the developed thresher, mean EMG (mV, expressed as % equivalent of mean MVC) of left leg muscles viz., Rectus Femoris, Tibialis Anterior, Biceps Femoris and

Gastrocnemius was 19.86, 17.79, 19.31 and 33.48%, whereas for existing thresher, it recorded 31.16, 23.95, 26.08 and 50.20% similarly (Fig. 4.30). The strength required for developed was lower than the existing thresher by 36%, 26%, 26% and 33% for Rectus Femoris, Tibialis Anterior, Biceps Femoris and Gastrocnemius muscles respectively. Further, Wilcoxon signed-rank test showed that all four muscles elicit a statistically significant change Rectus Femoris ($Z = -3.672$, $p<0.001$), Tibialis Anterior ($Z = -3.239$, $p = 0.001$), Biceps Femoris ($Z = -2.758$, $p<0.01$) and Gastrocnemius ($Z = -4.184$, $p<0.001$) in muscles strength levels while operating developed and existing pedal threshers.

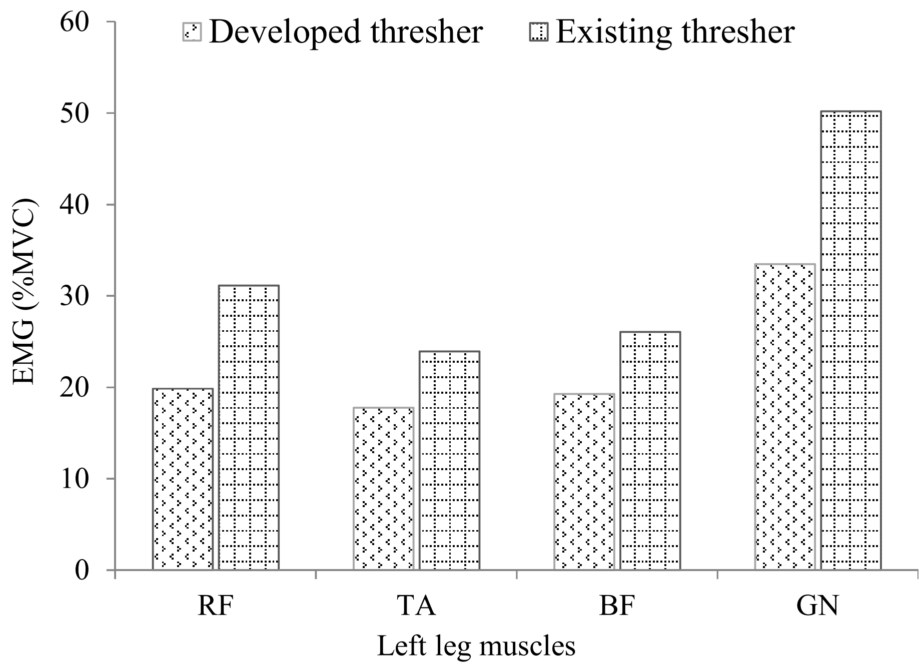


Fig. 4.30 The RMS %MVC graph plot for left leg muscles (Rectus Femoris-RF; Tibialis Anterior-TA; Biceps Femoris-BF and Gastrocnemius-GN) with developed and existing paddy threshers

4.7.6.3 MCV (Newton, N) for Selected Muscles

This experiment aimed to compare the muscle force required for operating existing and developed paddy threshers. For the developed thresher, mean EMG (Newton, expressed as equivalent of mean MVC) of right leg muscles viz., Rectus Femoris, Tibialis Anterior, Biceps Femoris and Gastrocnemius was 47.80, 45.99, 38.89 and 73.83 Newton, whereas for existing thresher, it recorded 72.01, 63.11, 43.16 and 107.74 Newton similarly (Fig.

4.31). Further, Wilcoxon signed-rank test showed that all four muscles elicit a statistically significant change Rectus Femoris (Z = -2.973, p = 0.003), Tibialis Anterior (Z = -3.108, p = 0.002), Biceps Femoris (Z = -2.220, p = 0.027) and Gastrocnemius (Z = -3.188, p = 0.001) in muscles strength levels while operating developed and existing pedal threshers.

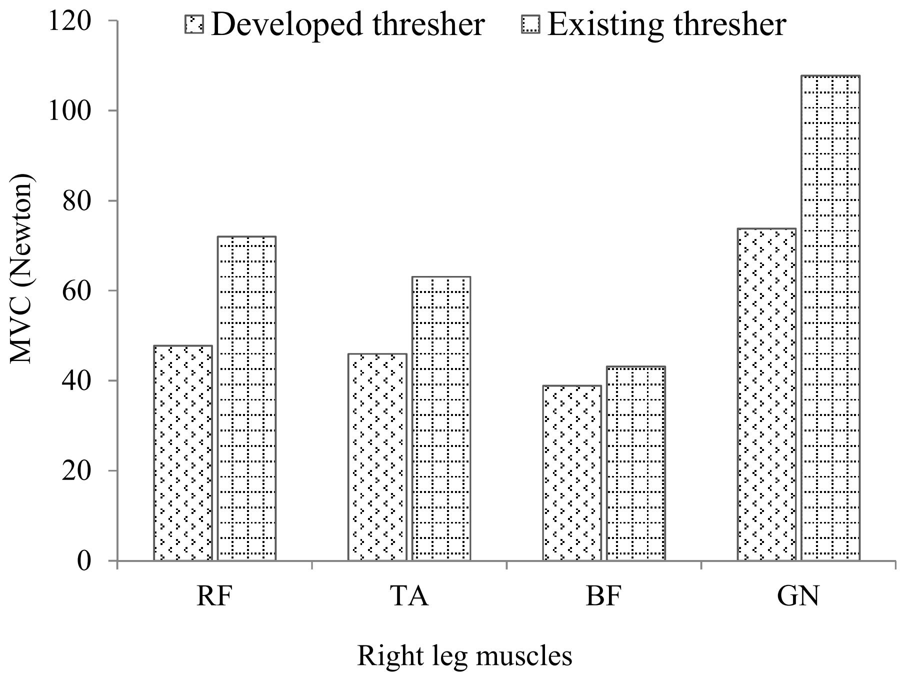


Fig. 4.31 The MVC (Newton, N) force graph plot for right leg muscles (Rectus Femoris-RF; Tibialis Anterior-TA; Biceps Femoris-BF and Gastrocnemius-GN) with developed and existing paddy threshers

Similarly, mean value of MVC force for left leg muscles was also determined. For the developed thresher, mean EMG (Newton, expressed as equivalent of mean MVC) of left leg muscles viz., Rectus Femoris, Tibialis Anterior, Biceps Femoris and Gastrocnemius was 40.25, 36.63, 39.12, and 68.66 Newton, whereas for existing thresher, it recorded 63.93, 48.71, 53.97, and 102.64 Newton similarly (Fig. 4.32). Further, Wilcoxon signed-rank test showed that all four muscles elicit a statistically significant change Rectus Femoris (Z = -3.700, $p<0.001$), Tibialis Anterior (Z = -3.215, p = 0.001), Biceps Femoris (Z = -2.892, p = 0.004) and Gastrocnemius (Z = -4.211, $p<0.001$) in muscles strength levels while operating developed and existing pedal threshers.

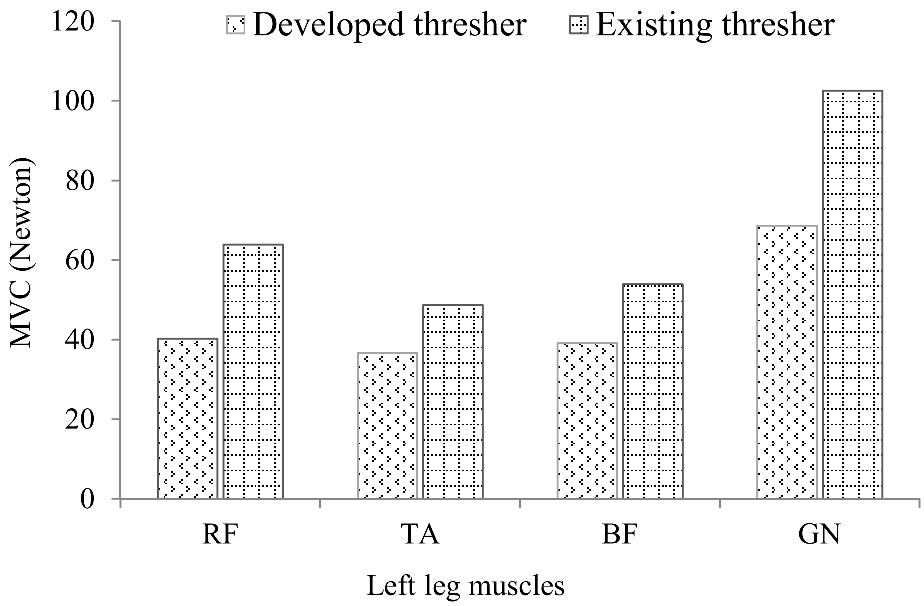


Fig. 4.32 The MVC (Newton, N) force graph plot for left leg muscles (Rectus Femoris-RF; Tibialis Anterior-TA; Biceps Femoris-BF and Gastrocnemius-GN) with developed and existing paddy threshers

4.8 Laboratory Testing – Measurement of Actuating and Working Forces

Force, as a direct measure of biomechanics of physical efforts exerted to undertake any given action, or chain of actions, can be of two types – static and dynamic. In case of pedal thresher, it is dynamic in nature. It is generally accepted that, high-repetition jobs demanding consistent high force are more likely to develop musculoskeletal disorders than the low-repetition jobs that involves low-force normally. For the existing thresher, greater force was required for pedaling, signifying predisposition of developing musculoskeletal disorders of lower extremity. Therefore, to decrease the actuating and working forces required to operate pedal operated paddy thresher was the first step towards aiding the reduced chance of occurrence of muscular fatigue in the leg muscles. In order to measure the actuating and working forces while pedaling, a setup was developed which consists of various attachments including clamps and the load cell (Fig. 4.33). The actuating force (kg, Mean ± SD) for developed and existing threshers was found to be 3.89 ± 0.56 and 5.4 ± 1.35 respectively. Similarly working force (kg, Mean ± SD) was measured and found to be 6.19 ± 0.85 and 9.36 ± 2.21 respectively. Further, Wilcoxon signed-rank test showed that, developed and existing threshers elicited a statistically significant difference in actuating ($Z = -3.364$, $p<0.01$) and working ($Z = -3.688$, $p<0.001$) forces required while operating the respective thresher. For any pedal-operated paddy thresher, repetitive exertion is obligatory and thus cannot be avoided, but decreasing the amount of force required for pedaling could be effective to decrease the risk of musculoskeletal ailments (Openshaw and Taylor, 2006).

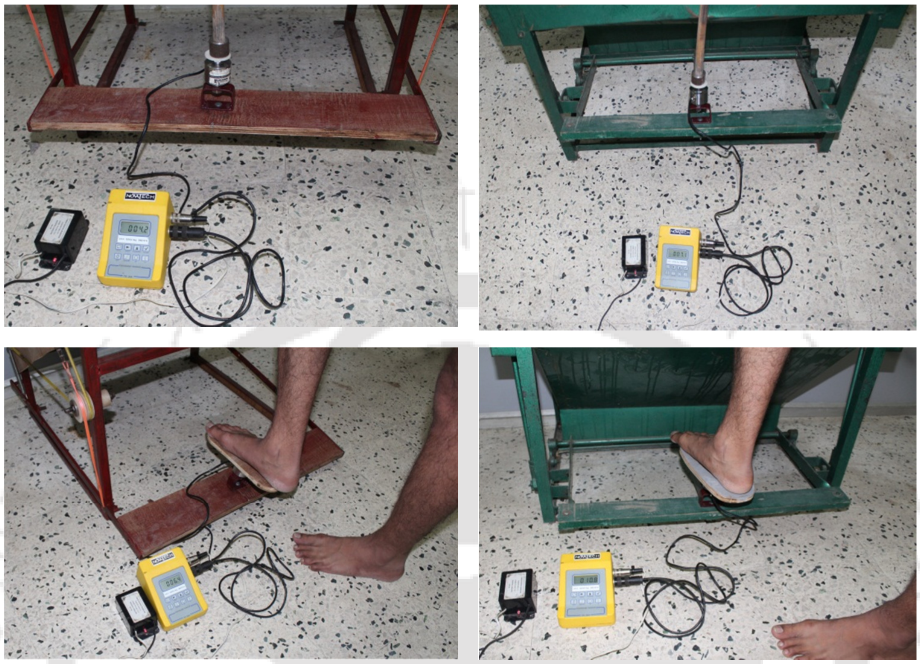


Fig. 4.33 Test setup for measuring actuating and working force while pedaling

4.9 Field Testing – Experimental Procedures

4.9.1 Meteorological station

During field testing of paddy thresher, weather information was obtained using the Kestrel 4500 pocket weather tracker (Nielson-Kellerman, Philadelphia, USA; specifications is given in Appendix 10) as shown in Fig. 4.34. The weather station was placed adjacent to the testing area, away from any structures or vegetation that may influence environmental measurements. The weather tracker was used to record temperature, humidity and wind speed, so as to ensure similar experimental conditions for any volunteer.

Fig. 4.34 Kestrel 4500 pocket weather tracker

4.9.2 Monitoring of heart rate

Heart rate (HR) is one of the primary physiological parameters identified to increase with physical workload and energy demands. Over moderate work intensities, HR retains reasonably linear relation to oxygen consumption (Astrand and Rodahl, 1997). HR is characteristically and conveniently used for indirect prediction of energy expenditure and physical workload in the field. Here, HR was measured using polar heart rate monitor (Polar RS800CX, Finland; specifications is given in Appendix 8) as shown in Fig. 4.35, which consists of (i) an elastic chest strap with electrode sensor getting in touch with moist skin over the heart and an signal transducer to detect the heart rate and transmit the same to a receiver on the wrist and (ii) the signal receiving unit on the wrist, which displays the instantaneous heart rate, and has a facility to set an alarm to detect HR outside the set range.

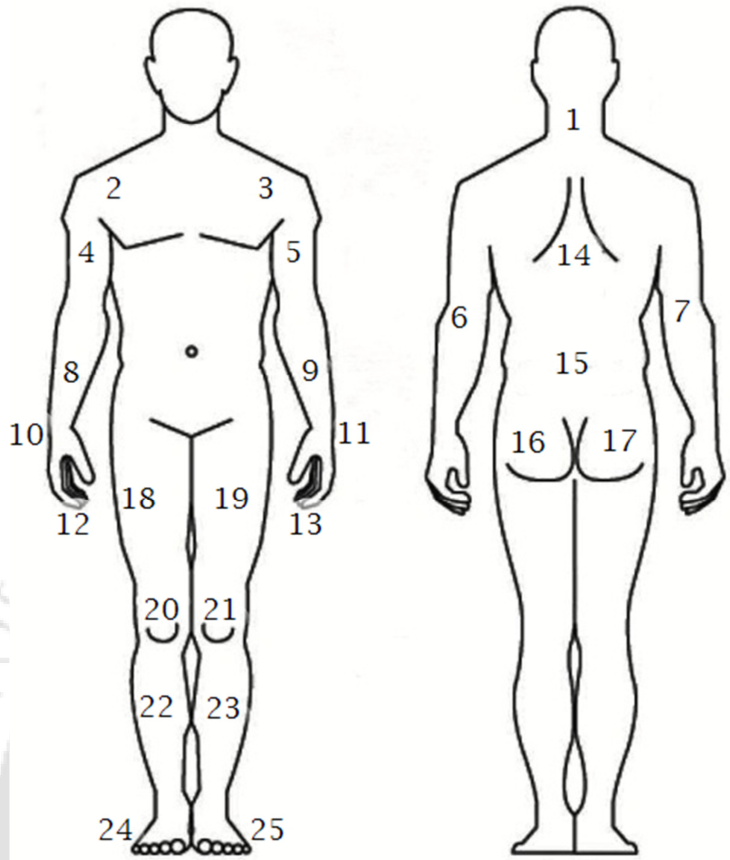
Fig. 4.35 Polar heart rate monitor and accessories

Before fixing the sensor strap it was cleansed with spirit-cotton to remove dust, moist, grease and sweat (if any) of the previous subject. The sensor on the chest strap monitor was moistened with tap water for better conductivity and fixed on the chest, followed by the receiver (wrist watch) tied on subject's preferred hand. Before recording the HR, subject was allowed for quiet rest for 5 min to avoid abnormal reading (Pal, 2001). The start of rest was marked and averaged values of physiological responses during last 5 min were taken as the resting values. Then they were asked to operate pedal operated paddy thresher for 35 min continuously. Finally the subjects were allowed to sit and relax until the recovery HR equated to the resting. The recorded data was transferred to computer through S-series infrared interface and compiled heart rates for rest, work and recovery. The heart rate data of 6th to 35th min was considered as working heart rate. The heart rate for rest and work were averaged to get the mean value of heart rate for workers. The work pulse value was calculated by subtracting the mean heart rate during work with the mean heart rate during rest. The oxygen consumption of subject on their measured heart rate was estimated based on general equation as given by Singh et al. (2008).

4.9.3 Subjective ratings

A number of subjective rating scales available for assessing subjective response of comfort / discomfort are in use for designing and evaluating products. Comfort / discomfort have been considered as two discrete opposite states on a continuous scale ranging from extreme comfort to extreme discomfort through a neutral point (Kuijt-Evers et al., 2004). Discomfort has been widely used to evaluate ergonomic interventions (Sauter et al., 2005). Several authors defined discomfort in different ways such as lack of comfort or lack of ease (Allen, 1990); mental or physical uneasiness (Merriam-Webster, 2007); an absence of comfort or ease; uneasiness, hardship, or mild pain (Discomfort, 2007) and so on.

The most popular local discomfort scales are based on a procedure by Corlett and Bishop (1976), called body part discomfort (BPD) rating. Ratings were obtained using a modified version of Bishop-Corlett body map (Corlett and Bishop, 1976) and the Borg CR 10 Scale (Borg, 1990). The participants rated discomfort for their whole body and each of 25 local body parts (Fig. 4.36). The perceived regional discomfort for each subject was assessed for each of 25 body regions after threshing was completed (Proforma is illustrated in Appendix 6). Every time the participants were reminded about the best / worst score (e.g. for discomfort, zero is the best – no discomfort at all). Each body region was numbered differently to avoid confusion. The subjects were thoroughly familiarized with the assessment techniques prior to participation in the study. The discomfort score was rated by responded by Borg's CR 10 scale. The scale anchors are as follows: 0: no discomfort, 0.5: extremely weak, 1: very weak, 2: weak, 3: moderate, 4: somewhat strong, 5: strong, 7: very strong, 10: extremely strong discomfort. Subjects selected a number from 0 to 10 based their perception of discomfort.



1 – Neck; 2 – Right shoulder; 3 – Left shoulder; 4 – Right arm; 5 – Left arm; 6 – Right elbow; 7 – Left elbow; 8 – Right forearm; 9 – Left forearm; 10 – Right wrist; 11 – Left wrist; 12 – Right hand; 13 – Left hand; 14 – Upper back; 15 – Lower back; 16 –Right buttocks; 17 – Left buttock ; 18 – Right thigh; 19 – Left thigh; 20 – Right knee; 21 – Left knee; 22 – Right leg; 23 – Left leg; 24 – Right foot; 25 – Left foot

Fig. 4.36 The 25 local body parts (adapted from Corlett and Bishop, 1976)

4.9.4 NASA task load index

The NASA TLX is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales viz. Mental Demands, Physical Demands, Temporal Demands, Performance, Effort, and Frustration. The NASA TLX is a bipartite evaluation procedure consisting of both weights and ratings. The first component needs the rater to evaluate the contribution of each factor (its weight) to the workload of any specific task. There are 15 possible pairs of comparisons of the six scales (Fig. 4.37). Subjects encircle the member of each pair that contributed more to the workload of that task. The number of times that each factor is selected is tallied. The tallies can range from 0 (not relevant) to 5 (most important, than any other factor).

Mental Demand or Physical Demand	Physical Demand or Temporal Demand	Temporal Demand or Effort
Mental Demand or Temporal Demand	Physical Demand or Performance	Temporal Demand or Frustration
Mental Demand or Performance	Physical Demand or Effort	Performance or Effort
Mental Demand or Effort	Physical Demand or Frustration	Performance or Frustration
Mental Demand or Frustration	Temporal Demand or Performance	Effort or Frustration

Fig. 4.37 Possible pair-wise comparisons of the six subscales

The overall workload score for each subject was computed by multiplying each rating by the weight assigned to it by the subject. The sum of all such weighted ratings for each task was divided by 15 (the sum of the weights). Methodology for NASA-TLX subjective work load assessment for paddy threshing by existing and developed thresher was implemented as per the chart given in Appendix 5.

4.9.5 Energy expenditure rate

Traditional methods of farming are known to demand much more energy than modern farming methods. Nag et al. (1980) reported oxygen consumption rate during various activities (viz. Table 4.3) to range between 0.47 – 0.87 l/min. He pointed that pedal threshing operation required more energy than manual threshing by beating as shown in Table 4.3.

Table 4.3 Physiological responses of agricultural males during agricultural operations (Nag et al., 1980)

Activity	Energy cost (kJ/min)	AWPR (beats/min)
Sitting at rest	4.25 ± 09	75.2 ± 5.5
Manual threshing by beating	19.26 ± 1.18	135.8 ± 4.0
Pedal threshing	27.56 ± 3.25	140.8 ± 4.3
Pedal threshing helper	13.53 ± 1.99	120.3 ± 9.9

AWPR - Average work pulse rate; Values are mean ± standard error

For calculation of Energy Expenditure Rate from heart rate, the Varghese et al. (1994) regression equation was used which is as follows.

$$EER = 0.159 \times AWHR - 8.72$$

where,

EER = Energy expenditure rate, kJ/min.

AWHR= Average working heart rate, bpm

4.9.6 Oxygen consumption rate

The oxygen consumption rate (amount of oxygen consumed by the whole body per unit time) was computed from the heart rate values of the operator and is given by the following equation (Singh et al., 2008).

$$OCR = 0.0114 \times AWHR - 0.68$$

where,

OCR= Oxygen consumption rate, l/min

AWHR= Average working heart rate, bpm

Nag et al. (1980) stipulated that consumption of 1 liter of oxygen at NTP (Normal Temperature and Pressure) is equivalent to 20.88 kJ of physiological energy. Therefore, OCR kJ/min was calculated by multiplying 20.88.

4.9.7 Work rest schedule

During any strenuous work in field, suitable rest is required for optimal work output. Maximal work output can be expected once the user is confortable. Therefore, rest pause during work is required for avoiding any kind of fatigue, injury and discomfort during any operation. Work rest schedule is calculated by Murrell (1965) formula as given below:

$$R = T(O_{work} - O_{rec})/(O_{work} - O_{rest})$$

where,

R = Rest time required, min

T = Total working time, min

O_{work} = Oxygen consumption during work

O_{rec} = Recommended oxygen consumption level, which is 33% of VO_{2max}

O_{rest} = Oxygen consumption during rest

4.9.8 Results and Discussion

4.9.8.1 Subject characteristics

Twenty male farmers were engaged for the ergonomic assessment of the developed and existing pedal operated paddy threshers at field (Fig. 4.38) after recording their anthropometric characteristics, as detailed earlier in Chapter 3 and Section 3.3.1.3. Descriptive statistics viz. Mean, SD, CV (%), minimal, maximal, 5^{th} and 95^{th} percentiles of various anthropometric characteristics of agricultural workers is given in Table 4.4. The average (± SD) of age, stature and body weight was 38.35 ± 5.73 years, 162.37 ± 4.61 cm and 54.90 ± 6.73 kg respectively.

Fig. 4.38 Field experiment for developed and existing pedal threshers

The subjects selected were in the age group of 18 – 44 years, as they are shown to retain their highest level of strength between 20 – 45 years (McArdle et al., 2006) and, were therefore chosen in such a way that the physical characteristics lay between the 5th and 95th percentile values of the Assamese male farmers. Stature and weight were used as selection variables. Fig. 4.39 shows that selected participant accomplished relatively well in terms of stature and weight relative to the field survey database of Assamese population (developed earlier in this research work vide chapter section).

Table 4.4 Descriptive statistics of various anthropometric characteristics of male agricultural workers (n = 20)

Parameter	Min	Mean ± SD	Max	CV	5th %ile	95th %ile
Age, year	20	38.35 ±5.73	44	14.95	28.92	47.78
Weight, kg	46	54.90 ±6.73	70	12.27	43.82	65.98
Stature	153	162.37 ±4.61	171	2.84	154.79	169.94
Elbow height	94	99.64 ±3.92	108	3.94	93.18	106.10
Trochanteric height	74	78.17 ±2.68	84	3.42	73.76	82.57
Knee height	41	44.84 ±1.93	47	4.31	41.66	48.01
Arm reach from wall	76	80.30 ±2.58	85	3.21	76.05	84.54
Shoulder grip length	65	69.60 ±3.67	81	5.27	63.56	75.63
Bideltoid breadth	39	42.08 ±1.54	46	3.65	39.55	44.61
Grip diameter (inside)	4	4.90 ±0.43	6	8.85	4.18	5.61
Maximum grip length	10	11.48 ±0.79	13	6.88	10.18	12.77
Hand length	15	17.46 ±1.09	20	6.25	15.66	19.26
Palm length	9	10.10 ±0.40	11	3.99	9.43	10.76
Foot length	22	23.89 ±1.04	26	4.34	22.18	25.60
Instep length	17	18.52 ±0.77	20	4.15	17.25	19.78
Foot breadth	9	9.57 ±0.54	11	5.61	8.68	10.45
Functional leg length	88	93.44 ±2.64	98	2.83	89.09	97.78

All the measurements are in cm until otherwise specified; Min. = minimal; Max. = maximal; SD = standard deviation; CV = coefficient of variation in %

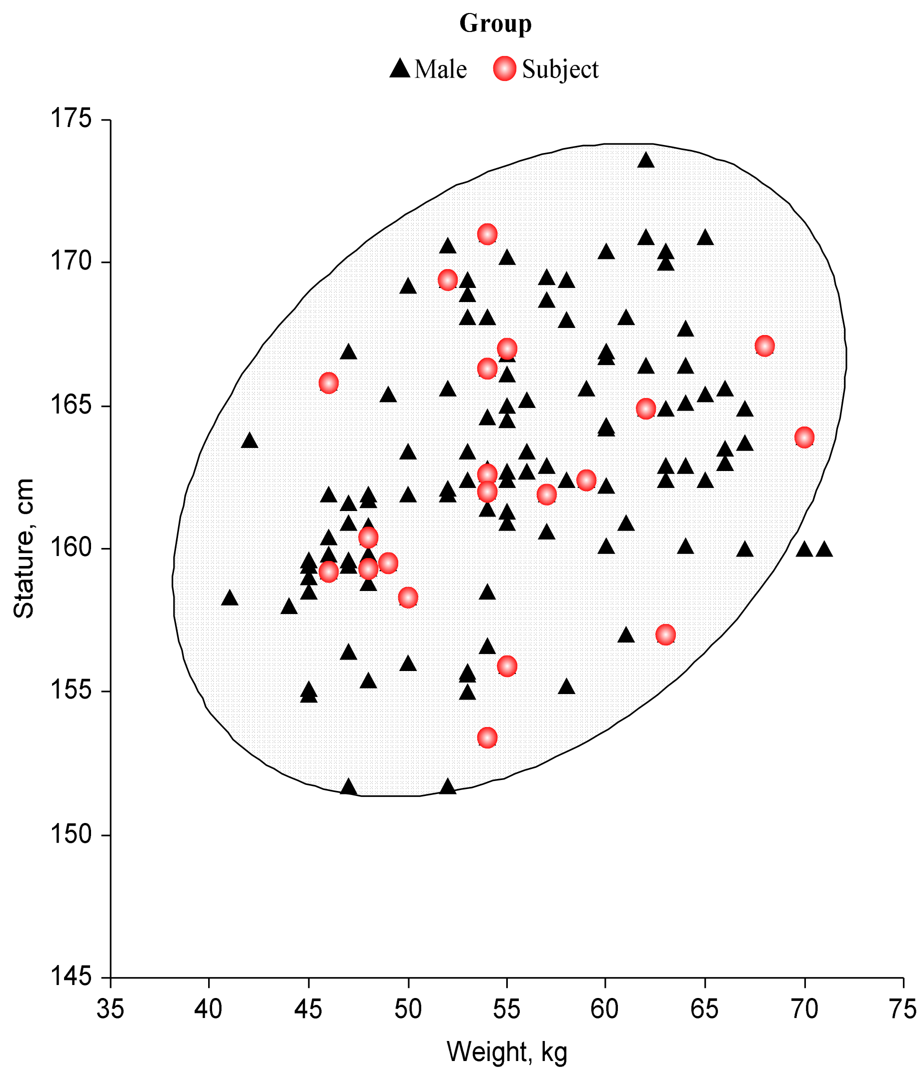


Fig. 4.39 Stature and weight of subjects relative to field survey - 95% probability ellipses

4.9.8.2 Heart rate measurement

In addition to physiological characteristics such as heart rate, two indices namely body mass index (BMI) (in kg/m^2) and body surface area (BSA) (in m^2) were also calculated, as shown in Table 4.5. BMI was measured for human body shape based on an individual's mass and height. According to BMI range classification (WHO, 2014), individuals were considered underweight when their BMI<18.5, normal range those between BMI 18.5 – 24.9, overweight those between BMI 25 – 29.9, moderate obesity those between BMI 30 – 34.9 and severe obesity when their BMI 40 and above. Based on the results of the BMI calculation it could be observed that average BMI value i.e. 20.85 ± 2.60 kg/m^2 was within the normal range of 18.5 – 24.9, as specified by WHO (2014).

Table 4.5 Physical and physiological characteristics of agricultural workers (n = 20)

Particular	Minimal	Mean ± SD	Maximal
Age, year	20	38.35 ±5.73	44
Weight, kg	46	54.90 ±6.73	70
Stature, cm	153	162.37 ±4.61	171
Experience, year	4	8.80 ±3.59	15
HRrest, bpm	70	74.42 ±2.70	79
HRmax, bpm	175	181.55 ±5.84	200
HRreserve, bpm	99	107.13 ±7.18	129
BSA, m^2	1.44	1.58 ±0.09	1.77
BMI, kg/m^2	16.73	20.85 ±2.60	26.06

BSA= (body weight$^{0.425}$×stature$^{0.725}$) ×0.007184 by DuBois and DuBois (1989); BMI = body weight divided by squared height in m (kg/m^2)

The AWHR increased 30.51% above the resting heart rate for the developed thresher compared to a 35.85% increase for the existing thresher, the mean difference between resting and working HR being 32.93 bpm for the developed thresher and 41.82 bpm for the existing one. The working heart rate while operating the pedal threshers for developed and existing thresher thus differed significantly ($t(19) = 10.71$, $p<0.001$). AWHR of the subjects during paddy threshing done by the developed thresher oscillated between 100.62 – 116.56 bpm with the mean of 107.35 bpm, whereas the corresponding HR values while using existing thresher ranged between 107.99 – 125.51 bpm with a mean of 116.24 bpm.

An illustrative graph of heart rate during the threshing is shown in Fig. 4.40, where the upper straight line reflects AWHR for the existing thresher and the lower straight line displays that for the developed one. Dewangan (2007) reported that the AWHR values reduction approximating a 20% in pedal operated paddy thresher over manual beating of paddy. According to classification of Astrand and Rodahl (1986) regarding working heart rate (i.e. < 90 bpm represents 'light work'; 90 – 110 bpm, 'moderate work'; 110 – 130 bpm, 'heavy work'; 130 – 150 bpm, 'very heavy work' and 150 – 170 bpm, 'extremely heavy work'), the threshing operation could be regarded as 'moderate' and 'heavy' work for 'developed' and 'existing' threshers, respectively.

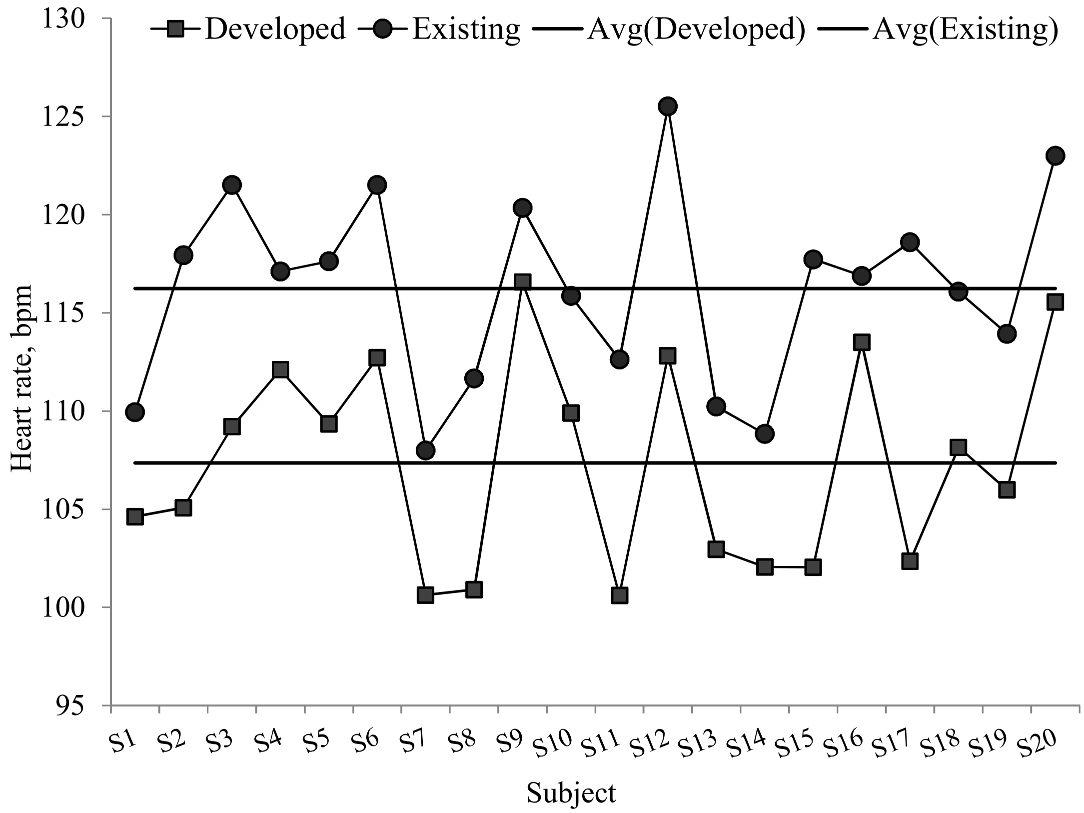


Fig. 4.40 Heart rate response while using developed and existing paddy thresher (average HR - lower straight line for developed thresher and upper for existing one)

4.9.8.3 Physiological cost of work

The physiological cost of work in terms of heart rate (HR), oxygen consumption rate (OCR) and energy expenditure rate (EER) is shown in Fig. 4.41. The EER and OCR were calculated based on resting heart rate and working heart rate with the help of formula discussed earlier (Chapter 4, Section 4.9.5 and 4.9.6). The average temperature, relative humidity and wind velocity were recorded as 27.32 ± 1.72 ^{o}C, 59.67 ± 3.22 % and 1.92 ± 0.34 km/h during the experiment. The observed difference (Mean ± SD) of HR, OCR and EER for developed and existing threshers was 32.73 ± 6.15 and 41.97 ± 8.29 bpm, 0.37 ± 0.07 and 0.48 ± 0.1 l/min; and 13.64 ± 2.56 and 17.49 ± 3.45 kJ/min, respectively. Increase in HR, OCR and EER were perhaps principally due to the lesser effort required for threshing with developed model. Student's *t*-test for Paired samples rejected the null hypothesis of equal means for HR, OCR and EER due to significant variation ($p<0.001$) in the outcomes for all physiological cost of work viz. HR vs. OCR, OCR vs. EER and EER vs. HR.

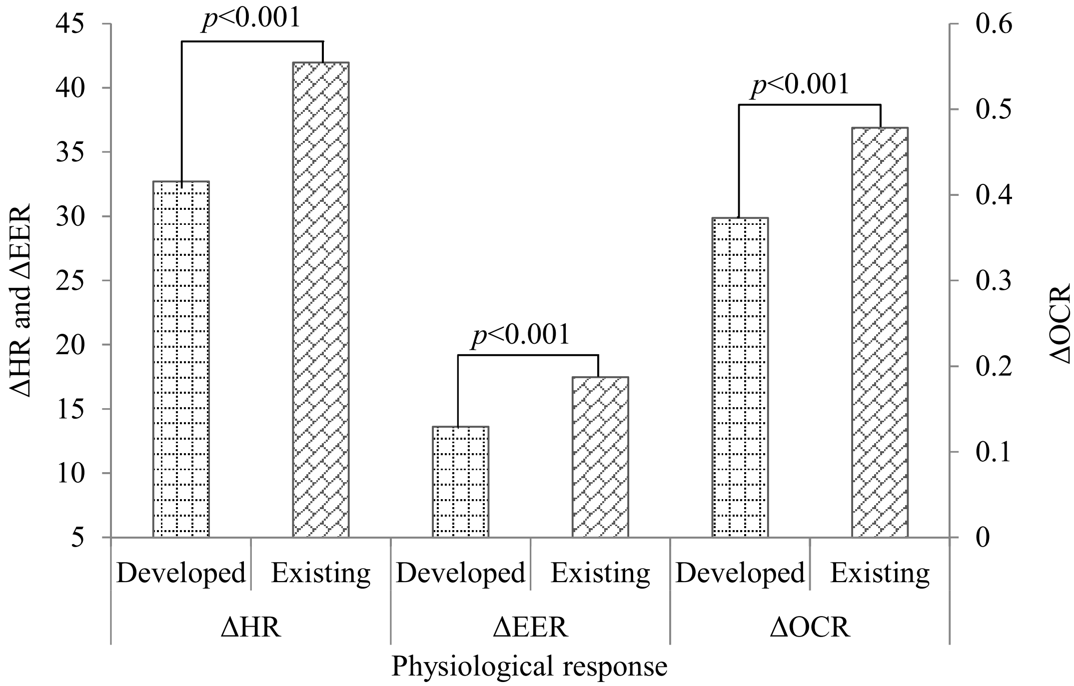


Fig. 4.41 Physiological cost of workers during paddy threshing operation (change in HR (ΔHR), bpm; Change in OCR (ΔOCR), l/min; Change in EER (ΔEER), kJ/min)

The prediction of EER using HR under field or laboratory conditions is fairly accepted method of evaluating operators' performance (Yadav et al., 2007). Morehouse and Miller (1976) reported that a period of 3-5 min could be considered suitable for stabilizing pulse rate, depending upon the nature of exercise. Tomilson (1970) stated that a rapid increase in the heart rate occurs at the start of work, attains highest value within the first 15 seconds of exercise and then gradually becomes constant.

4.9.8.4 Muscular fatigue

Handgrip and leg strengths were measured with grip dynamometer and leg strength measuring device before starting the work and after the completion of work. The Table 4.6 depicts the percentage change in handgrip and leg strengths of the subjects, before and after pedal threshing. It was observed that at the end of the work, right and left handgrip strength for existing vs. developed thresher was 34.71kg and 30.24 kg vs. 36.36 kg and 31.30 kg respectively. Similarly leg strength was found to be 25.81 kg and 23.86 kg vs. 29.76 kg and 25.10 kg for right and left leg strength for existing vs. developed thresher respectively. The % difference before and after threshing (indicating fatigue of the concerned musculature) recorded maximal for right and left legs strength followed by right and left handgrip strengths. Sharma and Sharma (1999) manifested and 8.33% change in grip strength for weeding activities by the farm women with age group of 21 to 30 years.

Table 4.6 Percentage change in isometric muscular strength while threshing paddy with developed and existing paddy threshers

Particulars		At rest	Developed At work	Existing At work	Developed % change	Existing % change
Hand	Right	38.41	36.36	34.71	5.48	9.76
	Left	32.74	31.30	30.24	4.53	7.72
Leg	Right	34.56	29.76	25.81	14.30	25.39
	Left	27.86	25.10	23.86	10.13	15.12

Note: % change in strength = 100×(strength data at rest-strength data after work)/ strength data at rest

The comparison between existing and developed paddy thresher was performed by paired Student's *t*-test (Table 4.7). The decreasing muscle strength during work might be due to fatigue of musculature actively participating for threshing activity. The reason for significant reduction in grip strength (Table 4.7) while threshing might be because of holding bunch of paddy crop and feeding the same at regular interval which caused static construction of the grip muscles and thereby leading to more fatigue to the grip muscles. This may develop upper body discomfort if hand grip strength significantly decreases before and after work. Further, leg strength also showed significant reduction due to pedaling activity in threshing operation.

Table 4.7 Student's *t*-test results for developed and existing models of paddy thresher for hand and leg strengths

Strength	Mean ± SD	SDEM	CI		t-value	df	Sig.
			Lower	Upper			
Right hand	1.65 ±1.08	0.24	1.14	2.16	6.82	19	<0.001
Left hand	1.06 ±1.73	0.39	0.25	1.87	2.74	19	0.013
Right leg	3.95 ±3.46	0.77	2.33	5.57	5.11	19	<0.001
Left leg	1.25 ±1.98	0.44	0.32	2.17	2.81	19	0.011

SDEM=Std. error mean; CI=95% Confidence interval of the difference

4.9.8.5 NASA task load index

Subjective workload while undertaking the task was assessed using Task Load Index by National Aeronautics and Space Administration (NASA–TLX). After completion of task (pedal operated threshing) using the existing and developed models of paddy thresher, the participants reported their experience through ratings using NASA-TLX scale. Normality of data was checked for choosing appropriate statistical analysis. For each participant, the weights were obtained before starting the experiment, by simple decisions regarding the relevance of a component of each paired combination for all the 6 dimensions, allowing to their personal definition of workload. The weights (Mean ± SD) assigned by the participants for Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration were 1.8 ± 0.7, 3.3 ± 0.47, 0.75 ± 0.55, 2.85 ± 0.59, 4.85 ± 0.37 and 1.45 ± 0.6 respectively. It could be seen from the Fig.4.42 that, the order of rating from the highest to downwards was Effort (EF) → Physical Demand (PD) → Performance (PR) → Mental Demand (MD) → Frustration (FR) → Temporal Demand (TD).

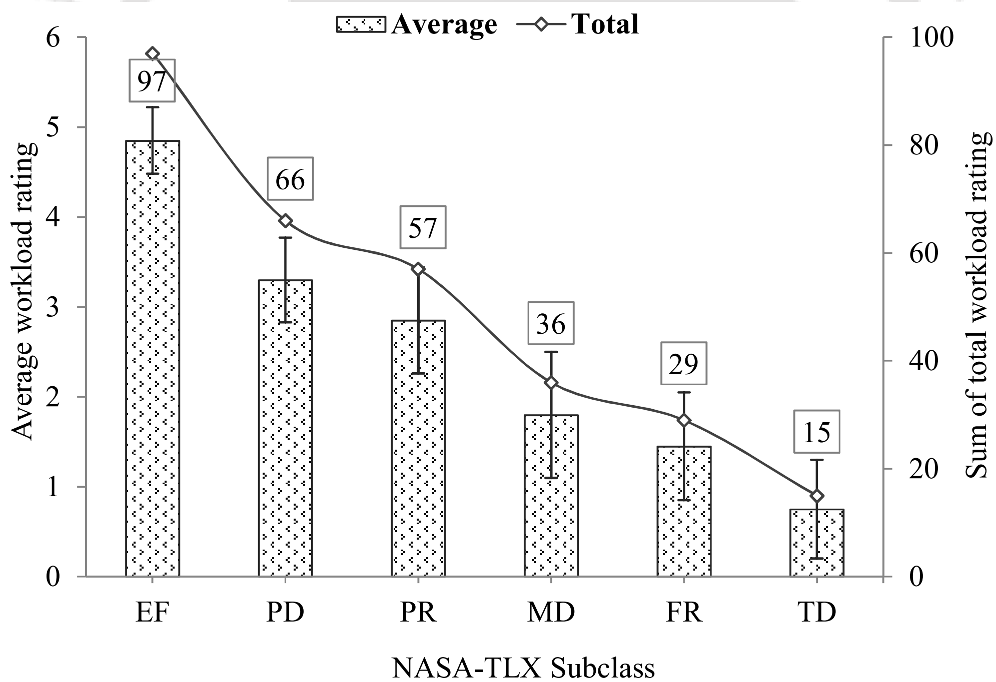


Fig. 4.42 NASA-TLX subjective average workload and sum of total workload ratings

NASA TLX subscales, surveyed separately, manifested higher ratings for the existing thresher and lower ratings for the developed thresher for all the subscales. The values obtained from the subscales were then undergone Student's t-test for paired sample, which revealed workload to be significantly different for Physical Demand, Effort and Mental Demand (Table 4.8). The mean value of NASA-TLX workload for existing thresher was found to be higher than developed thresher viz., Mental Demand (t (19) = 2.383, p<0.05), Physical Demand (t (19) = 6.619, p<0.01) and Effort (t (19) = 12.760, p<0.01). The average score for Temporal Demand, Performance and Frustration were higher for existing thresher compared to developed thresher however, did not differ significantly.

Table 4.8 Comparison of NASA-TLX load scores of developed and existing threshers

NASA-TLX Subclass	Developed thresher	Existing thresher	t-value	p-value
	Mean ± SD	Mean ± SD		
Mental Demand	14.50 ±3.47	17.05 ± 2.98	2.383	0.028
Physical Demand	33.50 ±3.32	40.45 ± 3.50	6.619	<0.01
Temporal Demand	26.45 ±5.77	28.05 ±5.15	0.947	0.356
Performance	15.75 ±4.89	17.15 ±4.66	1.028	0.317
Effort	28.75 ±3.34	40.90 ±3.06	12.760	<0.01
Frustration	17.35 ±5.22	18.85 ±5.90	0.757	0.458

The average value of NASA-TLX AWWL (Adaptive Weighted Workload) scores is displayed in Fig. 4.43, where smooth line and markers represents the % difference between the TLX factors for existing and developed threshers. The benefit of this weighting scheme was an increased sensitivity (to relevant variables) and decreased between-subject variability. It could thus be observed that, greater perceived workload was found for every subclass of NASA-TLX scale for the existing thresher. The highest % difference of AWWL scores i.e. 29.69 was observed for effort, followed by Physical Demand, Frustration, Mental Demand, Temporal Demand and Performance, suggesting that greater effort was required while using existing thresher. The overall subjective evaluation was performed with AWWL score, weighted average scores of the six indices, using the coefficient defined by the rank order of the raw scores. The overall AWWL score was found to be 30.77 and 24.39 for existing and developed threshers respectively. The overall percentage difference of workload was 20.73 and Student's *t*-test for paired sample showed significant difference in workload (t (19) = 11.037, p<0.001). The greater requirement of effort for operating the existing thresher could be due to ignorance of ergonomic interventions in thresher design leading to mismatch of workers capability and limitation.

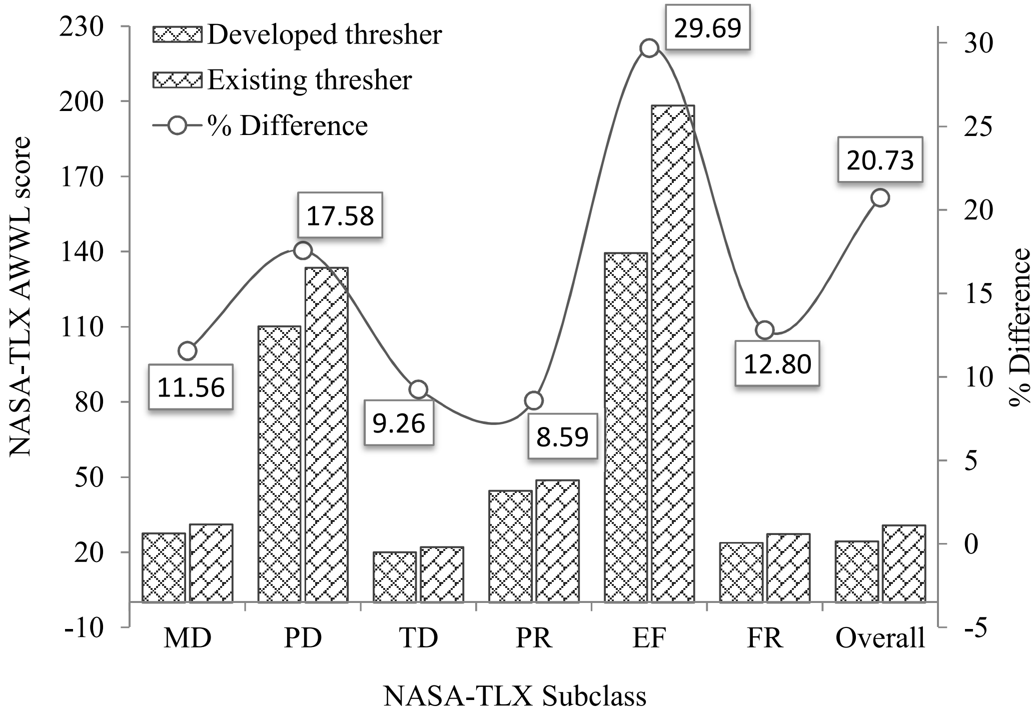


Fig. 4.43 Average value of NASA-TLX AWWL scores and percentage difference between existing and developed threshers (For all subscales, higher scores indicate greater perceived workload i.e. lesser is better)

4.9.8.6 Body part discomfort

The individual perception of exertion over time can be realized directly by assessing discomfort on various rating scales for overall discomfort, discomfort in exact body part or region of the body. In this research, subjective postural discomfort was computed using the body map after Corlett and Bishop (1976). The degree of discomfort felt in various parts was assessed on Borg's CR 10 subjective scale (0 – no discomfort to 10 – extreme discomfort). At the end of each experiment, subjects were asked to pinpoint their overall discomfort and body part discomfort rating on the scale. Distribution of body part discomfort scores was checked for normality with Shapiro-Wilk and Kolmogorov-Smirnov tests, resulting in statistics < 0.05 thus excluding the possibility of normality. Further, both frequency distributions and P-P plots showed that data violated the assumptions for a normal distribution. Therefore, non-parametric test i.e. Wilcoxon signed-rank test was executed. The % change in overall discomfort score for existing and developed threshers were 27.40 % and 10.27 % respectively. Further Wilcoxon signed-rank test showed significant difference in the average score ($Z = -4.011$, $p < 0.001$). Similarly, body parts discomfort score was also analyzed. The % change in body parts discomfort score for existing and developed threshers were 17.72 % and 5.30 % respectively. A Wilcoxon signed-rank test showed that decline was significant ($Z = -3.926$, $p < 0.001$).

The overall discomfort and body parts discomfort scores are presented in Table 4.9. Overall discomfort rating for existing and developed threshers was 5.75 and 4.15 respectively, whereas body parts discomfort rating for them was 46.75 and 38.45 respectively. During threshing of paddy, the group of muscles involved are stressed and relaxed alternately. Therefore the efficiency of the workers was more in developed model due to rendered relaxation while holding the bunch of paddy and in between pedaling operation while threshing. This might be the reason for lower discomfort scores at developed paddy thresher.

Table 4.9 Discomfort score of agricultural workers while operating developed and existing threshers

Particulars	Body parts discomfort		Overall discomfort	
	Developed thresher	Existing thresher	Developed thresher	Existing thresher
Minimal	33.00	43.00	3.00	4.00
Mean ± SD	38.45 ± 2.84	46.75 ± 2.27	4.15 ± 0.81	5.75 ± 0.97
Maximal	42.00	52.00	6.00	7.00
Sum	769.00	935.00	83.00	115.00

The percentage difference in body parts discomfort ranged between 7 – 33 %. The highest % difference of discomfort in existing and developed threshers was reported for lower legs followed by thighs, then foot, lower back, buttocks, wrists, knees, elbows, arms, shoulder, hands, upper back, forearm and finally neck as shown in Fig. 4.44. Most of the participants reported pain in calf muscle after using the existing thresher. This showed that body parts like thigh, calf muscle and ankle regions felt greater pain, possibly due to continuous pedaling with longer exertion of force for pedaling. It was perceived that, the operation of thresher demanded more than average physiological workload resulting in higher degree of discomfort in many body parts. Dimensions as well as capacity of thresher vary considerably and hence matching of salient dimensions of the machine with the body dimensions is an absolute must.

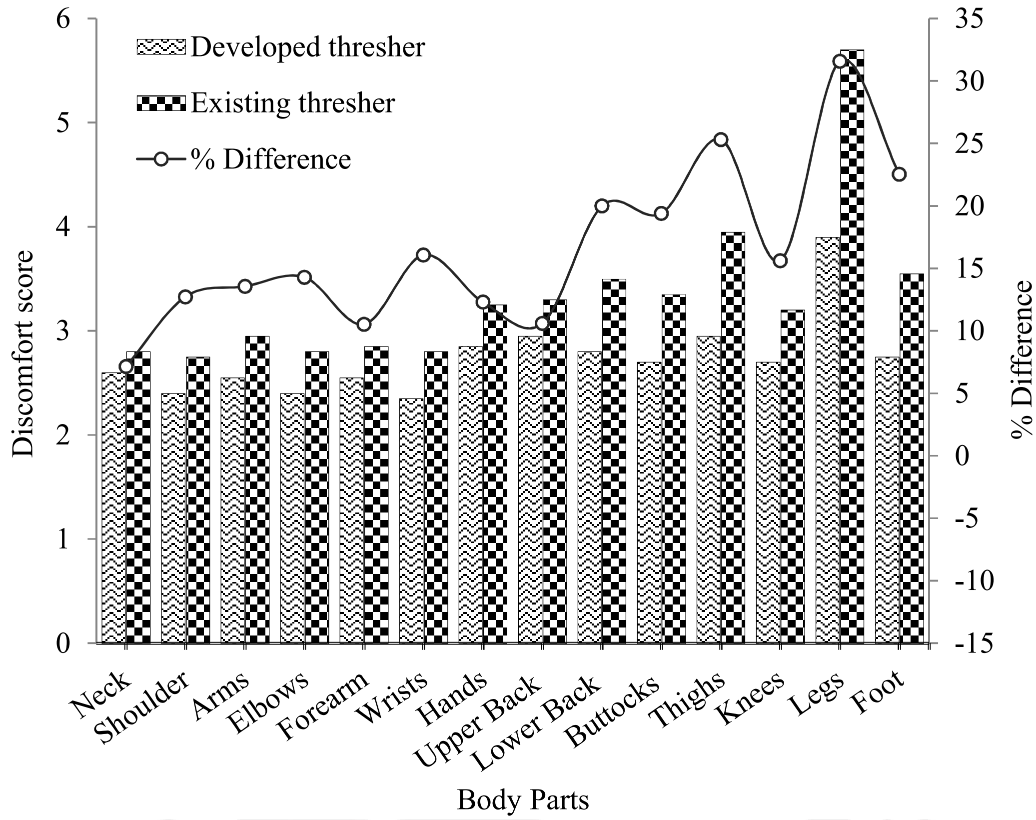


Fig. 4.44 Mean values of work related body parts discomfort score (Borg CR-10 Scale) during paddy threshing with existing and developed models

4.9.8.7 Work-rest scheduling

Perhaps the most corporate engineering approach to address human performance is work-rest scheduling. The average values of work-rest schedule for existing and developed threshers were 9.85 and 6.57 min for 30 min of threshing operation (Fig. 4.45). This meant that a worker working for the first 30 min should spend the last 6.57 and 9.85 min at rest before starting next cycle of 30 min work with developed and existing threshers respectively. The use of recommended rest-pause could prevent the fatigue contributing to loss of productivity. A dependent samples Student's *t*-test was performed after examining the assumption of normally distributed difference scores. The assumptions satisfied, as revealed by the skewness and kurtosis levels estimated to be -0.420 and -0.337 for developed vs. -0.711 and 0.663 for existing thresher, respectively, which was less than the maximum allowable values for a Student's *t*-test (i.e., skewness < |2.0| and kurtosis < |9.0|). The Student's *t*-test for paired samples indicated that the rest pause of developed and existing threshers differred significantly (t(19) = 13.59, p<0.001).

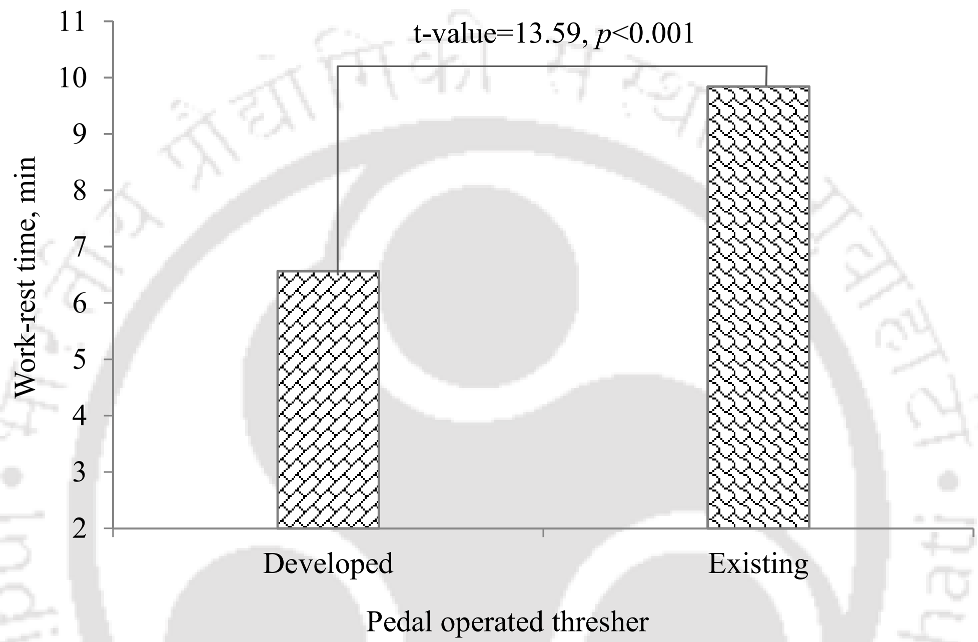


Fig. 4.45 Work-rest after 30 min of threshing with developed and existing threshers

4.9.8.8 Threshing capacity

The moisture content of grain and straw were measured with the help of grain moisture tester as shown in Fig. 4.46. The average threshing capacity (kg/h), calculated at moisture content (%) of 13.71 ± 1.96 and 23.4 ± 2.36 for grain and straw respectively, demonstrated to be 43.22 ± 3.92 with developed and 45.11 ± 3.34 with existing thresher respectively (Fig. 4.47). Further, a dependent samples Student's *t*-test was performed after examining the assumption of normality. The Student's *t*-test for paired samples indicated that the difference in output capacity of developed and existing threshers was statistically non-significant. Earlier studies (like Miah et al, 1994) also compared the different traditional methods of threshing like bullock treading, drum beating and manual threading with pedal threshing, and reported significantly higher threshing capacity and efficiency of the pedal threshing compared to the traditional methods (p<0.01).

Fig. 4.46 Measurements of moisture content of grain and straw

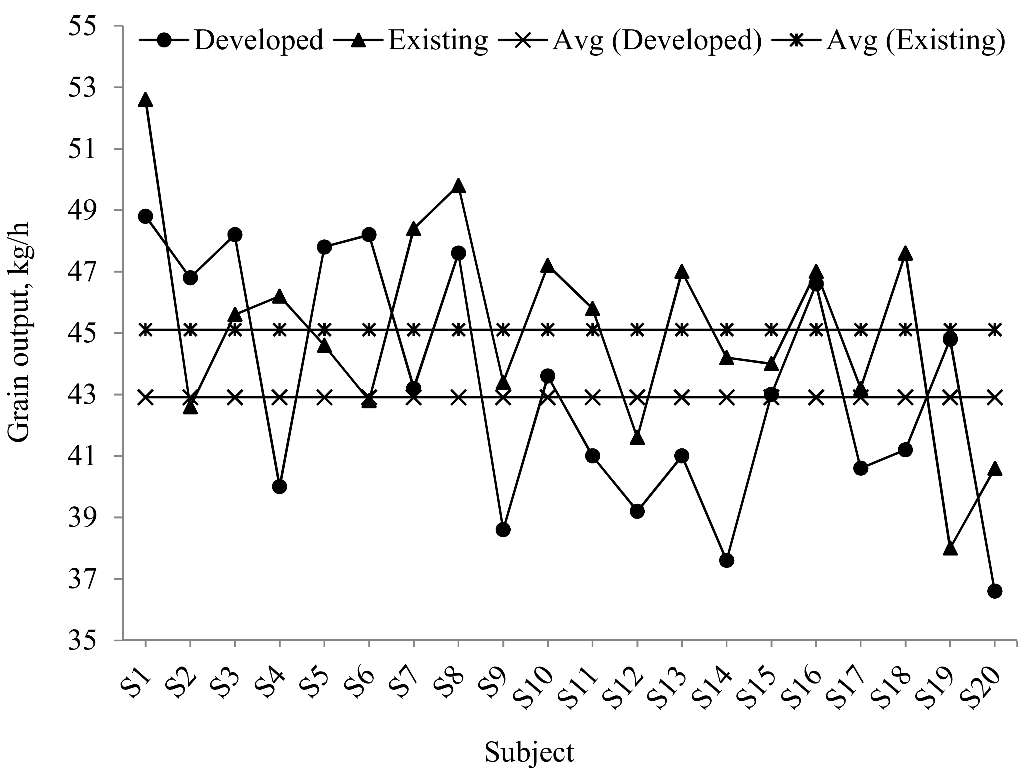


Fig. 4.47 Threshing capacity of developed and existing pedal operated paddy thresher

Chapter 5

Summary and Conclusion

Abstract – *This chapter summarizes the gist of the research work carried out with regard to pilot and field survey studies, development of isometric strength measurement device, a series of design and evaluation done for paddy thresher at various stages, results obtained through laboratory and field testing etc. Conclusions based on the findings of the studies presented in various chapters of this thesis, have been made here. Furthermore, this last chapter of the thesis describes how objectives of the present research have been full filled and how hypothesis have been tested.*

5.1 Summary

Paddy threshing in NER is carried out usually by traditional methods such as bullock treading, beating or crushing the grain by hand or foot, which requires an enormous human effort. These discomfited situations expose workers to many risk factors from ergonomic viewpoint. Furthermore, existing pedal paddy thresher is not suitable for NER realm owing to substantial weight lacking portability features. Therefore, a systematic approach, complying ergonomic design principles (anthropometric and biomechanical) for paddy threshing operation along with the users' physical and physiological determinants, deems to be a crucial yet most fundamental step to perceive the scope of the problems and eventually advance the scenario. So this piece of research focused at ergonomic design modification of the existing pedal operated paddy thresher making it flexible for all terrains across NER; and India, at large.

The last decade has beheld considerable development in the survey and compilation of biomechanical database of agricultural workers. This database is significantly important in human-centric design of tools and equipment. However, this basic database is not available for Assamese agricultural workers of NER. An extensive review of available literature manifested that the importance of isometric vertical leg strength for design of pedal operated paddy thresher is also not published elsewhere till date. Therefore, one of the impetus for this research was developing an indigenous isometric vertical leg strength measurement device to compile maximal isometric leg strength database with the participant in standing posture, unlike the one available for measurement with sitting postures only. For design and fabrication of the said instrument, following criteria were considered − (1) versatility, (2) safety, (3) comfort, (4) use-reuse flexibility, (5) system calibration, (6) accuracy and (7) cost. Several concepts were postulated to explore the feasibility of ergonomic design and designated finally that model, which fulfilled all the above criteria.

The 'mechanical design' option in DELMIA Human Modeling Software (v.5.19) was used to create 3D CAD model of conceptualized force measuring device. The manikins (digital human models, to decide the fitting range of adjustment) were created using Indian national anthropometric database for agricultural workers, since database for Assamese farmers were not available. The effective range was demarcated by 5^{th} percentile female and 95^{th} percentile male. The knee joint angle of 5^{th} (female) and 95^{th} (male) percentile was adjusted approximately between 150^0 and 90^0 in order to get maximal promising range of adjustment. Finite element analysis (FEA) was used for isometric force measuring device in order to predict deflection and stress distribution accurately for the relevant components, to make sure that, it could be operated safely. The design is considered to be safe, as FEA showed the proposed design of leg strength measuring device to satisfy the criteria for deflection and stress. Based on result of virtual prototype experiment, physical prototype was fabricated. The physical prototype of the device was calibrated and result showed excellent agreement between measured and predicted values ($R^2 = 0.999$). The minimum height of the device (from ground to foot rest) was 50 mm, with maximum possible upward adjustment of 150 mm.

Further, standardization of anthropometric measurement procedures was carried out with a pilot study involving 40 agricultural workers (20 male and female each) of Assamese population. The relative technical error of measurement and reliability coefficient for all measurements were found to be within acceptable limits – fairly close to 1 and above 95% respectively. The field study was conducted on 200 agricultural workers, divided into three age groups of <30, 30 – 40 and >40 years, for a set of 27 body dimensions. The selected dimensions were divided into 3 clusters comprising of 11 standing body dimensions including weight, 10 sitting dimensions and 6 body dimensions in sitting / standing postures.

Anthropometric database of male and female Assamese agricultural workers registered significant difference over Student's *t*–test ($p<0.05$). Anthropometric database of Assamese male farmers in the present survey were compared with database from other zones of India viz., Northern, Southern, Eastern, Western, Central and even Northeast, revealed significant difference (Student's *t*-test, $p<0.05$) in many cases. These variations in anthropometric database of Assamese population and other parts of India signposted that, blind adoption of agricultural tools / equipment designed for such regions might lead to occupational health issues. Principal component factor analysis (PCFA) with Varimax rotation was performed initially on 25 variables for a sample of 130 male anthropometric body dimensions. It was observed that the highest factor loading accounted for the largest variations component of 37.68% and remaining factors accounts for ~33.53% of the total variance. In addition to principal components factor analysis, regression analysis was also performed based on components derived from the PCFA. The following five measurements were selected for the prediction of equation viz., stature (ST), knee height (KH), Sitting height (SH), buttock-knee length (BKL) and sitting knee height (SKH). The contribution of stature for acromial height prediction showed highest significance ($r = 0.88$).

Handgrip strength was measured in standing position for both dominant and opposite hands. For each hand three readings were obtained with a ~3 min rest intervened between two subsequent trials to avoid muscle fatigue. Each participant was instructed to hold the handle of the dynamometer straight and squeeze with the right hand (dominant) first and then left hand (opposite) exerting maximum isometric strength for a period of 3-5 s without any significant movement of other body parts. The percentage variation in handgrip strength for (male vs. female) vs. (dominant vs. opposite hands) were found lower in the younger age group i.e. <30 years and higher for the elder age group i.e. >40 years. The independent sample Student's *t*–test exhibited significant difference in handgrip strength for both hands ($p<0.05$) between male and female across various age groups. Comparisons of handgrip strength between Assamese farmers and the other regions of India demonstrated the database of Assamese population to differ significantly ($p<0.05$) in most of the cases. These significant differences in strength of Assamese farmers with other states of India clearly advocated that, ergonomic design of tools /

equipment for Assamese farmers should give due and exclusive prominence to Assamese strength database.

The leg strength is quintessential for operation of pedal-operated paddy thresher. The second pilot study was conducted for measurement of exerted isometric vertical force with the same sample of 40 participants considered for anthropometric measurements for different knee joint angles i.e. 90°, 120° and 150°, with both right and left legs in standing position. The participants were restricted to performing heavy muscular activity before 2 – 4 hours to avoid a carryover effect at the time of experiments. Following the pilot study, field experiment was conducted with knee angle of 120^o, since noted maximum force was exerted at 120^o in the pilot study. Progressive with aging, muscle strength of both legs in male and female reduce. The independent samples Student's *t*–test showed significant difference in leg strength values for both legs ($p<0.05$) between male and female farmers across various age groups. Further, the combined leg strength database of male and female farmers across the age groups showed that, capability of right leg was significantly higher ($p<0.05$) than the left.

An exploration was performed for detailed information regarding design and physiological aspects of pedal operated paddy thresher. Most of the suppliers / manufacturers were found from West Bengal, India and none from NER, with large variability in physical design components of the thresher and same functionality i.e. four bar linkage mechanism. Maximal pain and discomfort was reported in calf muscle and upper thigh by most of the participants, perhaps due to nonconformity with standard ergonomic and design considerations. So the key motif for this research was to reform the design of paddy thresher based on normative anthropometric and biomechanical database of Assamese population compiled hereinabove.

To address these issues, in present research, a design of pedal operated portable paddy thresher suitable for Assamese farmers was hypothesized. The 3D CAD model of anticipated thresher was formed, followed by brainstorming and conceptualizing about the feasible solutions. The strength of critical parts of the machines was evaluated by FEA approach. For simulation in virtual environment, customized digital manikins (virtual human) of 5^{th}, 50^{th} and 95^{th} percentile male and female were created representing anthropometric database of the Assamese population. Various human factor aspects of CAD model of pedal thresher were evaluated in DELMIA with virtual manikins. Apart from this, important design features such as availability of proper clearance, protection from paddy dust, portability, compact size and operator safety were also considered. Succeeding virtual ergonomic evaluation of the thresher model with subsequent modification of its design, the physical prototype was upturned. Some important design features of the newly developed paddy thresher considering the prerequisite of hilly / plain terrains agriculture were as follows.

- ✓ *The existing 'four bar linkage' mechanism was replaced with the 'chain gear' mechanism to simplify power transmission system, thus reducing effort essential for pedaled threshing operation*
- ✓ *A grain shield was provided for reducing spread of dusts/ husks and thus respiratory protection*
- ✓ *Chain mechanism allowed rotating the threshing cylinder in one direction only, therefore there was no requirement of initial momentum to rotate drum.*
- ✓ *Pedaling speed of thresher is 60 cpm to achieve the required minimum peripheral speed of threshing cylinder at ~300 rpm.*
- ✓ *Adjustable pedal height with variable range of movement to satisfy the user with varying lower limbs' heights*
- ✓ *The weight of the new thresher was 23.5 kg (+ 3.5 kg for electric motor, if attached), compared to 45.8 kg, the weight of existing thresher. It can be easily carried by two persons only.*
- ✓ *Wheels were provided for convenient transportation.*
- ✓ *Easy assemble/ dissemble of major components (i.e. cylinder, grain shield, frame and power transmission mechanism etc.)*

The pre-existing and developed pedal operated paddy threshers were tested under both laboratory and field conditions. The EMG was done to estimate force required while pedaling the thresher under lab condition along with field evaluation of various physiological aspects like heart rate, energy expenditure, oxygen consumption rate, etc. Subjective rating techniques such as NASA–TLX and body parts discomfort have used for the evaluation of field workload. Muscular fatigues after exertion of isometric leg strength and handgrip strength were also measured. Rest-pause was then calculated to eliminate unnecessary fatigue.

The systematic approach of ergonomic evaluation techniques viz. direct measurement, observational method and subjective assessment were proved precisely worthwhile in identifying and analyzing the workload and risk factors for improvement of farmer's safety, comfort and efficiency. Following a similar approach could provide useful information needed for further design interventions of other agricultural tools. It was thus evidenced that implementing ergonomic and user oriented design with relevant normative database as reference, contribute towards improved user safety and comfort, finally enriching the agriculture.

The hypotheses formulated in chapter 1 were tested through the research endeavored in chapters 2 – 4. Hypotheses were tested based on research carried out in the northeastern state - Assam. Differences in anthropometric (Chapter 3, Section 3.5.4.2) and biomechanical data (Chapter 3, Section 3.6.1.3 and 3.7.1.2) of Assamese population in comparison to various regions of India as well as northeastern states indicated that regional anthropometric and biomechanical database are critical for design and development of agricultural tools and equipment suitable for agricultural workers of NER of India (establishing ***Hypothesis – I***). Conventional combine harvesters or modern threshing machines are not feasible in north-eastern region of India, due to hilly topography (nearly three forth of total area of this region is hilly in nature), socio-economic conditions, small land holding etc. Anthropometric incompatibility and requirement of high actuating force for pedal operation are the main hindrance for wide adoption of existing / available pedal-operated paddy threshers in this region. Thus, it could be stated that during design of agricultural tools and equipment for agricultural workers of Northeast Region of India, designers / engineers should not only concentrate on anthropometric and biomechanical (muscle strength) data but also consider the context (Chapter 4, Section 4.6) of use and local topo-geographical conditions (Chapter 1, Section 1.3 and 1.4) (establishing ***Hypothesis – II***).

5.2 Conclusion

In light of the outcomes and explanations in earlier chapters, and also from the actualities summarized above, it would be justified to conclude the following.

1. The present piece of research resulted in fabrication of a pedal operated paddy thresher, proved to be better and simpler over the extant traditional techniques, and even over the existing pedal operated paddy thresher; thus extending a 2-tier voucher of benefits to the target users (like Assamese farmers) as detailed hereunder.
    a) ***A convenient and simple substitute for extant traditional techniques.*** The fabricated thresher is a lightweight and portable substitute, which is easily affordable even for rural farmers with the distinct provision for easy assembling and disassembling.
    b) ***Simplification over the existing paddy thresher.*** The fabricated unit operates on a gear-and-chain mechanism, which is much simpler than the existing 'four bar linkage' mechanism. It requires lesser energy and minimal rest pause to operate the machine. Another plus point of developed model is that, there is no requirement of reverse rotation to render threshold momentum (since it operates only in the threshing direction), as is required with the conventional thresher.
2. Crucial to the ergonomically efficient utilization of this thresher, it was a necessity to assess and standardize the working leg strength required for pedaling using some vertical isometric leg strength measuring device; while no such device is available in the Indian market. Therefore, a prototype 'vertical isometric leg strength measuring device' was also fabricated, in order to determine the pedal height matching the desired knee angle and applicable leg force required.
3. The anthropometric and biomechanical database of an illustrative sample of Assamese farmers gathered in the present study for reference once again substantiated the unified solicitations of such normative database in ergonomic design of any tool / equipment, like the portable paddy thresher in this research. Implication of such database entrusts on a user-friendly ergonomic design solution, which in turn, proves to be more efficient, cost effective with simple mechanization and feasibility of local manufacture.

5.3 Key Contributions of Present Thesis towards Agricultural Research

- **Design and Development of First-of-its-Kind Indigenous Isometric Vertical Leg Strength Measurement Device**

  It is evident from the review of literature in the earlier sections (Chapters 2 to 4) that all the leg strength data available for Indian agricultural workers , have been collected only in seating postures; which would not be applicable for measurement of leg force in standing postures. In this line, the review also showed that till date there was no published normative database of isometric leg strength of Assamese farmers. Therefore, *this thesis thus intended to devise such an isometric vertical leg strength measurement device that would certainly assist the researchers to assess isometric vertical leg strength (standing*. The physical prototype of the isometric vertical leg strength measurement device was calibrated and result showed excellent agreement between measured and predicted values ($R^2 = 0.999$). When design, development and field evaluation are conducted using true representative samples, the designs become more appropriate for actually intended users. *This is where such a development finds its importance.*

- **Development of Anthropometric and Biomechanical Reference Database for Assamese Farmers**

  Till date, there is only one literature revealing anthropometric database of Assamese agricultural workers (40 males only; Dewangan et al., 2005). *The necessity to develop some anthropometric and biomechanical database with a bigger sample size of Assamese farmers was thus recognized crucial to facilitate research, design and development of tools / equipment in agriculture. With the objective to serve as a fundamental reference database for the Assamese farmers population, anthropometric and biomechanical database of Assamese agricultural workers were projected in present research.*

- **Application of Digital Human Modeling Based Approach in Design of Agricultural Machinery**

  The research application of Digital Human Modeling (DHM) is emphasizing on the necessity of using this technology for design and analysis of farm tools, featuring amalgamation of ergonomic guidelines along with other engineering design considerations. *Introduced for the first time in-depth study in Indian context about application of virtual simulation like digital human model based approach for ergonomics design and analysis in agricultural engineering ascents to have a bright and promising future.* By the next decade, it can be expected to serve as a key spotlighting tool on engineering design and ergonomic analysis.

- **Fabrication of Ergonomic, Cost Effective, Portable and User Friendly Pedal Operated Paddy Thresher**

Following required virtual ergonomic evaluations and thereafter necessary design modification of the thresher model, full-scale physical prototype was developed. The pre-existing and newly developed threshers were tested under both laboratory and field conditions to compare the physiological load (in terms of force requirement, muscle fatigue, body parts discomfort mapping, heart rate, energy expenditure etc.) as well as cognitive load (subjective ratings on NASA-TLX scale) during their operation. Newly designed pedal operated paddy threshers were found to be superior in comparison to the existing one.

The ergonomically designed pedal operated paddy thresher which is an outcome of present research bears important design features considering the prerequisites of agriculture of NER. These features are (a) grain shield for reducing spread of dusts / husks and thus respiratory protection; (b) 'chain gear' mechanism instead of 'four bar linkage' mechanism, to simplify power transmission system; (c) adjustable pedal height with variable range of movement to satisfy the user with varying lower limbs' heights; (d) attachable wheels for translocation of the thresher within short distance; (e) substantial reduction in overall weight of the thresher by modifying the design and selecting lighter materials; (f) easy assemble / dissemble of components (i.e. cylinder, grain shield, frame and power transmission mechanism etc.); (g) comfortable pedaling speed of thresher (i.e. 60 cycle per minute) to achieve the required minimum peripheral speed of threshing cylinder at ~300 rpm.

5.4 Limitations of the Study and Future Research Directions

Despite enormous and sincere efforts to achieve the best results out of it, there are always some concerns beyond the reach of the experimenter, lining some setbacks in the results. The undesirable and irrepressible limitations of this piece of research which could be taken for further investigation as future scope of research.

1. To achieve the aim of the present thesis work and to test the formulated hypotheses, research work/ studies were carried out in the state of Assam which is the largest paddy producing state across northeastern India and bears characteristics of having both plain land and hilly regions. It could be possible to extend similar research in other northeastern states of India and to develop more number of agricultural tools/equipment suitable for local people.
2. Anthropometric and biomechanical database not available on most of the NER populations (except Arunachal Pradesh and Meghalaya). This is where extensive research and surveys should be carried out to develop normative database across different NER states. Availability of such database would help in better design of products suitable for targeted users and thus in turn reduce incompatibility and safety issues.
3. This research preliminarily emphasized on the physiological, biomechanical and perceived exertion aspects of the participants (agricultural workers). Reflection of psychological, socio-economic and job stress facets of the agricultural workers might have added some comprehensive screening of the benefits.
4. Direct measurement of energy expenditure was not possible in present research due to unavailability of the respiratory gas analyzer system. In future research, direct measurement of energy expenditure could be considered.
5. Usability and performance of the newly developed thresher were tested with male participants/ volunteers only as the participation of female agricultural workers was very limited in experiments with electromyography and recording of heart rate. They refused for wearing the belt containing heart rate sensor (fastening chest belt) and allowing electromyography on lower limbs (placing electrodes on calf and thigh muscles).

6. An in-depth analysis of the traditional threshing activity through biomechanical approaches such as measurement of dynamic force, range of motion of joints, muscular activities using electromyography under field condition might yield yet unknown results.

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Appendix 1

Proforma for Anthropometric Survey

General Data

Date of survey……………………….. Time………………………

State…………………………………. District……………………

Village……………………………….. Police station………………

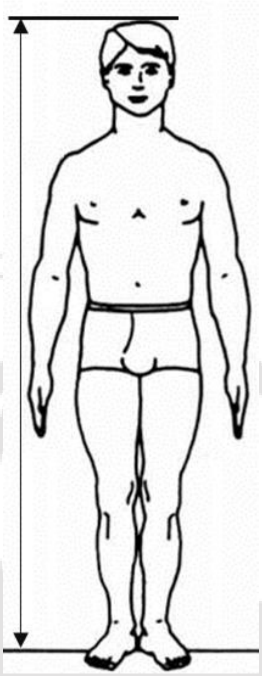
Sl. No	Subject	1	2	3	4	5
1	Name					
2	Sex					
3	Age					
4	Right/left handed					
5	Ethnic group					
6	Job specification					
Measurement to be taken in standing posture						
	Dimensions	Reading in cm (Unless otherwise mentioned)				
7	Weight, kg					
8	Stature					
9	Acromial height					
10	Elbow height					
11	Olecranon height					
12	Trochanteric height					
13	Knee height					
14	Arm reach from wall					
15	Shoulder grip length					
16	Shoulder breadth (bi-deltoid)					
17	Hip breadth					
Measurement to be taken in sitting posture						
18	Height					

19	Acromial height					
20	Knee height					
21	Popliteal height					
22	Buttock-knee length					
23	Buttock-popliteal length					
24	Foot length					
25	Instep length					
26	Foot breadth(ball of the foot)					
27	Functional leg length					
Measurement to be taken in sitting/standing posture						
28	Grip diameter (inside)					
29	Maximum grip length					
30	Hand length					
31	Palm length					
32	Hand breadth across thumb					
33	Hand breadth across metacarpal III					
34	Measurements of strength					
35	Hand grip strength, kg					
36	Hand grip strength, kg					
37	Leg Strength, kg					
38	Leg Strength, kg					

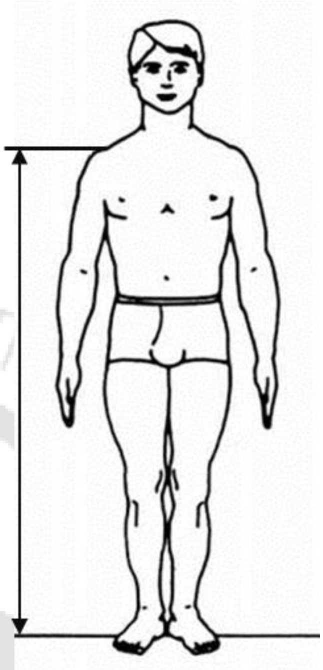
Appendix 2

An illustration of body dimension landmarks for measurement of anthropometric database

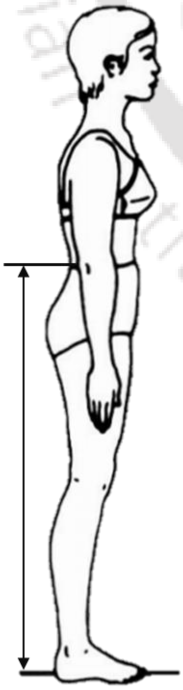
Weight



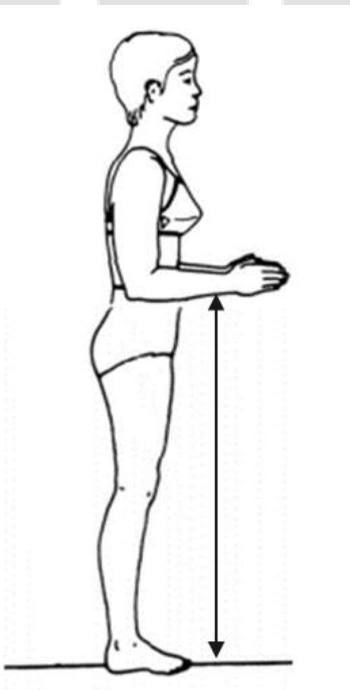
Stature



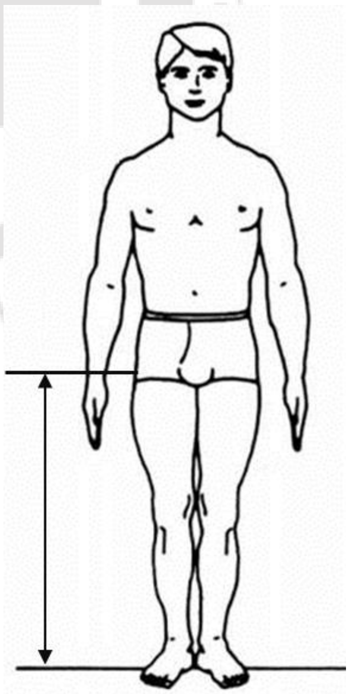
Acromial height



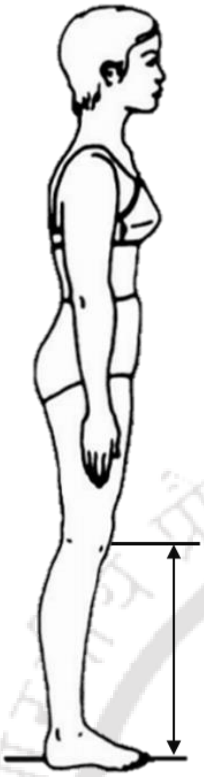
Elbow height



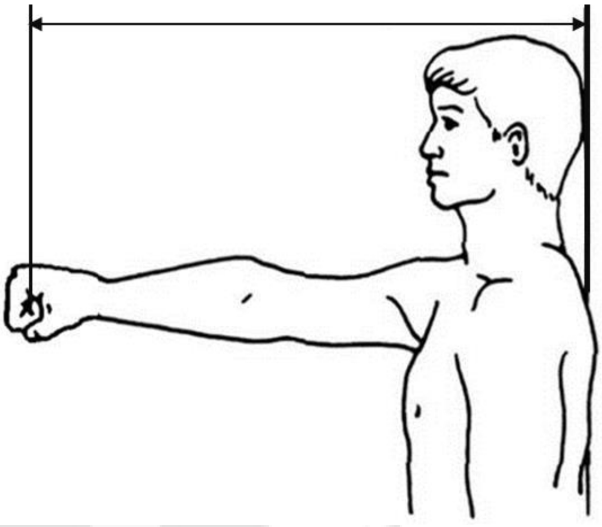
Olecranon height



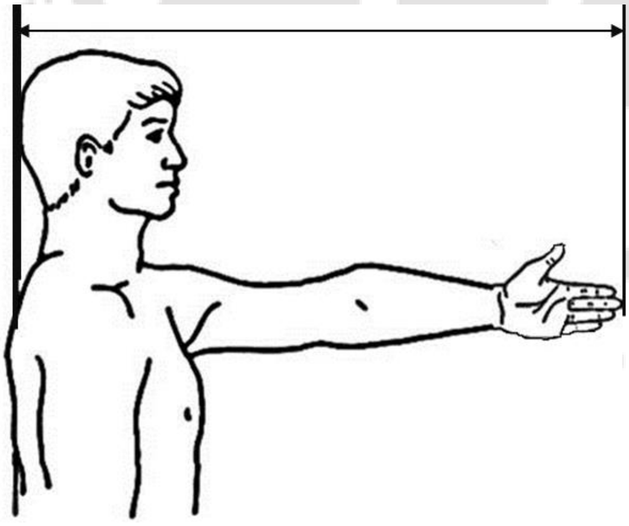
Trochanteric height



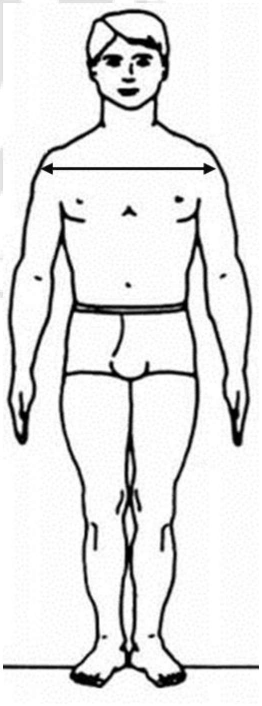
Knee height



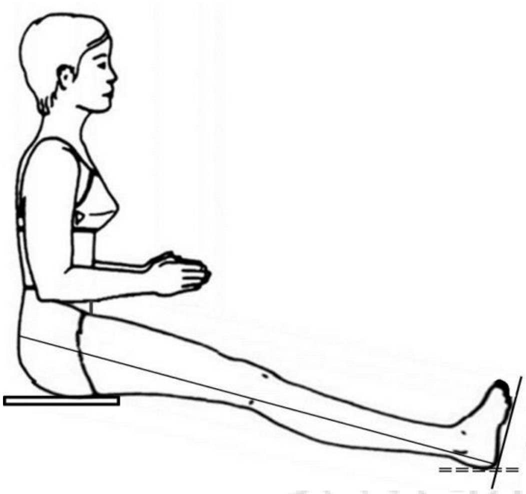
Shoulder grip length



Arm reach length



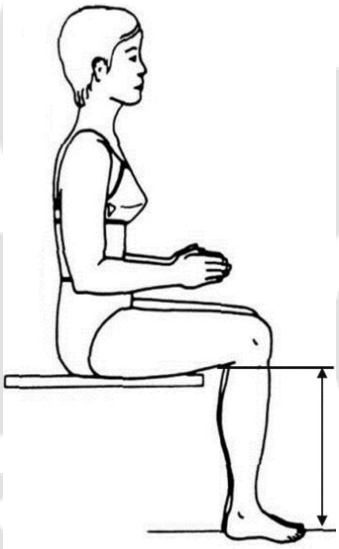
Shoulder width



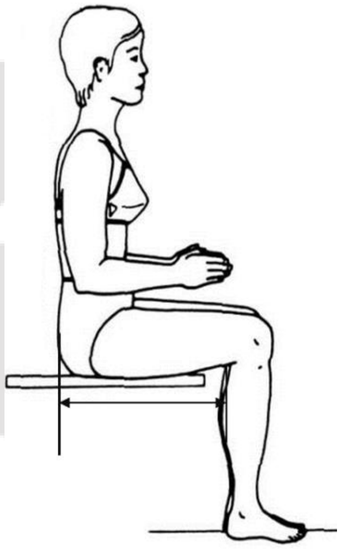
Functional leg length

Sitting height

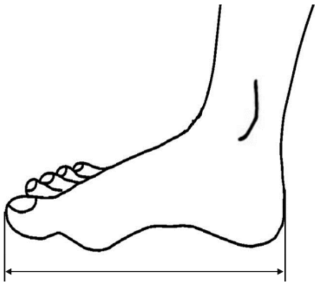
Knee height sitting



Popliteal height

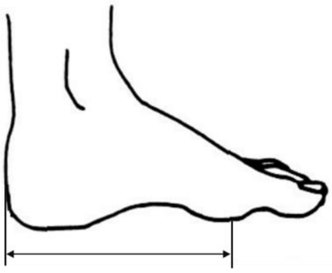


Buttock-popliteal length

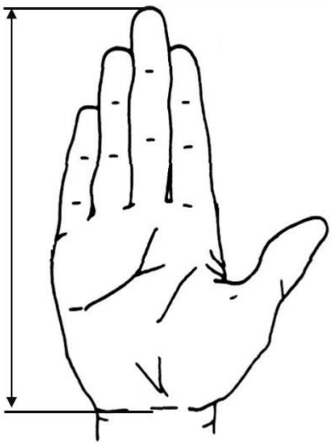


Foot length

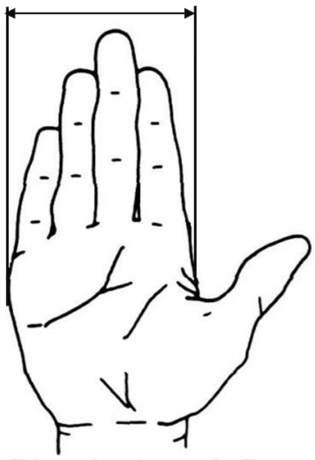
Foot width



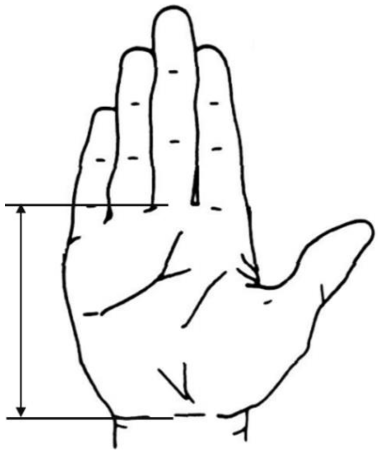
Instep length



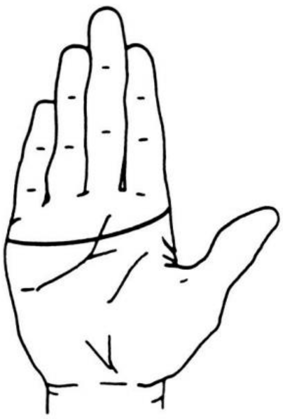
Hand length



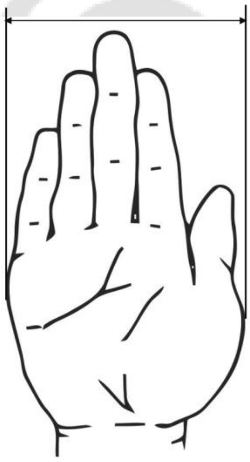
Hand width



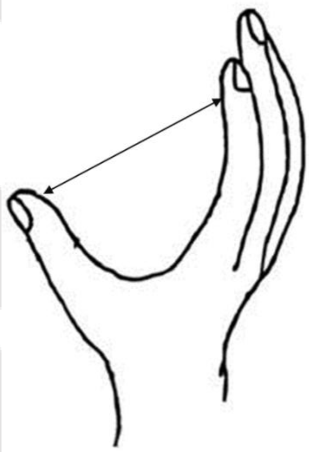
Palm length



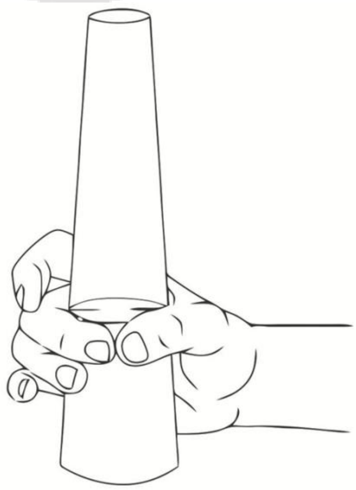
Hand circumference



Hand breadth across thumb



Maximum grip length



Maximum grip diameter – inside

Appendix 3

Measurement definitions of anthropometric dimensions

The following are measurement definitions used in this study (taken from NASA, 1978 and Gite et al., 2009).

1. Weight: Body weight as measured on a calibrated weighing scale. The subject stands erect and look straight forward.
2. Stature: The vertical distance from the standing surface to the top of the head. The subject stands erect and looks straight ahead.
3. Acromial (shoulder) height: The vertical distance from the standing surface to the most lateral point of the acromial process of the scapula. The subject stands erect and looks straight ahead.
4. Bideltoid (shoulder) breadth: The horizontal distance across the body at the level of the deltoid landmarks. The subject stands erect with his arms hanging naturally at his sides.
5. Shoulder grip length: The horizontal distance from a pointer held in the subjects' fist to a wall against which he/she stands, measured with the arms extended horizontally.
6. Arm reach from wall: The distance from the wall to the tip of the middle finger measured with the subject's shoulders against the wall, the hand and arm extended forward.
7. Olecranon height: The vertical distance from the standing surface to the height of the under surface of the elbow, measured with the arm flexed 90 degree and the upper arm vertical. The subject stands erect and looks straight forward.
8. Elbow height: The vertical distance from the standing surface to the depression at the elbow between the humerus and the radius. The subject stands erect with his arms hanging naturally at his sides.
9. Trochanteric height: The vertical distance from the standing surface to the most superior point of the greater trochanter of the femur. The subject stands erect looking straight ahead, heels together and weight distributed equally on both feet.
10. Sitting height: The vertical distance from the sitting surface to the top of the head. The subject sits erect, looking straight ahead.
11. Knee height, sitting: The vertical distance from the floor to the uppermost point on the knee. The subject sits erect with his knees and ankles at right angles.

12. Popliteal height-sitting: The vertical distance from a footrest surface to the back of the right knee-Measured with an anthropometer. The subject sits with the thighs parallel, the feet in line with the thighs, and the knees flexed 90°.
13. Buttock-popliteal length: The horizontal distance from the rearmost surface of the buttock to the back of the lower leg. The subject sits erect. The thighs are parallel and the knees flexed 90° with the feet in line with the thighs.
14. Functional leg length: Sitting erect on a chair, the subject extends his or her right leg forward with the knee straightened. The distance from the heel of the foot to the posterior waist landmark is measured along the long axis of the leg.
15. Foot length: The distance, parallel to the long axis of the foot, from the back of the heel to the tip of the most protruding toe. The subject stands with weight equally distributed on both feet.
16. Foot breadth: The maximum horizontal distance across the foot, at right angles to the long axis. The subject stands with weight equally distributed on both feet.
17. Instep length: The distance from the plane of the heel to the point of maximum medial protuberance of the foot.
18. Hand length: The distance from the wrist landmark to dactylion. The subject sits with the hand flat on a table, palm up, with fingers together and straight.
19. Hand breadth: The breadth of the hand between metacarpal-phalangeal joints II and V. The subject sits with the hand flat on a table, palm down, with the fingers together and straight.
20. Hand breadth across thumb: The breadth of the hand as measured at the level of distal end of the 1^{st} metacarpal of the thumb.
21. Hand circumference: The circumference of the hand passing over the metacarpal-phalangeal joints II and V. The subject sits with the hand flat on a table, palm down, fingers extended, and thumb abducted.
22. Palm length: The distance from the base of the hand to the furrow where the middle finger folds upon the palm.
23. Grip diameter (inside): Subject holds a cone around the largest circumference that can be grasped with the thumb and middle finger just touching. Record the diameter of the cone corresponding to this maximum circumference.
24. Grip strength: The grip strength of the hand measured with handgrip dynamometer when the subject stands erect with his arms hanging downwards.

25. Maximum grip length: The maximum length between the tip of the index finger and the tip of the thumb while the palm, thumb and fingers are in grip position.

Appendix 4

Pedal operated paddy thresher suppliers / manufacturers participated in this survey from different states of India

Sl. No.	Manufacturer/Supplier	State
1	Banabethi	West Bengal
2	Becon Engineering Corporation	West Bengal
3	Hind Engineering Works	West Bengal
4	JJ Engineering Corporation	West Bengal
5	Maharaja Engineering Works	West Bengal
6	Mahavir Pumps Manufacturing Pvt. Ltd.	West Bengal
7	Master Mill Store	West Bengal
8	Premier Magnetos	West Bengal
9	Sarada Industries	West Bengal
10	Saraswati Engineering Works, Howrah	West Bengal
11	Sharma Engineering Works	West Bengal
12	Sohini Udyog	West Bengal
13	SR Industry	West Bengal
14	Tri-Sakti Industries	West Bengal
15	Dharanee Agrovatoar	Tamil Nadu
16	JK Engineering	Tamil Nadu
17	Thomas International	Tamil Nadu
18	Trima International	Tamil Nadu
19	Amar Agricultural Machinery Group	Punjab
20	Gobind Agro Products	Punjab
21	NKN Mechanical Works	Punjab
22	Raidco Kerala Ltd	Kerala
23	AS Engineering Enterprise	Maharashtra
24	Shree Vyankateshwar Industries	Maharashtra
25	JK Engineering	Uttar Pradesh
26	Agro Vision	Jharkhand
27	Dhol Iron Repairing & Fabrication Works	Rajasthan
28	Kartar Scientific Industries	Haryana
29	Subash Iron & Agricultural Industries	Odisha

Appendix 5

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
यह काम मानसिक रूप से कितना भारी / कठिन था ?

Very Low — Very High

Physical Demand — How physically demanding was the task?
यह काम शारीरिक रूप से कितना भारी / कठिन था ?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
मेरी रफ़्तार काफी धीमी है और काम पूरा करने के लिए और तेजी चाहिए . ऐसा आपको कितना ज्यादा लगा?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
जो काम करना था, उसे करने में आप कितने सफल हुए ?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
अपने क्षमता स्तर से काम करने के लिए आपको कितनी कड़ी मेहनत करनी पड़ी ?

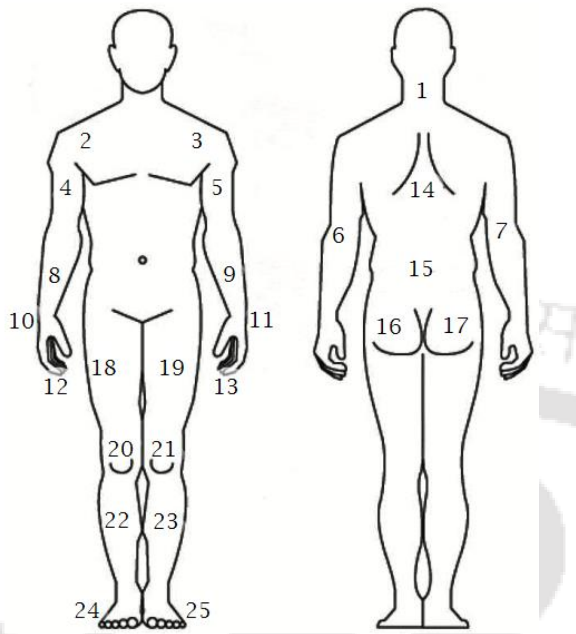
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
काम करते समय आपने अपने आपको कितना परेशान, असुरक्षित, हतोत्साहित, निराश या चिढ़ा महसूस किया?

Very Low — Very High

Appendix 6

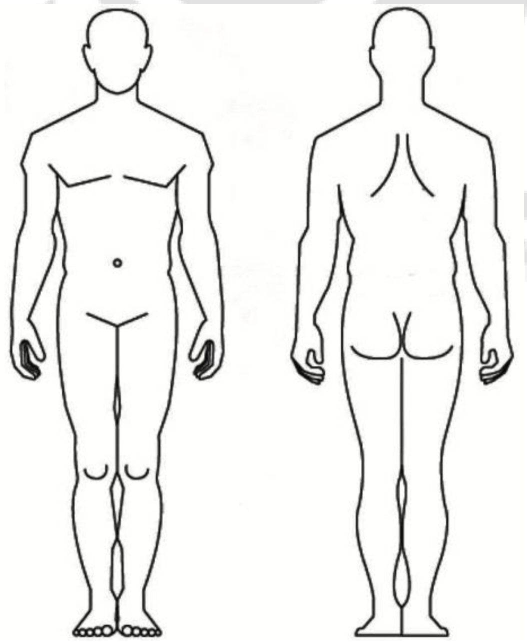
(a) Local Body Part Discomfort



0 : No discomfort
0.5 : Extremely weak (Just noticeable)
1 : Very weak
2 : Weak
3 : Moderate
4 : Somewhat strong
5 : Strong
6
7 : Very strong
8 :
9 :
10 : Extremely strong discomfort

1-Neck; 2- Right shoulder; 3- Left shoulder; 4- Right arm; 5- Left arm; 6- Right elbow; 7- Left elbow; 8- Right forearm; 9- Left forearm; 10- Right wrist; 11- Left wrist; 12- Right hand; 13 - Left hand; 14 - Upper back; 15- Lower back; 16 Right buttocks - ; 17 –Left buttock ; 18 - Right thigh; 19 - Left thigh; 20 - Right knee; 21 - Left knee; 22 - Right leg; 23 - Left leg; 24 - Right foot; 25 - Left foot

(b) Whole Body Discomfort



0 : No discomfort
0.5 : Extremely weak (Just noticeable)
1 : Very weak
2 : Weak
3 : Moderate
4 : Somewhat strong
5 : Strong
6
7 : Very strong
8 :
9 :
10 : Extremely strong discomfort

Please, assign a number (0 to 10) corresponding to your sense of discomfort

Appendix 7

Specification Trigno™ Wireless EMG Systems

Particular	Specification
Typical Operating Range	40 m
RF Frequency Band	240-2483 MHz (ISM)
Power Consumption	<6W (operation)<14W (during recharge)
Sensor Recharge Time	< 2.5 Hours
USB Type	USB 2.0 compliant, high speed
Temperature Range	5-50 degrees Celsius
Maximum number of Sensors	16
Signal group delay	48ms
EMG Signal Range	± 5V
Effective EMG Signal Gain	909 V/V ±5%
Channel Offset (r.t.o.)	± 157 mV (max)
Baseline Noise	<0.5mV RMS
DAC Filter Bandwidth	DC-500 Hz, 160 dB/Dec.
Passband Ripple	< 2% with Sin(X)/X correction
Connector Type	Scsi-68, Type II

Appendix 8

Specification of Polar heart rate monitor

Particular	Specification
Manufacturer	Polar Electro Oy, Finland
Model	RS800CX
Battery type	CR2032
Maximum files	99
Maximum time	99 h 59 min 59 s
Operating Temperature	-10°C to +50°C
Recording interval	1s, 2s, 5s, 15s, or 60s
R-R Recording	Yes, accuracy of 1 ms
Heart rate measurement	bpm, %, and % HRR
Heart rate measuring range	15-240 bpm
Accuracy of heart rate	± 1% or 1 bpm, whichever larger
Data transfer	Compatible with Polar ProTrainer 5 software via IrDA USB Adapter
System Requirements	Windows® 2000/XP/Vista 32/64-bit or Windows 7 32/64-bit IrDA compatible port (an external IrDA device or an internal IR port)

Appendix 9

Specification of Novatech load cell

Particular	Specification
Manufacturer	Novatech Measurements Limited, England
Model	F256
S/N	37073
Minimum load	0.1 kg
Maximum load	125 kg
Temperature range	-10 to +50°C
Repeatability	±0.02% of rated load
Transducer model	TR-200
Type	Microprocessor based
Display Type	LCD display
Input Range	Up ±5mV/V
Electrical Connection	5 pin binder socket

Appendix 10

Kestrel 4500 Weather & Environmental Meter

Particular	Specification
Weight	102g
Display type	Dot matrix LCD with electro-luminescent backlighting
Battery	2 off AAA alkaline, included, user replaceable
Temperature (1 sec response)	
Operational range	-45.0°C to +125.0°C
Specification range	-29.0°C to +70.0°C
Accuracy	±1°C
Relative Humidity (1 min response)	
Operational range	0% to 100%
Specification range	5% to 95% non-condensing
Resolution	0.1%
Accuracy	±3% (when unit allowed to equilibrate to external temperature)
Speed (1 sec response)	
Operational range	0.4m/s to 60m/s (0.8 to 135.0mph)
Specification range	0.4m/s to 40m/s (0.8 to 89.0mph)
On axis accuracy	± 3% of reading or ± 0.1 m/s.
Calibration drift	<1% after 100hrs operation at 7m/s

Appendix 11

List of publications in Journals and Conferences relevant to the present research work

Book Chapter Publication

1. Patel, T., Karmakar, S., Sanjog, J., Kumar, S. and Chowdhury, A. (2013). Digital human modeling for ergonomic evaluation of tractor operator's workplace. In: Ergonomics for Enhanced Productivity. Edited by P. Parimalam, M. R. Premalatha and P. Banumathi. ISBN 978-93-82880-43-1, pp. 203-208, *Excel India Publishers*, New Delhi, India.

International Publications (Peer Reviewed)

Conference Proceeding Publications

1. Patel, T., Sanjog, J., Sahoo, A., Das, B., and Karmakar, S. (2014). Assessment of reliability and technical error of measurement associated with anthropometric data collection. *In Proceedings of International Ergonomics Conference* (HWWE: December, 3-5), Indian Institute of Technology, Guwahati, Assam, India, (p. 769-775), ISBN: 978-93-392-1970-3.
2. Sanjog, J., Patel, T., and Karmakar, S. (2014). Reduction of hand grip strength as an indicator towards discomfort of upper body extremities. *In Proceedings of International Ergonomics Conference* (HWWE: December, 3-5), Indian Institute of Technology, Guwahati, Assam, India, (p. 655-259), ISBN: 978-93-392-1970-3.
3. Patel, T., Sanjog, J., Kumar, P. and Karmakar, S. (2013). Analytical study of isometric muscular strength of agricultural workers: Indian perspective. *International Conference on Ergonomics and Human Factors "Ergo 2013: Ergonomics for Rural Development*" 4th–6th December, Department of Human Physiology with Community Health. Vidyasagar University, Midnapore, West Bengal, India, 56-65.

Journal Publications

1. Patel, T., Sanjog, J., and Karmakar, S. (2015). Isometric handgrip strength of agricultural workers from northeast region of India. *Agricultural Engineering International: CIGR Journal*, 17(1):130-140.

2. Patel, T., Sanjog, J., Kumar, P., and Karmakar, S. (2014). Isometric muscular strength data of Indian agricultural workers for equipment design: Critical analysis. *Agricultural Engineering International: CIGR Journal*, 16(2), 70-79.

3. Patel, T., Karmakar, S., Anthropometric and strength data of Indian agricultural workers for farm equipment design, L. P. Gite et al., (Ed.): International Journal of Industrial Ergonomics, Volume 44, Issue 1, January 2014, Pages 189-190.

4. Patel, T., Karmakar, S. (2014). Introduction to Ergonomics, third ed., R.S. Bridger. Taylor & Francis/CRC Press, *International Journal of Industrial Ergonomics*, 44 (6), 892–893.

5. Patel, T., Karmakar, S. (2014). Automotive Ergonomics: Driver-Vehicle Interaction, Nikolaos Gkikas (Ed.), CRC Press/Taylor & Francis, *Journal of Transport Geography*, 41, 346-347.

6. Karmakar, S., Sanjog, J., and Patel, T. (2014). Digital human modeling and simulation in product and workplace design: Indian scenario. *International Journal of Engineering Research and Applications (IJERA)*, Special issue. pp. 06-12. [ISSN: 2248-9622]

7. Patel, T., Sanjog, J., Chowdhury, A. and Karmakar, S. (2013). Applications of DHM in agricultural engineering: A review. Advanced Engineering Forum, 10, 16-21.

8. Patel, T., Karmakar, S., Sanjog, J., Kumar, S. and Chowdhury, A., (2013). Socio-Economic and Environmental Changes with Transition from Shifting to Settled Cultivation In North-Eastern India: An Ergonomics Perspective. *International Journal of Agricultural Science and Research*, 3(2), 117-136.