ERGONOMIC EVALUATION OF MANUAL AGRICULTURE ACTIVITIES AND DESIGN OF HAND–OPERATED TOOL FOR FARM WORKERS

DOCTOR OF PHILOSOPHY (Ph.D.)

THESIS

BY

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A Doctoral Thesis on

Ergonomic Evaluation of Manual Agriculture Activities and Design of Hand–Operated Tool for Farm Workers

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CERTIFICATE

This is certify that the thesis entitled **"Ergonomic Evaluation of Manual Agriculture Activities and Design of Hand–Operated Tool for Farm Workers"** being submitted by **Rahul Jain (2014RME9036)** to the Malaviya National Institute of Technology Jaipur for the award of the degree of **Doctor of Philosophy** in Department of Mechanical Engineering is a bona–fide record of original research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirement for the submission of this thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

Dr. M. L. Meena

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DEDICATED

To my parents

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ABSTRACT

India is the renowned producers of numerous crops in the world, and there is a significant amount of small–holding farm workers across the country that produces crops using manual implements. Due to high rural area belongings, farming is a major source of employment for a significant amount of population. Health and productivity of the farm workers doing manual agriculture activities are very poor due to traditional tools and systems. Agriculture tasks begin with the land preparation task and end with crop cutting task that is fairly repetitive, time–consuming and strenuous in type. The farm workers face high amount of work–related health problems due to the zero or low level of safety and health education. If appropriate changes/ergonomic interventions applied, these modifications would be beneficial in dropping down/preventing work–related health problems. The current thesis work observes the farming tasks mainly manual agriculture activities, for determining the associated risk factors influencing musculoskeletal system as well as productivity of the farm workers and finding the effects of various postures on grip strength (GS). The ergonomic analysis of the work provides the basis for designing an intervention/tool using standard ergonomic principles.

The current research work is principally distributed into three sections. The first section introduces the ergonomic analysis of the manual agriculture activities in which an effort was made using explicit assessment methods like modified Standard Nordic questionnaire, rapid upper limb assessment (RULA) and rapid entire body assessment (REBA). Approximately 77 % of farm workers reported pain in one or more body parts. Higher RULA and REBA scores for more than 90 % farm workers specified further examinations and modifications in work methods/tools immediately. Different risk factors like age, gender, daily working hours, hand dominance, perceived fatigue and work experience associated with MSDs in one or more body parts, were also determined using logistic regression methodologies.

The second section evaluates the GS of the farm workers. Due to working in the awkward postures (i.e., bent, kneeling, etc.) at various angles on the different handle configurations, farm workers have to exert more force/strength on the existing tools which will decrease the performance level. Therefore, effects of various postures on GS were examined which helps to determine the optimal work settings. This will further result in improving the health as well as performance/efficiency of the farm workers.

The third and last section describes the design and development of the hand–operated tool for weeding activity. The tool was designed virtually as well as physically. Firstly, the

tool was designed and tested in the virtual environment by checking the RULA scores. After testing in the virtual system, the physical design was fabricated finally. The physical design was tested and evaluated in the field by 30 workers for validation of conception. The testing of the tool was done considering few assumptions/conditions. The results of these conditions further evaluated using Taguchi design of experiment method for finding the optimal conditions for tool operation. Also, pre and post effects of the tool were evaluated. The outcomes of these evaluations and the recommendations for future improvement in the work are described at the end of the thesis.

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LIST OF ABBREVIATIONS

ANNOVA	Analysis of Variance
ASI	Archaeological Survey of India
FAS	Foreign Agriculture Service
GDP	Gross Domestic Product
GS	Grip Strength
Ha	Hectare
HICs	High–Income Countries
ILO	The International Labour Organization
LMICs	Low–Middle–Income Countries
LICs	Low–Income Countries
LBP	Lower Back Pain
MMERT	Multi–Method Ergonomic Review Technique
MSDs	Musculoskeletal Disorders
NIOSH	National Institute of Occupational Safety and Health
NRC	National Research Council
OR	Odds Ratio
PI	Performance Index
RULA	Rapid Upper Limb Assessment
REBA	Rapid Entire Body Assessment
SNQ	Standard Nordic Questionnaire
SD	Standard Deviation
S/N ratio	Signal to Noise Ratio

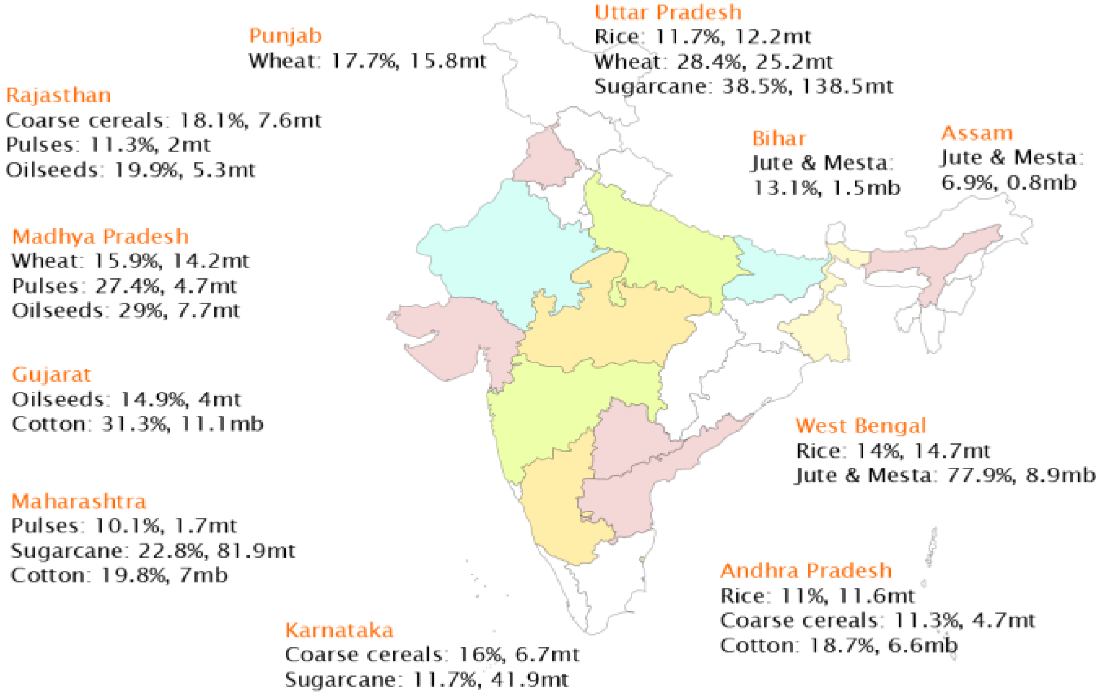
CHAPTER 1

INTRODUCTION

1.1 Background

The farming in India originates long years ago from the era of Indus Valley civilization and slightly earlier in few places of Southern India (Gupta, 2004). Currently India positions second worldwide in terms of farm production. Farming and associated sectors like fisheries and forestry accounted for 13.7% of the gross domestic product (GDP) in 2013, and about 50% of the labour force (Matta and Sharma, 2014). The financial influence of farming to India's GDP is gradually decreasing day by day with the nation's profit expansion. Still, in standings of demographic information, farming is the largest financial region and performs an important part in the total socio–economic structure of the country.

India is in the three highest worldwide producers of various grain and cereal crops, including cotton, fruits, peanuts, pulses, rice, wheat and vegetables. Rajasthan is one of the Indian states which has typically agrarian population throughout the state. Also in terms of production of cereals, pulses and oil seeds, Rajasthan contributes a lot to the country (Figure 1.1).



Source: Annual report 2014–15, Ministry of Agriculture, India

Figure 1.1: State wise distribution of crop production

As per records, India traded 39 billion $ (U. S. dollar) value of agricultural products, attaining it the seventh leading agricultural exporter internationally (FAS, 2013). The second largest cultivated land is available in India after United States (159.7 million hectares) and its total irrigated harvest zone of 82.6 million hectares is biggest in the world.

Farming is the labor intensive sector of India. The farm workers are more exposed to work–related health problems than other advanced or organized sector workers due to various type of strenuous operations. Farm workers are involved in a different kind of work that includes repetitive jobs in awkward postures at low paid rates for the long duration which causes various work–related health problems. Regarding health concerns, farm workers usually have more types of work–related health issues such as anxiety and stress disorders, carpal tunnel syndrome, infectious and parasitic diseases, respiratory diseases, and tendonitis compared to organized sector workers (Saiyed and Tiwari, 2004). Also, to increase yield/production amount the farm workers depend on the existing tools and techniques in the farms. Working with these conditions (Figure 1.2) is not safe for the farm workers as reported by various Indian studies (Gangopadhyay et al., 2008; Das et al., 2013; Das, 2015) in which work–related health problems are common.

Figure 1.2: Farm workers during the various manual agriculture activities (a) women working with sickle in squatting posture, (b) men working with spade during spading activity, (c) men working with long handled hoe during ginger harvesting

Work–related problems are the physical and sensitive reactions that occur when the conditions of the work do not meet the capabilities, resources or the requirements of the worker (Saiyed and Tiwari, 2004). In farming work, various type of operations require high energy demand (Nag and Nag, 2004). Due to these indications, it is evident that ergonomic investigation needs to be done to safeguard job demand–fitness–compatibility with the aim of making the operations more humane according to the various occupations requirements. Musculoskeletal disorder (MSD) may be chosen as a major stressor constraint which is stated as a condition where the farm worker experiences discomfort in the elbow, hand, hip, knee, neck, low back, and shoulder, also multiple joints displaying ache, pain, swelling and tingle. The economic/financial loss due to these type of disorders influences not only the individual but also the company/industry/sector and the society/country as a whole. Work–related health is a situation where the work–related factors correlate with human factors in such way that the people deviate from normal working. Therefore, better work–related health is clearly associated with health and safety knowledge of the workers. In normal situations, work–related health problems appear as an unavoidable portion of working lifecycle. A solid connection exists among the work–related pressure of farm workers and productivity. According to report of National Institute of Occupational Safety and Health, occupational stress is the unsafe physical and emotional reaction that happens when the desires of the operations do not match with the skills, resources or the requirements of the employee. As per few reports of nineties, around 120 million work–related accidents and 2 lakh mortalities worldwide were projected to happen yearly (Niedhammer, et al., 1998). The common work–related problems associated with the farm workers are MSDs are described in Figure 1.3.

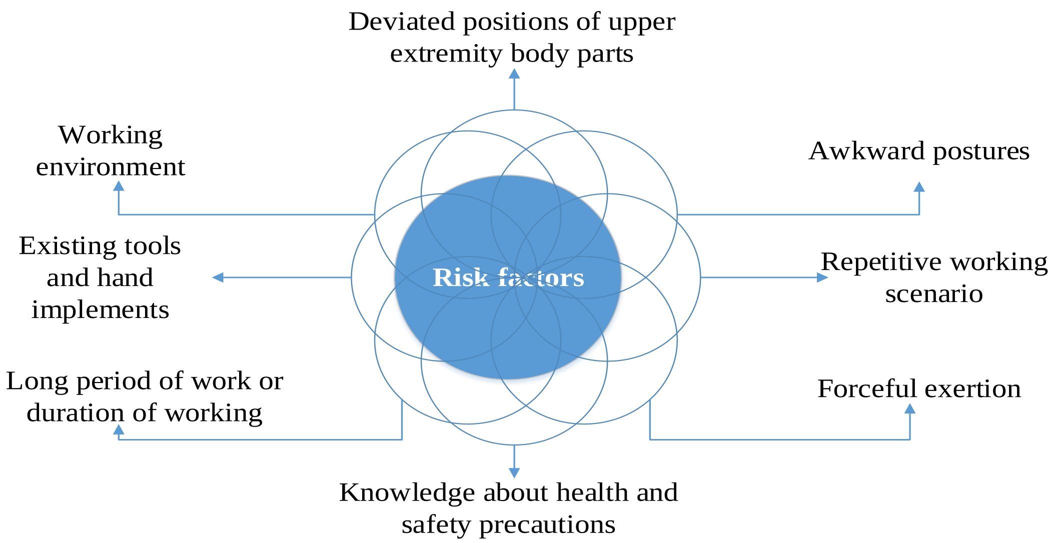


Figure 1.3: Risk factors for MSDs in farming occupation

Presently, work–related MSD is one of the most important issues found by researchers/ergonomists at work globally. Multiple ergonomic methods have been researched to reduce the work–related health problems in various type of work settings in India. However, agriculture farm workers are still more prone to the work–related health concerns. These risk factors further develop disabilities if no prevention strategies are followed. The current policies/regulations also do not safeguard the majority of farmers. The ergonomic risks associated with manual activities are mostly due to the incorrect methods and un–ergonomic design of tools used at work. These design issues and poor safety/health knowledge are the primary causes of specific work–related health problems such as different type of MSDs among the workers. The MSDs are similar to 4–point of fire as presented in Figure 1.4. The concentration of any one of the factors i.e., environment, fuel, heat and oxygen or combination of any one or more may causes fire, similarly combination of any one of the MSDs risk factors, i.e., various positions of body parts, force exertion, pain frequency and postures (sitting or standing) causes the MSD risks.

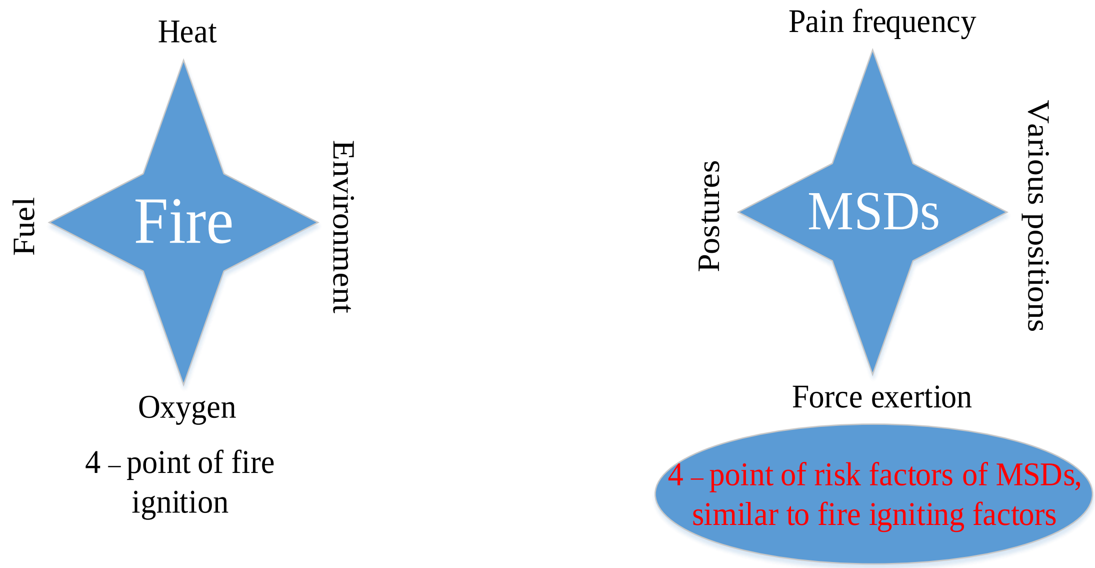


Figure 1.4 MSDs risk factors similar to 4–point ignition of fire

The principle aim of ergonomics is to attain an optimum solution for individuals and their working conditions. The different issues in this working procedure are workers' productivity and physical well–being (Kuoppala et al., 2008). A strong association exists among the worker's comfort and productivity. In the real environment, it may be achieved by ergonomic intervention. Ergonomic intervention in design improves work performance and overall health. For ergonomic design, the study of risk factors in work setting, identification and reducing the associated risks in a planned way could be the right method (Muzammil et al., 2011). The intervention/tool is designed preferably to increase productivity with efficiency and comfort; most of the health issues and injuries are generated due to unexpected actions which will be reduced with the help of appropriate planning and design of work (Grote, 2014). Gangopadhyay and Dev (2014) discussed various cases of interventions and their effectiveness for reducing the MSDs, also different physiological working situations improved after correcting the awkward postures.

Ergonomics interventions intended for enlightening working conditions at both the level of people (micro) and work group (macro). Obviously, these points are interrelated with each other. In recent years, there has been a growing work to examine the reasons of work–related health problems (pain in various body parts) and prevention actions. The knowledge of ergonomics and its treatment applications to these difficulties that related with the new technological advancement offer both a significant viewpoint and a preventive method to modify working tools design as described in Figure 1.5 may be utilized.

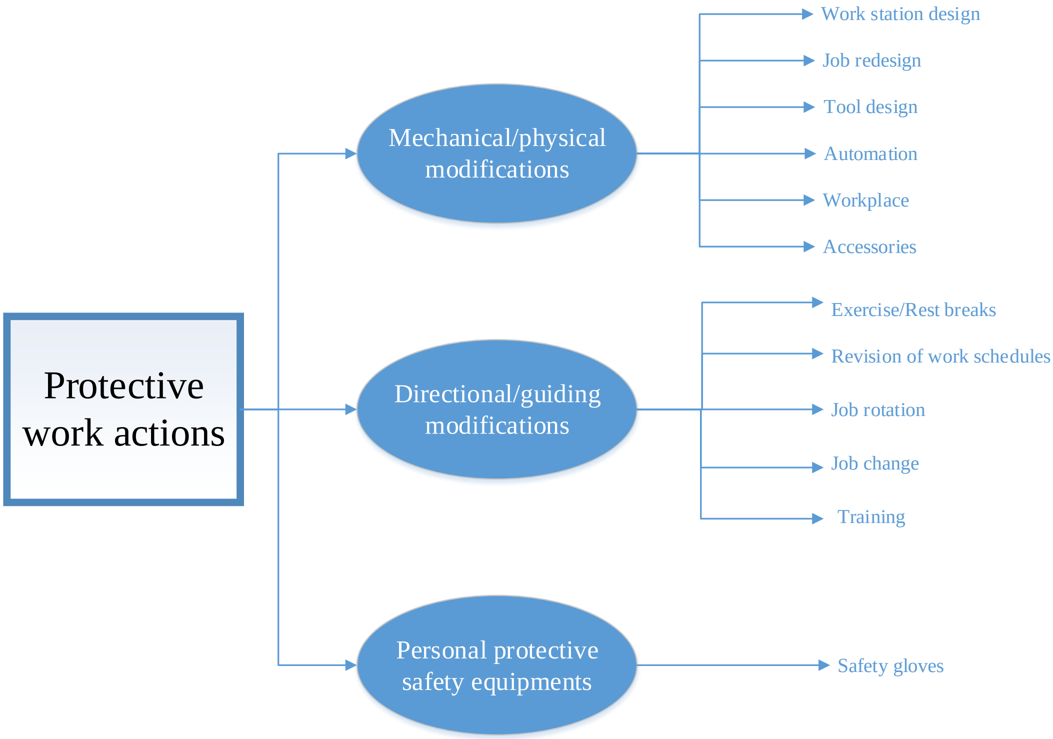


Figure 1.5 Protective work actions for MSDs prevention: path for intervention/tool evolution approach followed in current research

Through these philosophies in notice, the detailed goal of the current research was to develop and assess an ergonomic intervention/tool for the prevention/reduction of upper extremity injury risk in workers of the selected occupation (farm workers involved in manual agriculture activities).

1.2 Motivation for the research

In today's world of occupational work load and productivity, improving work and working condition is necessary. In most of the industries, safe work settings are considered as a vital source for excellent work–related health which can help in improving the productivity and quality of industries. It can be assumed that musculoskeletal difficulties can be decreased by improving the biomechanical and psychosocial load at work. In recent time, various researchers and organizations have started to consider humanizing workplace/work tool design which will improve the health of worker and safety at work. In spite of high occurrence rates of MSDs, the sources and paths of development are not completely identified. Numerous factors (individual, work–related, and psychosocial) have been linked with MSD development. However, significant implications are not available because of less investigation on farm workers involved in manual agriculture activities in the reported literature. There is an absence of research and schemes for intervention in the area of manual agriculture activities which includes various issues that need to be resolved. The prominent issues are as: development of multi–faceted ergonomic intervention, risk factors for musculoskeletal disorders (MSDs) and posture analysis of farm workers involved in manual agriculture activities and working on different type of handles in various postures.

1.3 Aim and objectives of research

The current research primarily concentrating on the recognition of risk factors for MSDs, effect of various postures on grip strength (GS) have been introduced; that could be helpful for design, development and evaluation of ergonomic intervention/tool for manual working. The key aim of the current research is to design, develop and evaluate the ergonomic intervention/tool for preventing MSDs during manual agriculture activity. The specific objective of this research is given below.

I. To determine the risk factors for MSDs generation among farm workers doing manual agriculture activities.
II. To analyse the posture and hand tools used by farm workers.
III. To find out the effect of various postures on the GS.

IV. To design, develop and evaluate an ergonomic intervention/tool for farm workers.

1.4 Research hypothesis

During the initial visits of farms located in the eastern Rajasthan, various problems associated with work–related health and productivity were observed (i.e., pain incidence among the farm workers involved in manual agriculture activities and its other effects). Literature scarcely described any detailed research describing the above defined problems and, furthermore, farm workers commonly using the traditional methods and tools without carrying about the difficulties faced during the manual agriculture activities.

Thus, two exact issues were considered to be solved. Initially effort was completed to determine the prevalence of MSDs and association of the risk factors with MSDs among farm workers involved in manual agriculture activities that might offer indication for developing intervention/tool emphasis and furthermore, work was completed to lay down a policy for creating a solution to enriched performance of the farm workers. Hence, two hypotheses were bordered, as stated underneath, to work upon.

H1: Work–related health issues are prevalent among farm workers involved in manual agriculture activities in eastern Rajasthan with extreme amount of ergonomic risks.

H2: A planned intervention/tool design through ergonomic principles can adjust the work–related health problems and productivity of the farm workers employed in manual agriculture activities.

1.5 Thesis structure

As per the subject of the research and sequential representation of work done throughout the research, the thesis is separated into six different chapters which are as following:

Chapter 1 comprises with introduction of the research work and showcased the aim and objectives of the current work.

Chapter 2 contains a literature review related to risk factors of MSDs development, different type of interventions and terminology used for design of interventions. The chapter sum up the literature at the end and research gaps were identified to built–up a framework for achieving the aims and objectives of research.

Chapter 3 is dedicated to the methodology used in the current research. In broad form, this chapter deals with the questionnaire formulation, pilot and main investigation of research, target population and sample, methods of data collection and statistical analysis.

Chapter 4 presents the primary goal of research work which is divided into two parts as follows:

a. To determine the MSD occurrence in upper extremity regions among farm workers involved in manual agriculture activities. The relationship of MSDs to individual and work–related factors also determined to find out the risky factors. The risk level for manual agriculture activities in stooped postures were evaluated using the rapid upper limb assessment (RULA) and rapid entire body assessment (REBA) methods.
b. The effects of various postures on GS were analysed which helped to find out the suitable working condition during manual agriculture work.

On the basis of risk identification and suitable working condition for manual agriculture work, an intervention/tool was designed using ergonomic principles which will be discussed in *Chapter 5*.

Chapter 6 offers summary, findings, limitations/drawbacks of the current research and scope for future work.

CHAPTER 2

LITERATURE REVIEW

The chapter outlines the outcomes of literature review on farm workers involved in manual agriculture activities and intervention design for musculoskeletal disorders (MSDs) prevention, and attempts to determine the gap for research in the area through various literary works which provides solution pathway in this course. From the previously published literature and renowned work reported in context of India, it was clear that farm working is a main occupation industry in the country. On the basis of the conclusions of these works, an attempt was accomplished to discover the work done. Initially, ergonomic researches of agriculture sector conveyed in literature were studied. Then, the interventions in the farming field together with manual farm working were reviewed. Also, research was done to find out the necessary points considered during the intervention design and implementation. The main purpose of literature evaluation is to done the comprehensive research for the current area of themes, by means of an origin for finding areas in which further research would be beneficial. The approach utilized for the literature evaluation is demonstrated in the Figure 2.1.

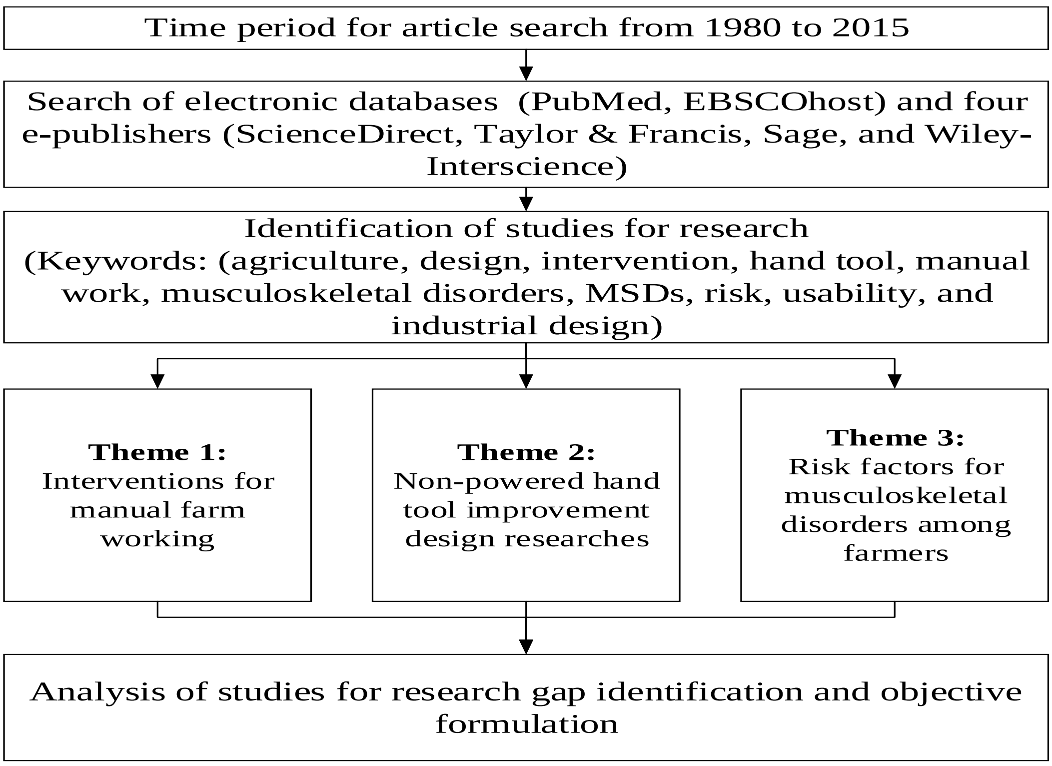


Figure 2.1: Approach of literature evaluation

The literature search is carried out in various databases and e–publishers using selected search terms (‘agriculture’, ‘design’, ‘intervention’, ‘hand tool’, ‘manual work’, ‘musculoskeletal disorders’, ‘MSDs’, ‘risk’, ‘usability’, and ‘industrial design’). The above searched articles than classified in the three main themes (Figure 2.1) for description of the reviewed articles which is discussed in the upcoming sections.

2.1 Interventions for manual farm working

Farming is more prone to occupational hazards and risks due to less technical development presently. The scientific literature regarding prevention of MSDs and other occupational health risks in agriculture have recognized in various studies. Agricultural research (Masters et al., 1998) plays a significant role in raising 21 agricultural productivity. There is a huge amount of literature available in agricultural research for MSDs (Meyers et al., 1997; Alene and Coulibaly, 2009) and technology in productivity growth (Khidiya and Bhardwaj, 2012). If numbers of accidents are examined agriculture ranks among three most hazardous sectors (Somavia, 2003).

Several reviews in agriculture published are distributed as ‘ergonomic intervention in agriculture’ (Deroo and Rautiainen, 2000; Schuman, 2002; Hartling et al., 2004; Kirkhorn et al., 2010) and ‘status of safety, production at agriculture farms in developing countries’ (Rogan and O'Neill, 1993; Rainbird and O'Neill, 1995; Nag and Nag, 2004). Prior to attempting this review for the role of interventions in agriculture, two systematic reviews (Deroo and Rautiainen, 2000; Hartling et al., 2004) are identified as a base. These reviews concluded that some ergonomic design initiatives must be taken for improving knowledge, attitudes and behaviours toward the farm safety.

Some of the research question was used for categorizing the articles. These questions are as follows: (a) Keyword related to ergonomics, (b) country– and crop–wise distribution, (c) targeted problem for developing intervention, and (d) intervention tools used.

2.1.1 Research distribution

The distribution covers several scientific disciplines, including MSDs, occupational health and safety risks, industrial design, ergonomics, and hand tool design. A big number of methods on hand tool design, a different type of education programs supporting the farm environment. Figure 2.2 shows that maximum studies lie in the three keywords industrial design, intervention development and evaluation, and farm health and safety.

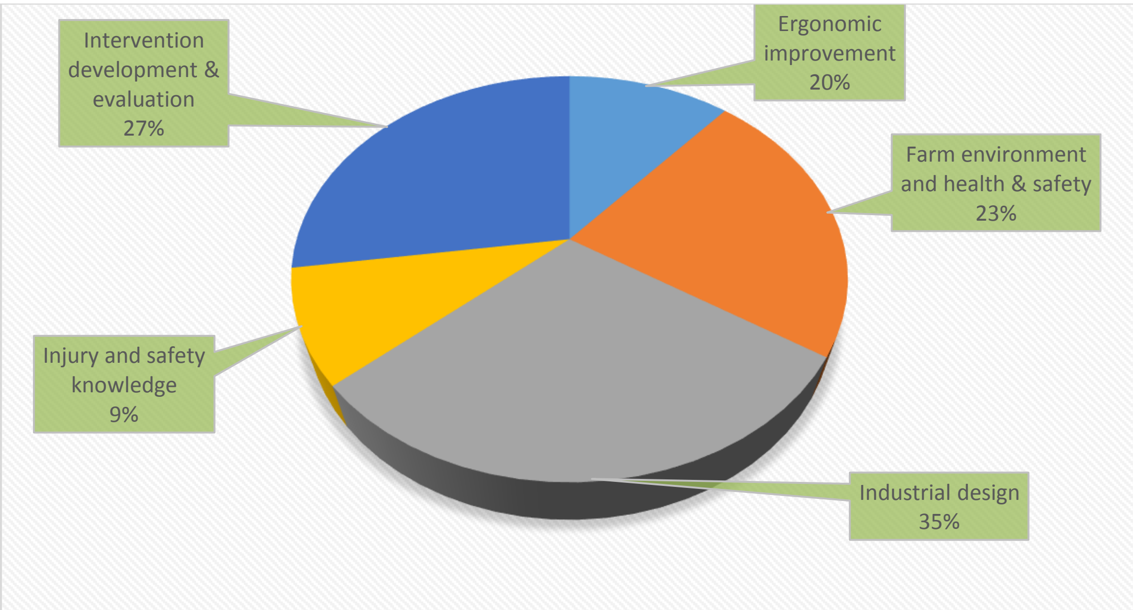


Figure 2.2: Keywords wise distribution of research work

Also, research was distributed according to the type of interventions which is presented in the Table 2.1.

Table 2.1: Classification of interventions according to earlier literature (N = 47)

S. no.	Major category	Reference
1.	Engineering interventions (n = 32)	Nag et al., 1988; Gite, 1991; Tewari et al, 1991; Janowitz et al., 2000; Sutjana et al., 1999; Sutjana, 2000; Earle–richardson et al., 2005; Earle–richardson et al., 2006a; Earle–richardson et al., 2006b; Freivalds et al., 2006; Kato et al., 2006; Miller and Fathallah, 2006; Ramahi and Fathallah, 2006; Tang et al., 2006; Yadav and Pund, 2007; Goel et al., 2008; Kumar et al., 2008; May et al., 2008; Kotowski et al., 2009a; Kotowski et al., 2009b; Vanderwal et al., 2011; Yoo et al, 2011; Bhattacharyya and Chakrabarti, 2012; Costa and Camarotto, 2012; Khidiya and Bhardwaj, 2012; Kishtwaria and Rana, 2012a; Kishtwaria and Rana, 2012b; May et al., 2012; Singh et al, 2012; Bao et al, 2013; Karsh et al., 2013
2.	Educational interventions (n =7)	Adiputra et al., 1995; Landsittel et al, 2001; Chapman et al., 2004; Morgaine et al., 2006; Stave et al., 2007; Chapman et al., 2008; Vyas, 2012
3.	Personal protective equipment interventions (n = 3)	Forst et al., 2004; Abrahao et al., 2012; Earle–richardson et al., 2014
4.	Multi–faced interventions (n= 3)	Rautiainen et al., 2004; Mehta et al., 2012;Tovar–Aguilar et al., 2014
5.	Other type of intervention (n =2)	Rautiainen et al., 2005; Faucett et al., 2007

Country–wise and crop–wise distribution of the studies also carried out which is shown in Figures 2.3 and 2.4.

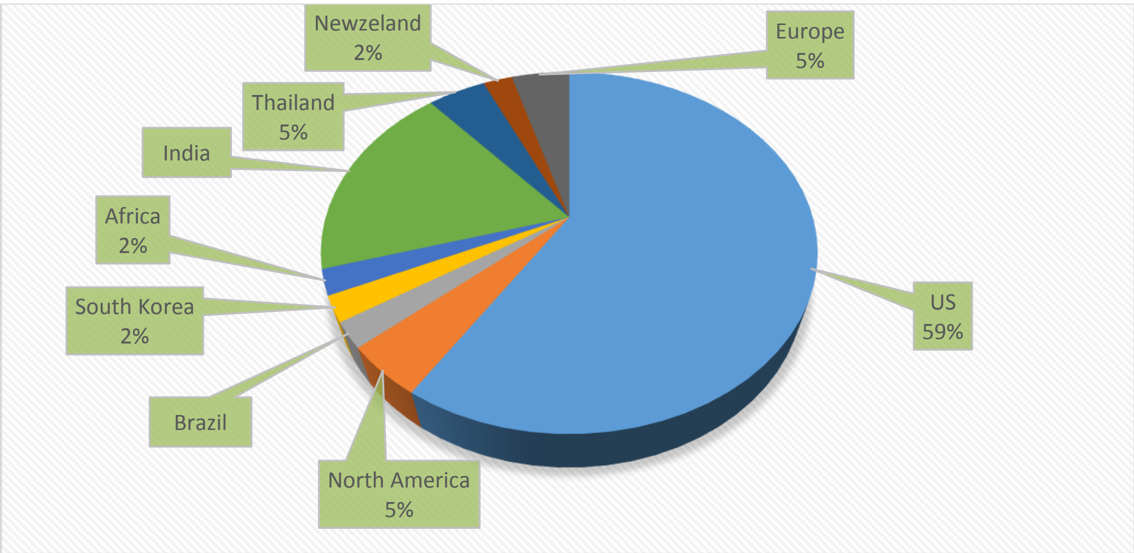


Figure 2.3: Country wise distribution of research work

The maximum study is found in the US, so there is the need for such studies to be done in the developing countries (DC) like Africa, India, some more Asian countries, etc.

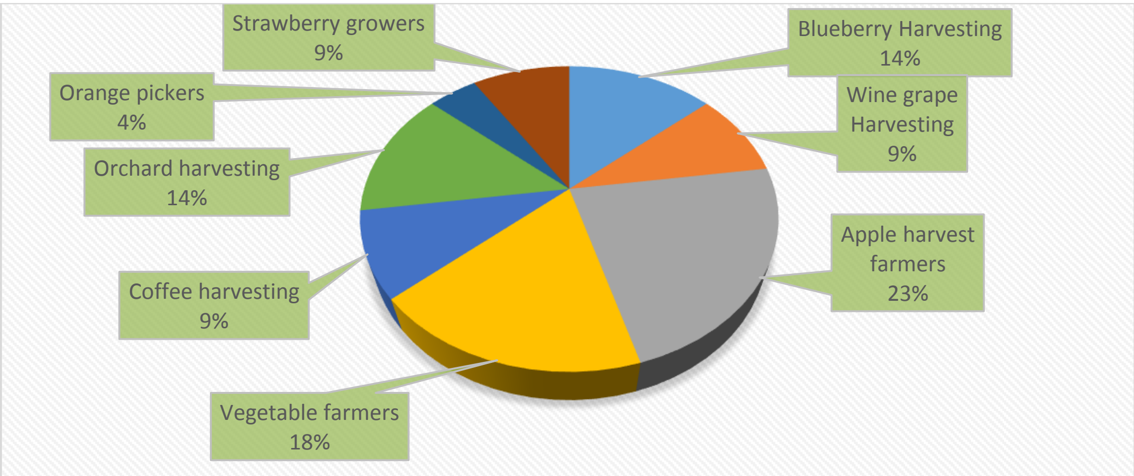


Figure 2.4: Crop wise distribution of research work

Figure 2.4 shows the crop–wise distribution of 63 studies out of which most of the intervention researched for apple crop farmers.

2.1.2 Targeted risks in agriculture

Many researchers and organizations (ILO, World Bank, NIOSH, etc.) claim that agriculture farmers have various problems related to MSDs and other occupational health risks. The selected studies used for solving various problems are presented in Figure 2.5 which closely related to the MSDs and other occupational risks associated with the farmers.

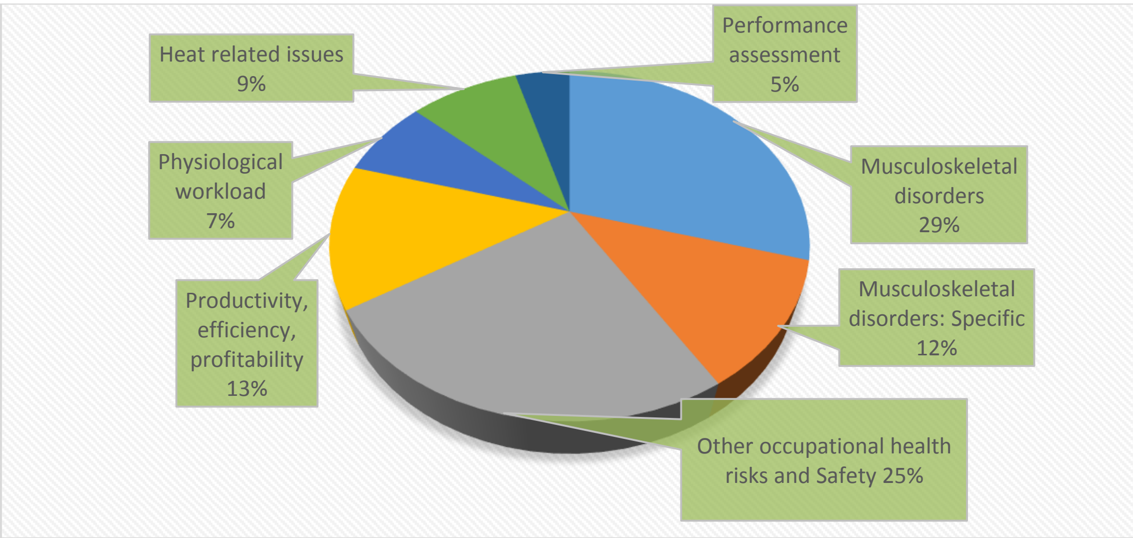


Figure 2.5: Targeted problem during intervention development wise distribution of research work

2.1.3 Intervention developed

This literature covers descriptions of various methods and tools developed in the farm environment. Figure 2.6 classifies using general approach used in the study as the design, educational training, and some other type of improvements like the new system, some simulation studies, wage and incentive studies, etc.

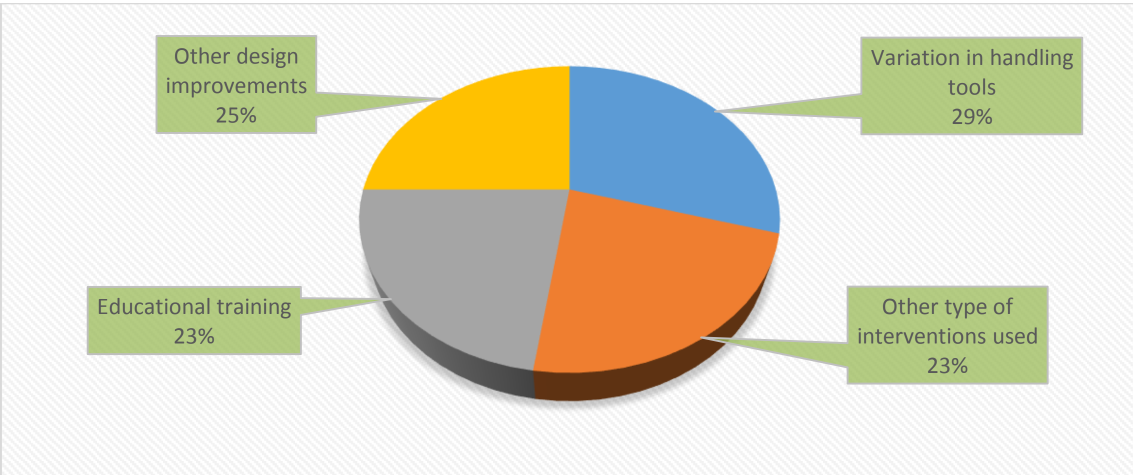


Figure 2.6: Intervention tool development wise distribution of research work

For the future research, two priorities can be raised for critical comments of the reviewed studies. At first, for the improvement of the quality of research, these elements are necessary: use of existing knowledge for design and development, use developed studies for a particular activity or on–farm environment, and effectiveness of study for prevention of various problems should be checked properly. Second, it was important to develop such strategy for effectiveness research, so that complete intervention system can be evaluated. Occupational health and ergonomic intervention research in Agriculture farms is a well–known field of study. Most of the information taken from the literature, although it is needed to check the quality of the research on the basis of existing knowledge of methodological assessment tool. Among all the options available, it was important to develop cost–effective programs and framework that can be applied to larger scale quickly.

2.2 Design considerations for non–powered hand tools

Work–related health problems are produced from repetitive working in uncomfortable postures using traditionally hand tools (Mital, 1991; NRC, 2001). Mostly upper extremities are the commonly damaged body part among workers utilizing traditional hand tools. The forces employed due to repetitive movements, uncomfortable postures and traditional hand tools are primarily responsible for damages (Kilbom et al., 1993; Nejad et al., 2013). MSDs in conjunction with design discrepancies affect the workers, the organization and the nation's economy by growing disability, discomfort and well–being care expenses, as well as reducing comfort and productivity (Kuijt–Evers et al., 2004; Das et al., 2005; Marsot, 2005; Motamedzade et al., 2007; Dianat et al., 2015). Hence, these adverse outcomes need to be improved by employing ergonomic principles at organizations/nations/work. If employed, these variations would be very effective in decreasing work–related health difficulties.

Numerous strategies (Mital and Kilbom, 1992a; 1992b; Dababneh et al., 2004) have been established to teach researchers in improving safety at work ergonomically. The International Labour Organization (ILO), the Canadian Centre for Occupational Health and Safety (CCOHS), and the US Occupational Safety & Health Administration (OSHA) have also established various strategies for well–being at work. Work–related health problems persist in lower–income–countries (LICs) and lower–middle–income–countries (LMICs) because of inadequate chances present for workers to utilize ergonomically developed tools. Similarly, the maximum industries in these nations employ workers who do not have appropriate level of knowledge/education to use ergonomic philosophies and safety strategies at work. Hand tool interventions are commonly recommended as a necessary tactic to diminish work–related health issues (Das et al., 2005; Marsot, 2005; Motamedzade et al., 2007; Hsu and Chen, 1999; Mirka et al., 2009; Adeleye and Akanbi, 2015).

Investigation connected to the agriculture and allied sectors was testified largely in LICs and LMICs because of the larger dependence of the people on these sectors. Productivity performs an important part for the labours in these sectors as their earning depends on productivity and is very low due to high level of heavy labour and fatigue engaged. Hence, to improve employees' earning/productivity, work–related health problems and fatigue want to be decreased. In high–income countries (HICs), the study on non–powered tools in these areas was noticed to be inadequate as the maximum work is automated. The manufacturing sector appears to have secured more significance in HICs as the industries in these nations are more planned. Also, legislative rules encourage them for well–being and safety at work (e.g., OSHA, CCOHS, etc.).

Most of the research studies targeted MSDs as major health problems. Also in some studies (Motamedzade et al., 2007), specific MSDs like upper limb disorders, carpal tunnel syndrome and ulnar deviation were targeted. A few studies have targeted other health problems like blisters, sprains, swellings, etc. Very few researches highlighted cost and materials in the category of product factors, since the hand tool enhancement–related work is frequently done in HICs where the cost of a tool does not create any issue. Instead, in LICs and LMICs the cost of a tool can be likely to be an important aspect for examination. Thus, this aspect needs to be considered during hand tool design. Several investigators have worked on variation in tool features as per the employee's anthropometry, comfort and work stresses.

Literature discloses that there is insignificant investigation connected to hand tool modifications in LICs. Similarly, less investigation is discovered in LMICs, but in the agriculture area only. It is expected that the current research will encourage investigators to develop tools and workplaces utilizing ergonomic philosophies in LMICs and LICs. Papers linked to ergonomic modification in tools and inhibition of certain precise MSDs is inadequate. Therefore, the industries which use old approaches at work want more importance on ergonomic modification in tools. The current research specifies that there are numerous factors which can be altered to change tools ergonomically. Furthermore, the efficacy of change can be determined by flexibility in the setting and necessities of the product, tasks and employee. Certain significant features of the process/task that are described in the literary works have been accumulated in the current research. In the background of human–hand tool system factors, different aspects have been combined, which can be useful for changes in non–powered tools (Table 2.2). Product and qualitative factors are described as the important factors in the literature.

Table 2.2: Variables for human–hand tool system design

Human–hand tool factor	Aspect
Human factor	Biomechanical stress; muscular load, strain, effort, activity
	Blisters; high force exertions; pressure points; wrist movements
	Applied force; torque; pinch force and efficiency
	Age, gender, isometric strengths, anthropometric variables
Product factor	Tool properties (length, diameter, height, sharpness, weight etc.)
	Cost and material of tool
	Grip properties (gripping capability, size, force, span, length, strength)
	Handle properties (sharp edges, length, weight, cross section, diameter, slipperiness, shape,)
	Blade properties (coatings, length, height, thickness, stiffness, curvature, sharpness, life, shape, length, diameter, grip, hardness)
Task factor	Working posture, awkward wrist postures
	Repetitive motions, wrist and finger strain
	Tool opening angle, orientation
	Working stress or area
	Lifting angle, surface angle, work height
	Physical workload
	Cutting velocity
Qualitative factor	Comfort, discomfort, satisfaction
	Functional, fit, usability
	Boredom, fatigue, rest
	Efficiency, performance, productivity
	Incentive, income, maintenance, training, working hour
	Vibration
	Tactile feel, ease in use
	Appearance, colour, dullness

2.3 Risk factors for MSDs

Presently, work–related problems are the most significant difficulties found in various sectors worldwide. In various nations, preventing/reducing these problems are considered as a nation–wide importance. The financial damage because of those issues not only disturbs individual working but also the companies and nation/society all together. These work–related problems are not current issues. Long years ago, in year 1706 Bernardo Ramazzini, an Italian physician believed as the founder of occupational–health, described that poor working environments is responsible for numerous risk factors of MSDs (Najarkola, 2005). The World Health Organization (WHO) has considered work–related stress as multi–factorial in feature. A variety of risk factors e.g., physical, psychological, work characteristics, individual characteristics and socio–cultural matters generate the work–related health problems. The intensity of risk changes according to the period a worker is subjected to risk factors, the incidence at which they are subjected, and the level of the risk. Figure 2.7 displays the outcome of MSDs due to various risk factors.

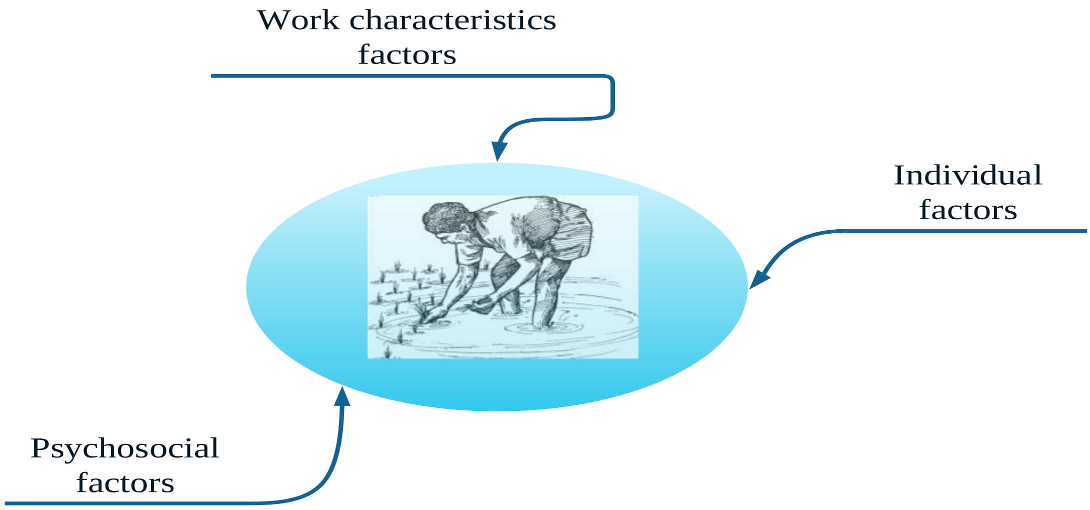


Figure 2.7: MSDs as outcome of relations between various factors with reference to manual agriculture activity

Farming is a substantially difficult profession with difficult operations that generates MSDs (Gomez et al., 2003) which includes damages in bones, cartilages, joints, ligaments, muscles, nerves, spinal discs, and tendons, and can integrate carpal tunnel syndrome, connective tissue injuries, pain, sprains, strains, soreness, and tears (Da Costa and Vieira, 2010). The acute MSDs for long duration generates long–standing pain and disability/ill–health (Woolf and Pfleger, 2003). Lifespan occurrence and 6–month occurrence amounts for farm workers involved in manual agriculture activities are very extreme (Ng et al., 2014). Besides affecting from pain, sickness and injury, they can also confront to various problems like decreased work–ability and, accordingly, decreased farm earning (Whelan et al., 2009), deprived work life for example imperfect social communication rising from MSD decreased movement, and the beginning of other work–related health issues (Lizer and Petrea, 2008).

The contribution of individual and work parameters behind the development of MSDs reported on farm workers in LMICs (Ng et al., 2014; 2015) was insufficient. Ng et al. (2015) indicated that smaller daily work and lengthier breaks during work duration increased the risk of disorders in neck and shoulders among harvesters. In one more study form Ng et al. (2014), they analysed the association of productivity loss and quantity of daily work with MSDs and found significant results. Various researches in HICs also investigated the risk factors for MSDs (Xiang et al., 1999; Park et al., 2001; Gomez et al., 2003; Sprince et al., 2007; Shipp et al., 2009; Nonnenmann et al., 2010). Maximum studies have targeted back pain for investigation (Xiang et al., 1999; Park et al., 2001; Sprince et al., 2007; Shipp et al., 2009), additional studies explored the whole body (Gomez et al., 2003; Nonnenmann et al., 2010). Age and years of working are found common risk factors in these studies (Table 2.3).

Table 2.3: Risk factors identified in the farmers

Body region	Reference	Risk factors	OR	95 % CI
Lower Back	Xiang et al., 1999	Depression	3.68	2.23–6.09
		Farming/ranching as occupation	1.66	1.17–2.36
		Worked in agriculture for 10 to 29 years	1.62	1.14–2.30
	Park et al., 2001	45–59 years of age	2.13	1.02–4.43
		Having a non–agricultural job as the major occupation	2.02	0.98–4.17
	Sprince et al., 2007	Age less than 45 years	3.32	1.75–6.20
		Doctor–diagnosed asthma	4.26	1.49–12.10
		Education beyond high school	2.12	1.13–3.90
		Difficulty hearing normal conversation	1.98	1.02–3.80
	Shipp et al., 2009	Age	1.03	1.00–1.06
		Depressive symptoms while migrating	8.72	1.80–42.25
		Fewer than 8 hours of sleep	2.26	1.16–8.12
		Fairly bad/very bad quality of sleep while migrating	3.25	1.78–10.25
		Sorting crops at work	0.18	0.06–0.55
		Working tree crops	11.72	1.91–79.44
	Nonnenmann et al., 2010	Tractor use	2.41	1.03–5.67
Wrist/ Hand	Nonnenmann et al., 2010	Tractor use	2.89	1.28–6.56
	Gomez et al., 2003	Age	1.10	1.02–1.19
Upper back	Nonnenmann et al., 2010	Number of years working on farm	3.07	1.17–8.04
Neck/ Shoulder	Gomez et al., 2003	Age	1.10	1.02–1.19
Hip	Gomez et al., 2003	Age	1.30	1.19–1.34
Knee	Gomez et al., 2003	Age	1.24	1.15–1.34

Some studies reported type of occupation, long hour tractor use for generation of MSDs (Xiang et al., 1999; Park et al., 2001; Nonnenmann et al., 2010). The relative contribution of risk factors may vary among LMICs, LICs and HICs. However, evidences revealed that individual and work parameters are important aspects of MSDs development (Davis and Kotowski, 2007; Kirkhorn et al., 2010). More research investigating risk factors for upper and lower extremities is needed as fewer studies have considered these regions.

2.4 Ergonomics and anthropometry

Ergonomics is the logical investigation of the connection among an individual and work. The application of ergonomics is particularly concerned with the design or redesign of working method, equipment and physical as well as organizational environment within which work takes place. The various capabilities and limitation of human–beings are also studied so that working people may be integrated into a well–planned human–machine system in order to increase their efficiency and satisfaction without jeopardizing their health and safety, thus heightening the quality of life of the human beings in work conditions.

India is a vast agricultural nation with the total cultivated area of about 142 million hectares (Ha). The human workforce involved in agriculture is about 241 million and amounts to 52 % of the total workers in the country. The traditional agriculture utilize mainly manual and animal power whereas use of mechanical power has also come up in the recent past. Equipment for different agricultural operations and suitable for manual, animal and mechanical power are commercially available in the country and many more are being developed in various research organizations. Many times it is observed that occupational disease, and low levels of productivity are the result of inadvertent neglect of ergonomical aspects in the design of equipment or workplace layout (Tichauer, 1978; Grandjean, 1989). Therefore, ergonomics has a very important role to play in the design and use of agricultural equipment for better performance as well as more human comfort. The annual investment in farm equipment industries in our country is about Rs. 50,000 crore. In tractor industries alone the investment is more than Rs. 10,000 crore per annum. There are more than 20,000 manufactures of agricultural machineries of which about 500 are in medium and large scale sector manufacturing tractors, combines, power tillers, pump sets and plant protection equipment, and village artisans manufacture other equipment/machines. Agricultural workers operate all these equipment. Therefore, to achieve enhanced performance and efficiency of human–equipment system along with better comfort and safety of operators, it is necessary to design tools, equipments and work places keeping in consideration the body dimensions and strength capabilities of agricultural workers.

2.4.1 *Anthropometry*

Anthropometry is the technology of measuring various human physical traits as size, mobility and strength, whereas engineering anthropometry is the effort to apply such data to design of equipment, workplace, and clothing to enhance the efficiency, safety and comfort of the operator since human machines interface decide the ultimate performance of the equipment/work systems. Anthropometric measures vary considerably with factors such as gender, race, and age playing a dominant role in this variability. The application of anthropometric data is, therefore, controlled largely by the anticipated user population. In Indian agriculture about 42 % of the workforces are women. Therefore, it is extremely important to give due conservation to gender issues while collecting the anthropometric data.

2.4.2 *Availability of anthropometric data*

In western countries a large amount of anthropometric data is available for reference and use. The anthropometric data bank assembled and maintained by the Aerospace Medical Research Laboratories, Dayton, Ohio (USA) is the largest single repository of raw anthropometric in the world. It contains data on US army and air force personnel as well as civilians. Some data for foreign populations are also available in the NASA data bank. ERGODATA is another data bank located at anthropology laboratory of Paris, University of France. It mostly contain European anthropometric data. In India, anthropological survey of India has been involved in anthropometric data collection since 1945. The main aim of these surveys has been to collect data on morphological characteristics of various population groups for anthropological studies. A project on all India anthropometric survey was initiated by Archaeological Survey of India (ASI) in 1961 and continued till 1969. During this period data on 60,000 male participants of about 300 different casts/tribes/communities throughout the country were collected. The body dimensions in this survey included stature, sitting height, weight and few other dimensions. During 1972–1980, an All India Bio–Anthropological survey was carried out by ASI to get baseline information of Indian population in terms of their physique, bodily disabilities, diseases, and anomalies, demography and food habits. In this survey only three body measurements viz. stature, weight and chest circumference were included. About 35,000 participants were covered from 351 locations across the country. In eighth plan, the ASI undertook anthropological survey on Indian women. In nine states the survey work has been completed while in others it is in progress. Some anthropometric data are available at Defence Institute of Physiology and Allied Sciences, Delhi. However, these data are on armed forces people and dimensions covered are few. Recently, National Institute of Design, Ahmedabad has published a monogram on anthropometric data of Indians. They have given data on 1,000 participants all over the country. However, most of the participants here are from student community or other occupational groups. There are very few studies available on anthropometric data on Indian agricultural workers (Pandey, 1970; Sen et al., 1977; Gupta et al., 1983; Gite and Yadav, 1989; Gite, 1996; Yadav et al., 1997). Again most of these are case studies and generally only male workers have been covered in these studies.

2.4.3 Use of anthropometric and strength data in design

At the start, it is necessary to define the user population. The important factors to take into account would be age, race, gender and occupation. As there is the large variation among the body dimensions, it is not economical or sometimes practically feasible to design the equipment/workplaces so as to suit 100 % of the users. Therefore, generally the design is made in such a way so as to satisfy 90 % of the users. This is achieved through use of 5^{th} percentile and 95^{th} percentile limits. It means that those people who fall outside these limits will not be matched with respect to the criteria concerned. They will be able to use the equipment but may be with less efficiency and comfort.

The anthropometric criteria fall into four main categories and deal with issues of:

- Clearance
- Reach
- Posture
- Strength

Clearance criteria deal with concern like headroom, legroom and so on. Access problem between and around obstacles also fall into this category. Here, the limiting user will be a large member of the population generally one who is 95^{th} percentile in the relevant aspect.

Reach criteria include those concerned with the location of controls or the storage of materials, and with a variety of situations where it is necessary to reach to perform a task. The limiting user will be a small member of the population usually 5^{th} percentile in the relevant aspect.

Postural criteria include those concerned with the location of the displays and controls at the heights of working surfaces. Here, a limiting use will have to be identified keeping in consideration the job requirement.

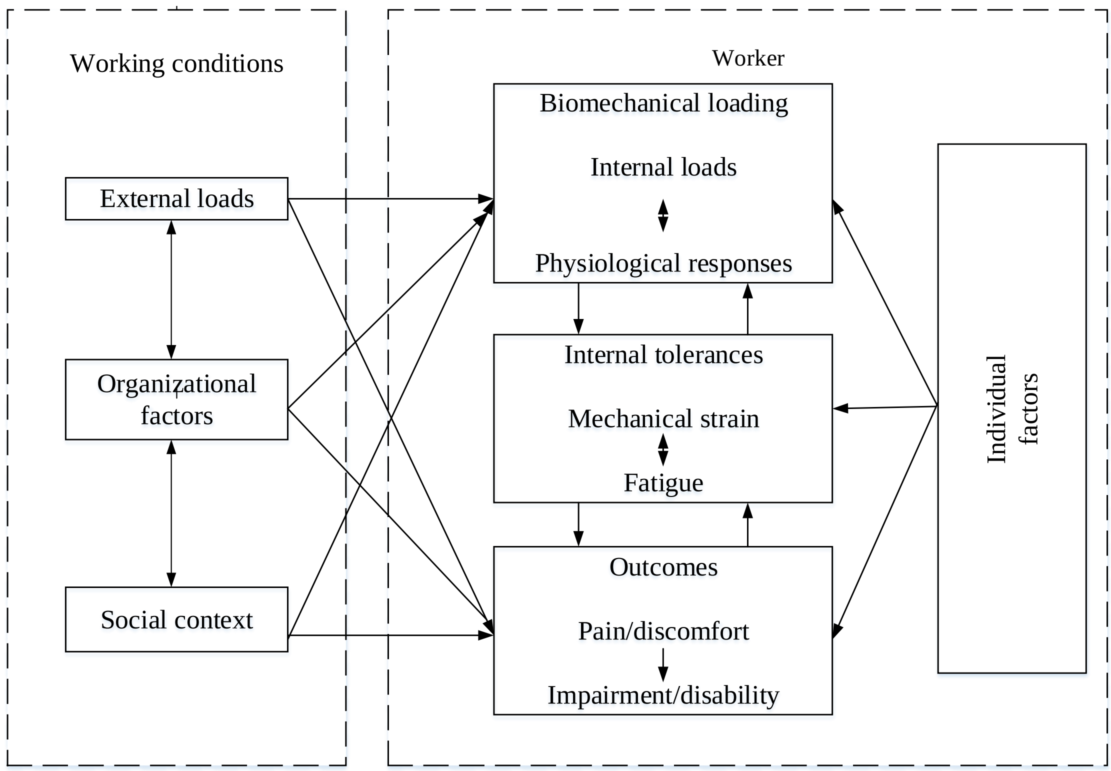
Strength criteria are applicable where a worker has to apply force to do the work. Generally here the strength of the 5^{th} percentile worker is taken as the design value.

2.5 Scope of design to enhance work–related health problems: Indian context

The intricate man–machine association and its neighbouring setting are most significant regions of study for improving work–related health in Indian scenario. After the freedom of India, in Indian industries, workers are experiencing pain due to traditional tools and work approaches. From the recent observation of Chauhan (2013), it is clear that in India, farmers devote 9 to 10 kcal/min in their tasks, which is very high. It was also observed in the literature that various awkward postures and use of traditional tool caused the loss of productivity up to 30% (Kang et al., 2016). The design of intervention has established to be a main source of damage when it is not considered with the environment specific requirements and not utilized appropriately. It is extremely essential to employ human factor methodologies to an intervention/product in its initial stages.

Weeding is a vital but equally work demanding farming operation. Kharif crops are mostly influenced due to weeds. Weeding operation incorporates about one–fourth of the total workforce requirement (900 to 1200 man–hours/hectares) in the seasons of cultivation (Nag and Dutt, 1979). Postponement and carelessness in weeding operation decrease the crop yield up to 60% (Singh, 1988). In India, approximately 4.2 billion rupees are used each year for managing weeds during crop production. Also, 40 million tons of principal food grains are vanished each year due to weeds (Singh and Sahay, 2001). In Asia, the yield was decreased up to 11.8 % due to weed, as stated by Dutta (1981). In India, the weeding operation is done with home–grown hand tools like *'Khurpi'* and spade. In recent times numerous hand–operated tools have been developed and tested for weeding operation. Usually the triangular and straight blade hoes developed by black smiths and village artisans are utilized during the work. Despite the tools available, the manual workers are still doing uprooting of weeds manually, which is work intensive and expensive.

Manually operated push–pull weeding machine available for various Indian regions, however, most of the farm workers are not using them either due to poor usability or lack of ergonomic modifications. Several types of cutting blades are utilized for manually operated weeding machine. For continuously pushed type weeding machine, V–shape sweep is ideal and other geometry of the cutting tool blade is depend on soil–tool–plant relations (Bernacki et al., 1972). Because of split land holding the mechanized weeding machines usage are very limited. Mostly human and animal powers are utilized for controlling the weeds using mechanical approach. Weeding done by mechanical approaches not only displaces the weeds found between the crop lines but also retains the soil surface loose, confirming better soil airing and water consumption capability. Manual weeding can give better results for controlling the weeds, however, the process of weeding takes long time (Biswas, 1990). Therefore, the mechanical design of push–pull weeding machine is necessary for improving health as well as productivity of the workers. Evaluation of the height of exposure to work–related health problems (MSDs) and risk factors can be a suitable base for proposing and applying an interventional procedure at work. Model of MSD risks examination scheme provided by National Research Council (NRC) is appropriate to consider during the design of an intervention/tool (Figure 2.8).



Source: NRC, 2001

Figure 2.8: Framework explaining MSDs hazards

2.5.1 Design philosophies: general

For designing handle height, length and shape, the anthropometric dimensions, strength data and farming conditions during the selected operations were the main attentions. Physical issues need to be considered in generating new model is defined underneath:

- For high level of comfort and minimum stress in usage of intervention, the handle should be designed such as hand and forearm need to be accompanying together. Also the contour of handle will influence the posture utilized to grasp it, therefore the contour of handle is a main aspect which can be utilized to decrease or reduce exhaustion faced by the worker (Lewis and Narayan, 1993).

- The main muscles, which bend the fingers and produce GS are positioned in the forearm. The wrist joint is expanded by long tendons of these muscles. Hence, the gripping ability of the fingers is influenced by the wrist position. Regular usage of manual implements in various positions of the wrist can cause fatal and non–fatal injuries (Tichauer, 1966) to both part of wrist (i.e., synovial coverings for guarding the tendons and median nerve crossing over the wrist).
- The cross–sectional shape of the intervention/tool handle influences the worker's operating performance and well–being. The powers produced in usage should be covered on the large pressure area of the palm (Lewis and Narayan, 1993).
- If the designed intervention/tool has a small handle that does not create the space between the coverage of the palm, high powers are generated at the midpoint of the palm. Hence, the handle should be designed such as it will far away from the hand when gripped (Lewis and Narayan, 1993).
- Sharp ends and curves may produce scratches, damages, or wear/tear. Therefore, investigator should take an action to remove such dangers by turning sharp ends and replacing curves by a large radius curve.

2.6 Summary of literature and research gap

A brief summary of literature research along with major area of research are as depicted in Figure 2.9. The figure illustrates a brief overview of the agriculture system and relative needs or area to be researched for improving the health and increasing productivity of the farm workers.

On the basis of literature review, following research gaps are identified:

- Application of multi–faceted ergonomic intervention is addressed by fewer researchers.
- Risk factors for MSDs and posture evaluation of farm workers involved in manual agriculture activities are investigated in fewer studies.
- Fewer researchers examined the impact of the different type of handles on grip strength at various postures.

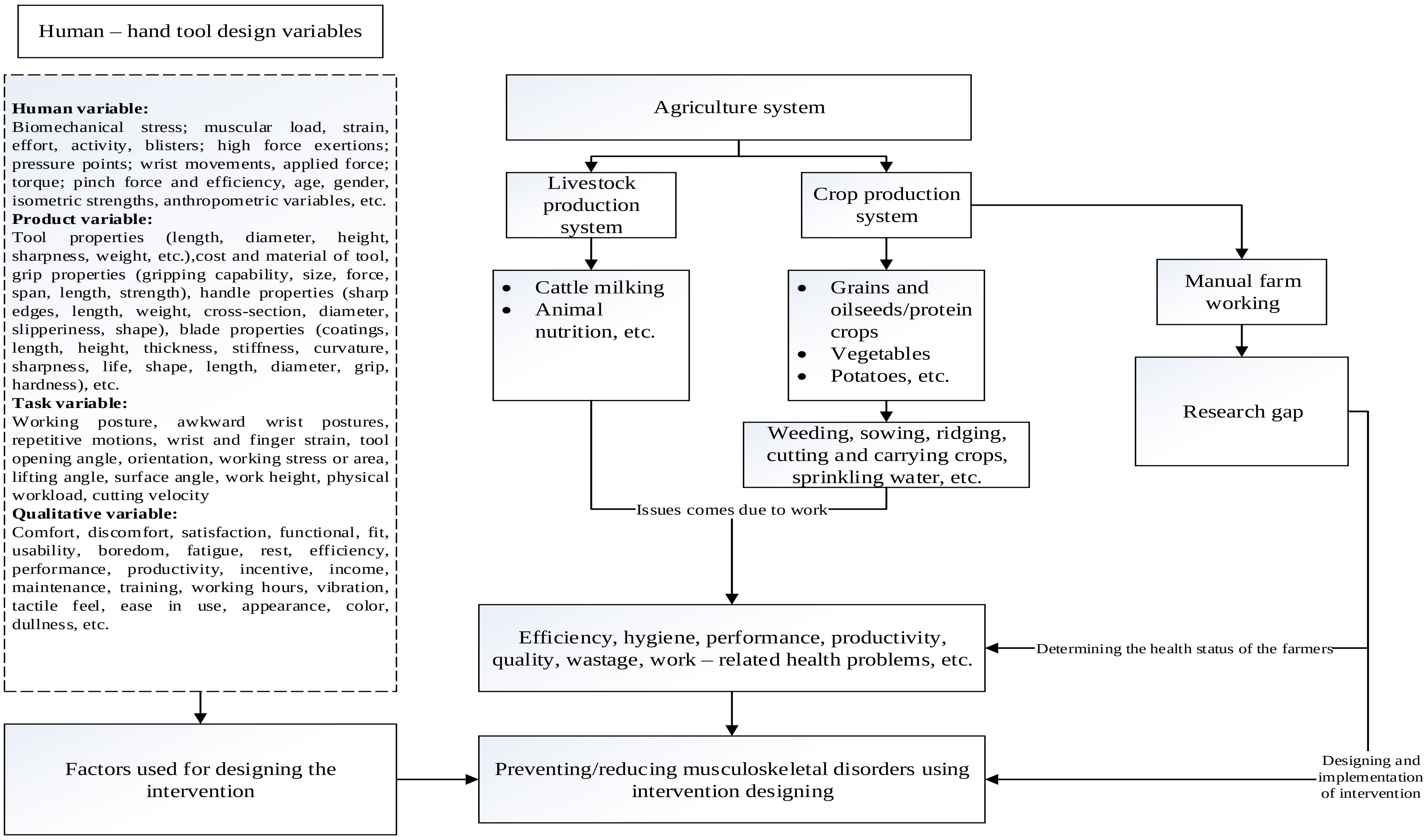


Figure 2.9: Synopsis of literature work carried out in the current research

CHAPTER 3

METHODOLOGY OF RESEARCH WORK

3.1 Framework of research

The current research intended for discovering solution of an instantaneous difficulty realized by a number of manual farming workers accompanied by developing procedure for intervention/tool design; the current investigation is partly practical and somewhat fundamental in method. The procedure implemented to achieve aim of the research work is presented in Figure 3.1.

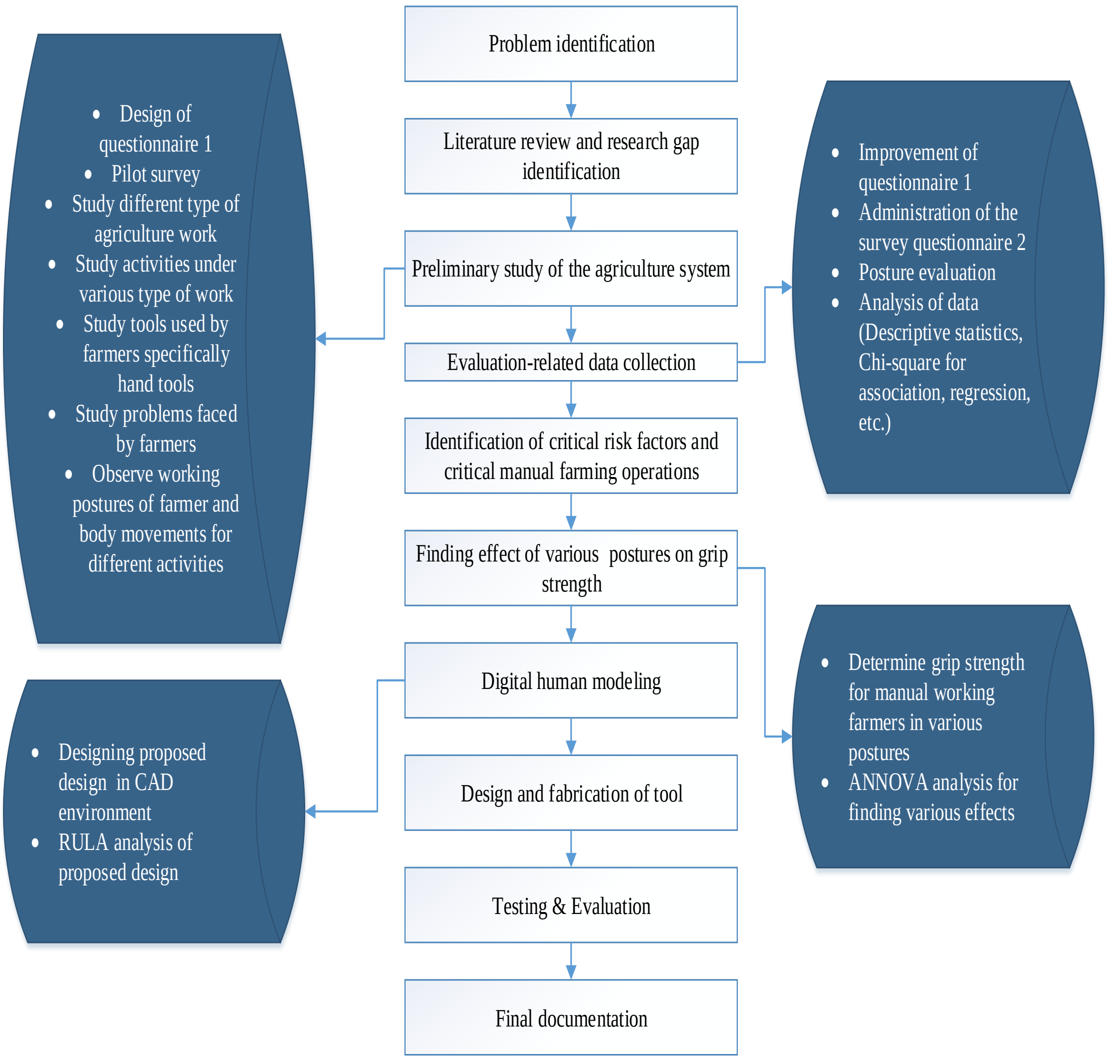


Figure 3.1: Research investigation procedure

Besides this comprehensive investigation methodology, there is a requirement to formulate the study design which demonstrates how the information would be collected and examined to pull out the conclusions/inferences from the current research. The current research is distributed into three stages i.e. ergonomic analysis of the existing work scenario, design intervention for establishment of work tool followed by assessment of the planned innovative idea. Figure 3.2 shows the synopsis of the research approaches.

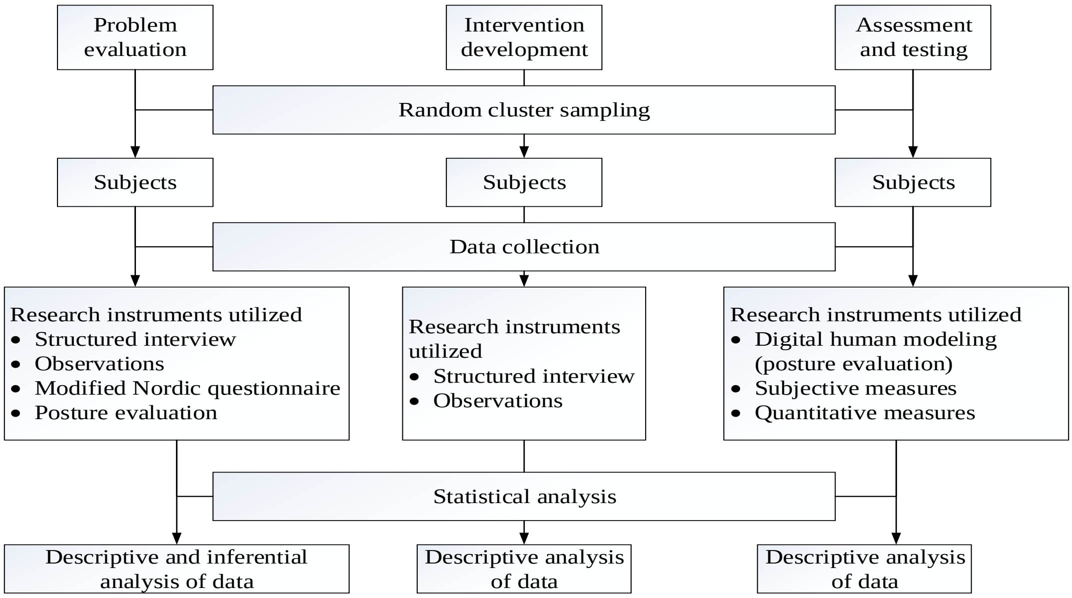


Figure 3.2: Synopsis of research approaches

3.2 Selection of participants

3.2.1 Ergonomic evaluation of manual agriculture activities

In Rajasthan, the farm workers commonly produce crops in three intervals, which contains of 2 long and 1 short phase of farming. In this state, during May–October (the interval of the current research), farm workers harvest several crops from which wheat and rice are the main growing crops. In crop production, farm workers (individually man and woman) are involved in various manual agriculture activities i.e., carrying and sowing seeds, weeding, ridging, sprinkling water, spading, and, cutting, picking and carrying crops. During these activities the maximum farm workers uses various equipments (i.e., sickles, spade, etc.) which are of same type for both hand domination and gender. The harvesting/cutting of crops utilizing hand tools and weeding activity require high amount of physical energy (Nag and Dutt, 1979; Nag and Chatterjee, 1981) as these events comprise laborious physical efforts for example gripping the tool strongly for fine hold and pushing and pulling of the tool. Because of these events and inappropriate anthropometric measurements of tools (i.e., length, weight, etc.), farm worker faces risk of acute injuries (Nag and Nag, 2004).Therefore, a cross–sectional research was carried out for farm workers of 4 districts of eastern Rajasthan using cluster random sampling. For the current research, 15 villages were selected randomly. All the villages were administered under the regulation of deputies; therefore, all deputies were requested to contribute, and they were briefed about the study. The deputies of 10 villages out of 15 accepted the request. The workers were chosen after discussion with the villages' deputies in line with the following conditions: (1) age of eligible worker should be more than 18 years and (2) he or she should use hand tools such as sickles, short– and long–handled hoes, spades, and so on, during the work on farms. In the current cross–sectional research, 140 farm workers were identified as potential participants. Selection strategy is depicted in the flow chart (Figure 3.3).

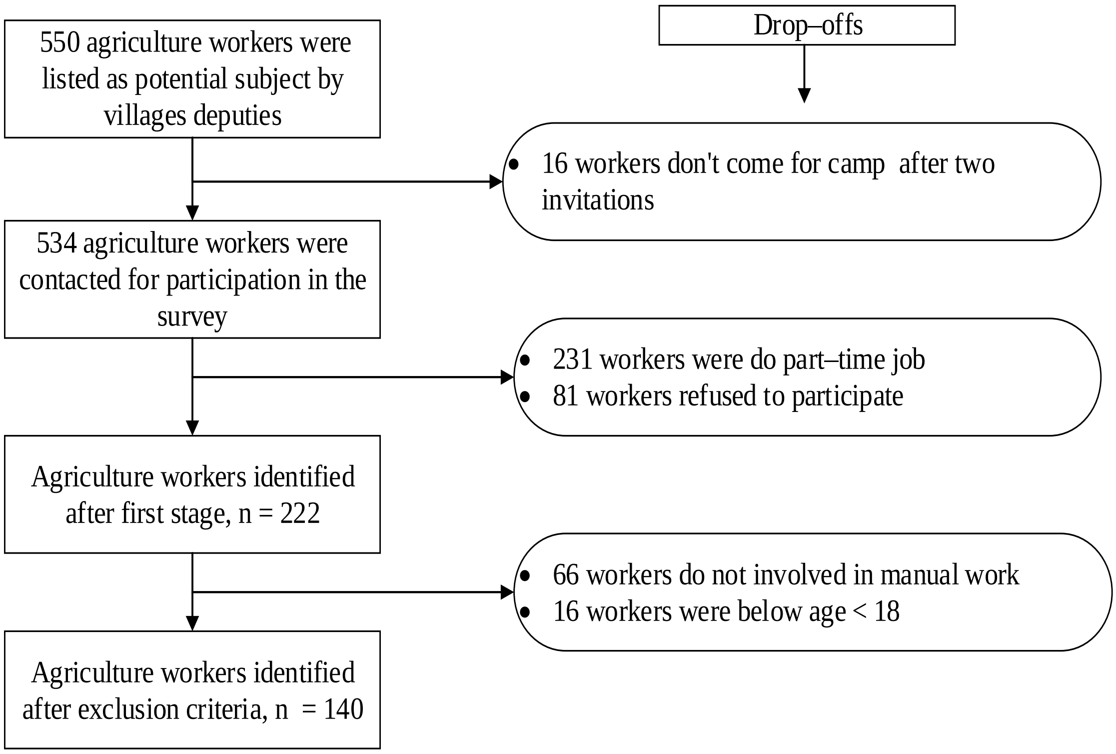


Figure 3.3: Selection of workers for current research

3.2.2 Effect of various postures on grip strength

Data was collected from three districts of eastern Rajasthan state of India. Moreover, from every district, 10–12 villages were nominated based on the healthy working population found during the preliminary study. From each village, 17–18 participants were selected with the help of village representatives. As grip strength (GS) relies on age, and in general, young adults have higher values of GS (Dewangan et al., 2010; Patel et al., 2014), the current research was implemented on younger individuals as participants to assess their GS. Therefore, the current research was implemented on 200 manual workers from the age range of 18–40 years.

3.2.3 Evaluation of hand–operated tool

Ergonomic and usability examination were performed to measure comfort and application of the newly designed hand–operated tool and the farm workers views. Fifteen skilled man and fifteen skilled woman, having age 29.6 ± 6.3, weight 64 ± 6.2, and stature 168.7 ± 5.4 cm joined during the testing of tool.

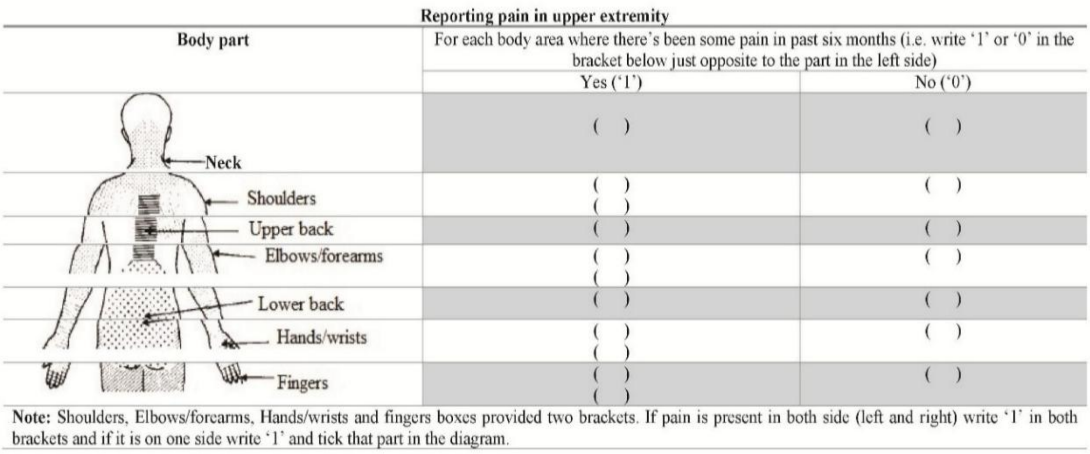
Data collection was done as per Helsinki modifications recommended in 2001. Every contributing participant permitted the conduct of research and informed signed consent was received from all participants joined the survey.

3.3 Data collection

3.3.1 Questionnaire for ergonomic evaluation of manual agriculture activities

In our pilot research conducted on the farm workers of Rajasthan, Standard Nordic Questionnaire (SNQ: Kourinka et al., 1987) was used directly due to which lots of problems were faced during questionnaire filling. Therefore, this questionnaire (Appendix–I) was modified for the current research to include questions mainly related to the upper extremity. This questionnaire was pilot tested on 20 workers before giving to all workers. The farm workers raised some issues/queries on the MSD reporting methods and work history–related questions, and the suitable issues/queries were considered during the preparation of the final questionnaire (Appendix–II). The information was acquired in the form of structured interview questionnaires.

The final questionnaire was divided into 3 sections. The first section of the questionnaire consisted of questions related to MSDs. A schematic of postures (Figure 3.4) was also presented in this section of the questionnaire to recognise the body regions where they experience pain, such as elbows/forearms, fingers, hands/wrists, neck, shoulders, and, upper and lower back.


Reporting pain in upper extremity

Body part	For each body area where there's been some pain in past six months (i.e. write '1' or '0' in the bracket below just opposite to the part in the left side)	
	Yes ('1')	No ('0')
Neck	( )	( )
Shoulders	( ) ( )	( )
Upper back	( )	( )
Elbows/forearms	( ) ( )	( )
Lower back	( )	( )
Hands/wrists	( ) ( )	( )
Fingers	( ) ( )	( )

Note: Shoulders, Elbows/forearms, Hands/wrists and fingers boxes provided two brackets. If pain is present in both side (left and right) write '1' in both brackets and if it is on one side write '1' and tick that part in the diagram.

Figure 3.4: Schematic presentation provided in questionnaire for MSDs reported

The participants were requested to respond “Yes” or “No” (“1” or “0”) in this section, regarding whether they experience any pain in the body region through the last six months. The next section of the questionnaire consisted of demographic queries related to age, gender, education, hand domination, anthropometric data (i.e., weight, height), and habit of smoke.

In the last section of the questionnaire, queries connected to daily working hours, total years of experience and multi–method ergonomic review technique (MMERT) to examine the level of discomfort or fatigue perceived by the farm worker, and level of satisfaction from income and hand tool usage were considered. In the current research, MMERT scale approach was used, which consists of scores from 0 to 2 (0 – low; 1 – moderate; 2 – high).

All the farm workers were interviewed separately after their working hours, and finally the questionnaires were filled by two interviewers in the field.

3.3.2 Posture evaluation of farm workers

The postures of the farm workers performing manual agriculture activities such as spading, sowing, weeding, ridging, cutting/harvesting crops, crop carrying and planting seeds, were observed and respective scores were filled in the observation sheets of RULA and REBA for postural analysis (Appendix–II).

For each observation, approximately 10–15 minutes of time was given to every individual, which also includes the filling of observation sheet. The farm workers working in squatting postures, were evaluated by RULA method, as during this working condition, farm workers’ upper extremity are primarily engaged in static motion. The farm workers working in kneeling and stooped postures were assessed by REBA method, as during this work, the entire body and limbs are engaged in dynamic motion. The calculated scores were divided into different exposure categories according to RULA and REBA methodologies (McAtamney and Corlett, 1993; Hignett and McAtamney, 2000).

3.3.3 Grip strength measurement

Demographic features of participants were documented by filling a self–reported set of questions to find out any previous damage, which may change the consequence of the investigation. Process and techniques were described to the participants suited for the inclusion requirements. Recurring measures research design was utilized to assess GS of participants in two body postures–sitting and standing with fixed shoulder in 45° forward flexion; three wrist and forearm positions– relatively neutral, flexion 45° and expansion 45°.

3.3.3.1 Equipment used and settings

Hand grip dynamometer was utilized for assessing the GS. The kit is user friendly and suitable for measuring strength in kilograms or pounds. In the current research, all GS measurements were logged in kilograms and further converted into Newton. The kit offers a flexible handle to support several dimensions of hands enabling the researchers to evaluate GS for various sized objects. The handle is adjustable at various grip positions (i.e., 2nd, 3rd, and 4th) according to the participant's ease. In the current research, maximum number of participants felt more comfortable with the 2nd position of handle. This fact also corroborates with the findings of Trampisch et al, (2012).

Measurement of GS was done in a grouping of body postures with shoulder forward flexed, elbow at 90° (Figure 3–2) and various variations in upper body parts (i.e., wrist and forearm). In both sitting and standing postures, each participant held the hand–grip dynamometer firmly for nearly 3s, and then continued the process in three intervals for three wrist and forearm positions: relatively neutral, flexion 45° and expansion 45°.

Figure 3.5: Postures of workers in (a) sitting and (b) standing for GS measurements

Participants took a 10s break between subsequent processes. Only the dominant hand of participants was tried in all situations and mean value of all measurements was recorded for further investigations. A break of one or more minutes according to the requirement of candidates among processes was provided to avoid excessive muscular fatigue.

3.3.4 Questionnaire for evaluating hand–operated tool

The ergonomic evaluation of hand–operated tool was done using modified SNQ (Appendix–II). The usability examination was done using subjective questionnaire which includes the questions on usability of the tool and evaluated on the 5–point Likert scale (Appendix–III).

In this phase, each participant contributed in two investigations. In each investigation stage weeding activity was evaluated, in which the worker did weeding operation utilizing existing and newly designed hand–operated tool. After the accomplishment of the investigation, the questionnaires were filled by the observer for assessing the subjective measure of comfort (usability questionnaire). After one month of trial/investigation, the score for MSDs was determined for the 15 days use of existing tool and 15 days use of newly designed hand–operated tool.

3.4 Reliability evaluation of research instruments

In the first step of the evaluation, the questionnaires were checked by field experts. For the accuracy of the questionnaire anatomy, the list of verbal terms, participant matters and coverage were also verified. The competent individual, who checked the research instrument, included two academicians (ergonomics experts) and one industrialist from agriculture industry. After getting the suggestions from reviewers, corrections have been made, then the altered research instrument were assessed to determine the restrictions or the difficulties in the questionnaire. This whole exercise provided refined questionnaire which was used for data collection. The whole exercise of questionnaire filling and posture assessment was done by two trained observers independently. Then, the information provided by both observers was judged and discriminated to check the consistency by experts. The inter–ratter reliability between observers for postural assessment was obtained to be 0.85.

3.5 Statistical analysis

3.5.1 Ergonomic evaluation of manual agriculture activities

The analysis of collected data was done with IBM SPSS (version 22.0) software. The statistical details of individual and work–related factors and ergonomic risks among participants were disclosed as a mean ± standard deviation (SD) and frequencies/rates for different categories of each factor. Chi–square analysis was accomplished to learn the associated MSDs with individual and work–related factors. According to Hair et al. (2006), logistic regression is a well–known statistical modelling methodology that is used to express the association between independent and dependent factors. Other modelling approaches are also available for this type of sophisticated modelling, but logistic regression is the most promising, as also suggested by Kleinbaum and Klein, (2010). Therefore, binary logistic regression method was used to determine the odds ratio (OR) of various risk factors for finding their effects on MSDs. The scores (1 or 0) obtained earlier from the questionnaire with respect to pain in different body parts were termed as dependent factors. There were 6 independent factors: age, work experience, gender (0 – female, 1 – male), hand dominance (0 – left hand, 1 – right hand), daily working hours (0 – greater than or equal to 6 hours, 1 – less than 6 hours), and perceived work fatigue (0 – low, 1 – moderate, 2 – high). The outcomes of binary logistic regression were checked for significance at $p < .10$, and 95% confidence intervals (CIs) were calculated. The prior checking of the model fit (i.e., the presence of outliers, collinearity, etc.) was done by Hosmere–Lemeshow goodness–of–fit test, and satisfactory results were obtained.

3.5.2 Grip strength measurement

SPSS version 22.0 was used for analysis of data. The age–group and gender–wise descriptive analysis for mean and standard deviation (SD) values was done for evaluation of GS in various conditions. Significant effects of various conditions on GS (total 6 exertions per participant per posture) were tested by repeated measures under analysis of variance (ANOVA) method for checking the variation within groups. Post hoc analysis was performed further for monitoring the significance level among various group comparisons.

3.5.3 Evaluation of hand–operated tool

The data on farm workers' observations were statistically verified to measure variations among the traditional tools and newly designed hand–operated tool. Also, the outcomes for prototype testing were evaluated using Taguchi design of experiment method for finding the optimal condition for hand–operated tool implementation in the real environment for longer time of operation.

CHAPTER 4

DATA OBSERVATION AND ANALYSIS

In the current chapter, basically data obtained during the ergonomic analysis of work and grip strength study is discussed (refer Appendix –IV for data). The analysis of the collected data is also presented and compared with contrast to the other findings worldwide simultaneously.

4.1 Risk factors for MSDs in farm workers involved in manual agriculture activities

Previously, many researchers have been studied the effects of risk factors on MSDs among farm workers involved in manual agriculture activities. In the literature, few study is present which deals with MSDs as well as the contributing risk factors among farm workers doing manual work. Therefore, the purpose of current research is to determine the MSDs prevalence in farm workers doing manual work (termed as manual workers), and to study the effects of contributing risk factors on the MSDs. The results according to the methods used are described in the next section.

The result of pilot study are presented in Table 4.1–4.2.

Table 4.1: Personal characteristics of the subjects

Characteristics	Number of workers (N= 60)	Percentage (%)
Age (in years)		
<30	24	40
31 to 40	14	23.3
41 to 50	16	26.7
>50	6	10
Weight (in Kg)		
<45 Kg	11	18.3
45 to 55 Kg	20	33.3
> 55 Kg	29	48.3
Height (in Cm)		
<160 Cm	21	35
160 to 170 Cm	30	30
> 170 Cm	9	15

Gender		
Male	30	50
Female	30	50
Marital Status		
Married	47	78.3
Unmarried	13	21.7
Qualifications		
Up to 10th std.	32	53.4
12th std.	9	15
Graduate	5	8.3
Illiterate	14	23.3
Monthly Income (in Rs.)		
Less than Rs. 6000	20	33.3
Rs. 6,000 to Rs. 10,000	16	26.7
Rs. 10,000 to Rs. 13,500	7	11.7
Greater than Rs. 13,500	17	28.3
Work Experience (in Years)		
< 5 Years	19	31.7
5–10 Years	7	11.7
10–15 Years	4	6.7
15–20 Years	5	8.3
> 20 Years	25	41.7
Average Working Hours in a Week (in Hours)		
< 28 hours	8	13.3
28–56 hours	20	33.3
>57 hours	32	53.3
Smoking Habit		
Smoker	28	46.7
Non–Smoker	32	53.3
Working Hand		
Right Hand	46	76.7
Left Hand	14	23.3

Personal data shows that majority (90%) of the workers belong to the age below 50 years whereas only 10% workers belong to the age above 50 years. The decrement in workers interest above 50 years was due to increased degree of the MSDs in body with age. Most of the workers (50 %) work more than 50 hours a week which results in higher MSDs. Farmers had significantly higher suffering from lower back, neck and wrist pain.

Table 4.2: MSDs prevalence among farm workers (N = 60)

Region	Yes	No
Neck	26	34
Shoulders	40	20
Elbows	39	21
Wrist	41	19
Upper back	31	29
Lower back	46	14
Hip	35	25
Knee	25	35
Ankle	27	33

The result of the main study shows that the highest prevalence frequency of MSDs was found in the trunk region. Further, the results also showed that 77.9 % of the participants experienced MSDs on one or more body part over the last six months. Fingers, wrists/hands and shoulders complaint were reported by 64.2%, 55.7% and 57.1% of the participants, respectively. Approximately 74% of participants reported low back complaints. The occurrence of MSDs for various body regions during the six months is presented in Table 4.3.

Table 4.3: Prevalence of MSDs among farm workers (N = 140)

Body part	Rate	Proportion (in %)
Neck	59	42.1
Shoulders	80	57.1
Elbows/forearms	66	47.1
Wrists/hands	78	55.7
Upper back	52	37.1
Lower back	103	73.6
Fingers	90	64.2
Any site	109	77.9

The mean of the age groups of the males (81.4%) was 34.25 (SD: 9.65), females (18.6%) was 38.36 (SD: 10.42), and approximately. 81% participants were greater than 26 years. A high proportion (85.7%) of the participants had high school knowledge. It was also identified that 77.1% of the participants were smokers. Table 4.4 shows that the participant’ mean BMI was found to be 22.12 (SD: 3.61). Approximately one–fourth of participants (24.2 %) had a BMI in the range of 25–30. In this survey female subjects were not participated actively due to their home responsibilities after working hours. So, the poor response of female workers during the survey could also be responsible for this difference.

The average year of working in farms was 10.62 (SD: 5.41) years. The average daily working in farm by the participants were 7.35 (SD: 2.29) hours a day. It was observed that 63.57% of the participants had been working from 5–15 years, and 18.57% of them had been working as a farmer for more than 15 years. Table 4.2 also shows that 70% of the participants in the study worked for greater than or equal to seven hours a day. There was only one break during the whole working day: a one–hour lunchtime. Most of the participants used hand tools like the sickle, spade, long and short–handled hoes. The majority of the participants (80.71%) used their right arms during the work. Also, the greater amount of participants (88.58%) indicated that they were dissatisfied by working with existing hand tools. Also, the disturbed or moderate level of fatigue due to working long hours was reported by 68.57 % participants. Before starting the investigation, knowledge and experiences of correct farm work approaches by participants in current study sample was checked. No ergonomic or appropriate applications were being carried out by the participants. According to chi–square analysis most of the individual and work–related factors were associated with MSDs scores except smoking habit. When the relations between the prevalence of MSDs and RULA scores were evaluated, no statistically significant relation was found with score B (neck, trunk, leg score). However, score A (upper–lower limb and wrist score) and the RULA grand score were highly associated with MSDs ($p < 0.05$).

Table 4.5 shows the associations of MSDs in various body parts with individual and work–related factors. Age was associated with the occurrence of pain in upper back (OR = 1.06, 95% CI: 1.00–1.13, $p<0.05$), wrists/hands (OR = 1.12, 95% CI: 1.04–1.21, $p<0.01$), fingers (OR = 1.14, 95% CI: 1.05–1.24, $p<0.01$), and elbows/forearms (OR = 1.14, 95% CI: 1.06–1.23, $p<0.001$). Neck complaints were only associated with the participants having the higher RULA score (>8) ($p < 0.05$). The perceived work fatigue was highly associated for high level of complaints in elbows/forearms (OR = 0.35, 95% CI: 0.12–1.01, $p < 0.05$).

Table 4.4: Individual and work–related characteristics and their association with MSDs (N= 140)

Independent factor (n[a])	Statistics Mean (SD)	Musculoskeletal Disorders		Significance
		With MSDs %[b] (109)	Without MSDs %[b] (31)	
Age (in year)				
≤25 (26)	Male: 34.25 (9.65) Female: 38.36 (10.42)	50	50	**
26–40 (84)		81	19	
≥41 (30)		93.3	6.7	
Gender				
Male (114)	–	82.5	17.5	**
Female (26)	–	57.7	42.3	
Body mass index				
< 18.5 or underweight (22)	22.12 (3.61)	68.1	31.9	*
18.5–24.9 or normal weight (84)		84.5	15.5	
25–29.9 or overweight (33)		66.8	33.2	
≥ 30 or obesity (1)		100	0	
Hand domination				
Left hand (27)	–	59.3	40.7	**
Right hand (113)	–	82.3	17.7	
Smoking				
Yes (108)	–	81.5	18.5	NS
No (32)	–	65.6	34.4	
Schooling				
Primary (15)	–	53.3	46.7	**
High school (120)	–	81.7	18.3	
Graduate (5)	–	60	40	
Farming experience (in years)				
≤5 (25)	10.62 (5.41)	68	32	**
5–15 (89)		76.4	23.6	
≥15 (26)		92.3	7.7	

Daily working in farms (in hours)				
≤6 (42)	7.35 (2.29)	64.3	35.7	**
≥7 (98)		83.7	16.3	
Salary satisfaction				
Low (54)	–	66.7	33.3	**
Moderate (50)	–	90	10	
High (36)	–	77.8	22.2	
Perceived work fatigue				
Low (44)	–	75	25	
Moderate (63)	–	71.4	28.6	**
High (33)	–	93.9	6.1	
Hand tool satisfaction				
Low (124)	–	81.5	18.5	*
Moderate (0)	–	0	0	
High (16)	–	50	50	
RULA/ A score				
≤5 (110)	4.66 (1.30)	81.8	18.2	*
≥6 (30)		63.3	36.7	
RULA/ B score				
≤7 (100)	6.33 (1.58)	75	25	NS
≥8 (40)		85	15	
RULA/ grand score				
≤6 (40)	5.94 (1.08)	67.5	32.5	*
≥7 (100)		82	18	

Note– MSDs: Musculoskeletal disorders, NS: not significant, SD: standard deviation

[a]n: quantities in braces demonstrates the total count in that variable in the first column, [b]percentage computed for each category of all factors with MSDs and without MSDs.

**significant at $p<0.001$, *significant at $p<0.01$.

Table 4.5: Factors affecting MSDs among farm workers: multinomial logistic regression (N = 140)

Factor	Neck (n = 59)			Upper Back (n = 52)			Shoulder (n = 80)			Lower back (n = 103)		
	OR	95 % CI	p	OR	95 % CI	p	OR	95 % CI	p	OR	95 % CI	p
Age	1.02	0.96–1.08	NS	1.06	1.00–1.13	*	1.02	0.96–1.08	NS	1.05	0.97–1.13	NS
Gender												
Female	1.00	–		1.00	–		1.00	–		1.00	–	
Male[a]	2.54	0.92–6.95	NS	1.72	0.63–4.69	NS	0.86	0.33–2.20	NS	1.37	0.48–3.86	NS
Hand domination												
Left hand	1.00	–		1.00	–		1.00	–		1.00	–	
Right hand[b]	1.36	0.55–3.38	NS	1.27	0.50–3.24	NS	1.76	0.72–4.29	NS	0.51	0.17–1.58	NS
Farming experience (year)	0.96	0.87–1.06	NS	1.01	0.91–1.11	NS	0.96	0.87–1.06	NS	0.99	0.88–1.11	NS
Daily working in farms (hour)												
≥7	1.00	–		1.00	–		1.00	–		1.00	–	
≤6[c]	1.01	0.38–2.70	NS	1.18	0.43–3.26	NS	0.65	0.24–1.74	NS	0.66	0.22–1.94	NS
Perceived work fatigue												
Low	1.00	–		1.00	–		1.00	–		1.00	–	
Moderate	0.77	0.34–1.77	NS	0.89	0.38–2.07	NS	0.75	0.33–1.69	NS	2.17	0.83–5.70	NS
High[d]	1.02	0.39–2.66	NS	1.14	0.43–3.01	NS	1.94	0.71–5.30	NS	0.81	0.29–2.29	NS
RULA/ A score												
≤5	1.00	–		1.00	–		1.00	–		1.00	–	
≥6[e]	0.78	0.31–1.94	NS	0.68	0.27–1.72	NS	0.65	0.26–1.60	NS	0.52	0.19–1.40	NS
RULA/ B score												
≤7	1.00	–		1.00	–		1.00	–		1.00	–	
≥8[f]	2.24	1.02–4.91	*	0.72	0.32–1.63	NS	1.33	0.60–2.94	NS	1.79	0.67–4.74	NS

Note– OR: Odds ratio, p: significance value, 95 % CI: 95 % confidence interval, NS: not significant, *significant at p<0.05.

[a]Interpretation: assessed for female participants, the OR of pain in particular body part of male participants.

[b]Interpretation: assessed for participants who do work with the left hand, the OR of pain in particular body part who do work with the righthand.

[c]Interpretation: assessed for participants who do farming more than 7 hours daily, the OR of pain in different body part who do farming work less than 6 hours.

[d]Interpretation: assessed for participants who have high level of fatigue in using the existing hand tool, the OR of pain in a particular body part in those who stated they hadhigh level of fatigue in using the current hand tool.

[e]Interpretation: assessed for participants who have RULA score A higher than 6, the OR of pain in a particular body part in those who stated they hadhigh score in using the current hand tool.

[f]Interpretation: assessed for participants who have RULA score B higher than 8, the OR of pain in a particular body part in those who stated they hadhigh score in using the current hand tool.

Table 4.5 (contd.): Factors affecting MSDs among farm workers: multinomial logistic regression (N = 140)

Factor	Wrists/hands (n = 78)			Fingers (n = 90)			Elbows/forearms (n = 66)		
	OR	**95 % CI**	**p**	**OR**	**95 % CI**	**p**	**OR**	**95 % CI**	**p**
Age	1.12	1.04–1.21	**	1.14	1.05–1.24	**	1.14	1.06–1.23	**
Gender									
Female	1.00	–		1.00	–		1.00	–	
Male[a]	4.11	1.42–11.89	**	2.21	0.76–6.43	NS	3.57	1.17–10.90	*
Hand domination									
Left hand	1.00	–		1.00	–		1.00	–	
Right hand[b]	0.94	0.36–2.43	NS	1.79	0.66–4.87	NS	1.45	0.54–3.88	NS
Farming experience (year)	0.93	0.83–1.03	NS	1.01	0.90–1.13	NS	0.95	0.85–1.06	NS
Daily working in farms (hour)									
≥7	1.00	–		1.00	–		1.00	–	
≤6[c]	1.36	0.48–3.83	NS	0.96	0.34–2.77	NS	1.08	0.38–3.08	NS
Perceived work fatigue									
Low	1.00	–		1.00	–		1.00	–	
Moderate	2.17	0.88–5.24	NS	1.56	0.60–4.08	NS	1.05	0.42–2.58	NS
High[d]	1.18	0.43–3.26	NS	0.62	0.21–1.83	NS	0.35	0.12–1.01	*
RULA/ A score									
≤5	1.00	–		1.00	–		1.00	–	
≥6	0.30	0.11–0.81	*	0.21	0.07–0.61	**	0.32	0.12–0.89	*
RULA/ B score									
≤7	1.00	–		1.00	–		1.00	–	
≥8	1.96	0.82–4.64	NS	1.36	0.54–3.44	NS	2.07	0.87–4.92	NS

Note– OR: Odds ratio, p: significance value, 95 % CI: 95 % confidence interval, NS: not significant, *significant at p<0.05, **significant at p<0.01.
[a]Interpretation: assessed for female participants, the OR of pain in particular body part of male subjects.
[b]Interpretation: assessed for participants who do work with the left hand, the OR of pain in particular body part who do work with the right hand.
[c]Interpretation: assessed for participants who do farming more than 7 hours daily, the OR of pain in different body part who do farming work less than 6 hours.
[d]Interpretation: assessed for participants who have high level of fatigue in using the existing hand tool, the OR of pain in a particular body part in those who stated they had high level of fatigue in using the current hand tool.
[e]Interpretation: assessed for participants who have RULA score A higher than 6, the OR of pain in a particular body part in those who stated they had high score in using the current hand tool.
[f]Interpretation: assessed for participants who have RULA score B higher than 8, the OR of pain in a particular body part in those who stated they had high score in using the current hand tool.

From Table 4.5, it is clear that the RULA score A was highly associated with the complaints in hand region (wrists/hands, fingers and elbows/forearms) which shows that high risk was generated due to working on traditional hand tools. RULA score B was highly associated with the complaints in neck (OR= 2.24, 95 % CI: 1.02–4.91, $p<0.05$). Most of the farm workers in crop cutting and weeding operation had RULA score equal to 7. Similarly, REBA scores were also found high for these operations. No farmer had a RULA score of 1 to 2 and REBA score up to 3. Table 4.6 and 4.7 depicts the information of RULA and REBA scores for various operations.

Table 4.6: Frequency of RULA scores for different manual agriculture activities

RULA score	Spading (20)	Sowing (16)	Weeding (23)	Ridging (18)	Cutting (25)	Crop carrying (19)	Planting Seeds (19)	Total (140)
1 to 2	–	–	–	–	–	–	–	–
3 to 4	2	1	–	1	–	4	4	12
5 to 6	8	6	9	7	9	6	5	50
equal to 7	10	9	14	10	16	9	10	78

From the outcomes of postural assessment, it is easy to conclude that crop cutting/harvesting and weeding are most risky operations as compared to others and need changes immediately.

Table 4.7: Frequency of REBA scores for different manual agriculture activities

REBA score	Spading (20)	Sowing (16)	Weeding (23)	Ridging (18)	Cutting (25)	Crop carrying (19)	Planting Seeds (19)	Total (140)
equal to 1	–	–	–	–	–	–	–	–
2 to 3	–	–	–	–	–	–	–	–
4 to 7	2	2	–	2	–	3	2	11
8 to 10	12	10	10	10	8	11	9	69
11 to 15	6	4	13	6	17	5	8	60

The current research detected that pain in neck, shoulders, elbows and forearms, wrists and hands, low back, hips and thighs, knees, and foots and ankles were found frequently in the crop cutting/harvesting and weeding operations. Workers had to bend during the weeding, crop cutting/harvesting, crop carrying and planting seeds exert stresses at the back and shoulders mostly. These findings are in line with the study conducted by Das, (2015) who detected high pain in the lower back and shoulder for similar type of operations. The findings also linked to the study of Gangopadhyay et al., (2005) who found higher frequency of MSDs in the upper limbs of preadolescent agricultural farmers. They have also found that farmers required to perform more repetitive tasks than employees of other developed sectors. The cutting/harvesting crop, and weeding operation required high energy demands (Nag and Dutt, 1979; Nag and Chatterjee, 1981) and these operations required high severity of work (Nag and Nag, 2004). Current research also found that farm workers doing weeding, cutting and carrying crop, operations had been exposed to higher MSDs due to long hour of daily working as compared to other operations. In the crop carrying operation, farm workers did not required to perform repetitive tasks for longer time similar to other jobs, it requires both pushing and pulling for small amount of time that requires use of large muscle–groups which forced them to face MSD complaints.

According to logistic regression results, age was observed as a likely factor causing the risk of MSDs in upper extremity body regions which is also similar in most of the investigations (Nonnenmann et al., 2010; Das et al., 2013). The current research showed that gender is highly associated risk factor for MSDs, which is easy to compare with a study Xiao et al., (2013). Xiao et al., (2013) found frequency of lower back pain (LBP) for 12 month among males (24.5%) and females (25%), which is substantial low from our research (i.e., 81.6 % in male and 53.8 % in female). The outcome of our research are not easy compare with the study performed on Colorado farmers by Xiang et al., (1999) which analysed back pain symptoms, especially LBP among farmers. Xiang et al.'s discoveries on the risk factor for LBP among Colorado farmers revealed the relationship of LBP with being depressed, farming/ranching as main activities and worked in agriculture for 10 to 29 years. Concerning to the work experience factor, farm workers doing manual agriculture activities from more than 15 years had more risk than workers doing manual agriculture activities from less than 15 year. There are various studies that have revealed a relationship between work experience and MSDs prevalence (Xiang et al., 1999; Nonnenmann et al., 2010; Keawduangdee et al., 2015) but other studies did not show a correlation between them (Gangopadhyay et al., 2008; Das et al., 2012; 2013). Current research analysed and found that farmer doing manual work from longer than 15 years may exposed to higher pain in shoulders, lower back, wrists/hands. Ng et al., (2015) reported pain in those farmers who worked daily more than 7 hours, compared with non–farm workers. In the present research, daily working hours found associated factor with various upper extremity positions except upper back and elbows, which is not in line with the findings of meta–analysis review conducted by Jadhav et al., (2015). However, male gender is the risk factor which is in line with their results. Assessment of MSDs was done only for the 6 months period of study and it was contradictory to the. However, results of current research are usual due to the results of our previous pilot research. The selections of farm workers were done by seeking assistance from village deputies which may create small amount of biasness in the selection of participants.

4.2 Performance evaluation of farm workers

According to the American Society of Hand Therapists (ASHT), a standard procedure for GS examination was outlined. By utilizing the ASHT principles, Richards (1997) implemented this procedure to study GS and found no significant variation among sitting and supine postures. Kattel et al., (1996) discovered that GS had a strong association with posture variation and peak value of the muscle power found at zero degrees shoulder abduction and elbow flexed at 135°. Zhang et al., (2014) noticed that males exhibited significantly higher GS in both hands than females in hand dominance. Although various aspects have been tested in previous investigations; yet relevant aspects cannot be streamlined for individuals/workers belonging to less advanced sectors or less technically developed sectors (i.e., agriculture, construction, etc.) wherein the place of working is not same as operating circumstances in advanced sectors. Also, some researchers had aimed to evaluate GS with mixtures of angles of various upper body part positions in two body postures (standing and sitting) in laboratories or advanced sector industries. As per reported literature, there is very less research pertaining to investigation of GS giving due consideration to the specific conditions of less advanced sector workers. Therefore to overcome this research gap, following objectives have been targeted in the current study:

- To measure GS with variations of postures and upper body parts (i.e., wrist, forearm, and elbow) among young male and female participants belonging to less advanced sectors (i.e., agriculture, construction, etc.).
- To find out the impact of these variations on GS values.

The GS values were logged in for various conditions as depicted in Table 4.8 within three age–groups for both the genders.

Table 4.8 Grip strength (in Newton) in various positions among different age groups and gender (N = 200)

Conditions		**Mean (SD)**							
Posture with fixed body part angle	Body parts with angles	Men (n = 120)				Women (n = 80)			
		18–25	26–32	33–40	Total	18–25	26–32	33–40	Total
Sitting (shoulder forward flexed at 45° and elbow at 90°)	Wrist neutral	379 (32.1)	380 (37.4)	369 (38.3)	420 (35.8)	249 (33.7)	262 (41.4)	264 (32.5)	257 (34.6)
	Wrist 45°flexion	324 (19.3)	326 (18.4)	326 (20.8)	325 (19.3)	209 (16.3)	214 (11.8)	211 (18.1)	210 (16.1)
	Wrist 45°extension	348 (21.5)	348 (21.9)	353 (22.4)	350 (21.8)	228 (22.8)	218 (19.8)	214 (20.7)	230 (21.6)
	Forearm neutral	358 (28.7)	354 (31.0)	356 (36.1)	377 (31.4)	229 (35.3)	224 (33.7)	231 (31.5)	229 (33.1)
	Forearm 45°flexion	314 (21.1)	316 (20.6)	311 (19.1)	314 (20.3)	195 (20.7)	193 (17.7)	194 (20.0)	294 (19.3)
	Forearm 45°extension	345 (33.6)	342 (30.3)	346 (29.7)	344 (31.2)	220 (31.0)	223 (29.2)	214 (29.4)	218 (29.8)
Standing (shoulder forward flexed at 45° and elbow at 90°)	Wrist neutral	385 (35.8)	382 (39.3)	386 (35.3)	406 (36.6)	242 (27.9)	246 (22.1)	256 (26.0)	248 (26.9)
	Wrist 45°flexion	338 (21.2)	336 (20.7)	339 (23.4)	338 (21.5)	219 (21.2)	211 (17.0)	211 (23.5)	214 (21.2)
	Wrist 45°extension	355 (26.2)	357 (23.2)	362 (27.1)	358 (25.4)	225 (23.2)	221 (20.5)	220 (22.0)	223 (22.6)
	Forearm neutral	405 (40.7)	391 (43.9)	402 (40.3)	427 (41.8)	259 (31.4)	273 (31.3)	261 (30.5)	262 (31.3)
	Forearm 45°flexion	356 (24.3)	359 (24.5)	344 (24.6)	354 (24.9)	229 (26.3)	221 (22.3)	233 (23.4)	229 (24.3)
	Forearm 45°extension	366 (28.4)	367 (26.2)	363(27.9)	366 (27.3)	242 (27.1)	254 (24.6)	244 (27.5)	245 (26.9)

Note– SD: standard deviation

According to the findings of the current research, GS for men participants was highest in standing posture with the wrist/forearm in neutral position followed by GS for sitting posture with the neutral wrist/forearm position. However, some values of GS in the forearm extension were close to the values of GS in the neutral position. A good decrement in GS values was seen for forearm flexion in standing posture.

The ANOVA outcomes show that there was no significant impact of different variations (error in positions) in upper body parts for sitting as well as standing postures (Table 4.9).

Table 4.9: ANOVA of grip strength in various conditions

Source		**Sum of squares**	**DF**	**Mean square**	**F**	**Significance**
Sitting						
Position	Sphericity assumed	478381.37	5	95676.28	128.08	0.000
	Huynh–Feldt	478381.37	4.29	111570.59	128.08	0.000
Error (Position)	Sphericity assumed	743279.79	995	747.02		
	Huynh–Feldt	743279.79	853.25	871.11		
Standing						
Position	Sphericity assumed	409034.58	5	81806.92	97.05	0.000
	Huynh–Feldt	409034.58	4.53	90387.29	97.05	0.000
Error (Position)	Sphericity assumed	838747.25	995	842.96		
	Huynh–Feldt	838747.25	900.55	931.38		

Note– DF: degree of freedom, F: F–test statistics

The data was tested by Mauchly's examination of sphericity, and was found to be violated ($\varepsilon < 0.75$) for sitting ($\chi2 = 105.9$, df = 14, $p < 0.001$) and standing postures ($\chi2 = 63.8$, df = 14, $p < 0.001$). Therefore, huynh–Feldt estimations of sphericity were utilized for modifications in degrees of freedom in sitting and standing postures. These outcomes indicated that no variations in body parts were considerably filthier except neutral wrist in both postures.

Post hoc analysis of different variations in body parts brought to light requirement of significant changes among all variations except wrist 45° extension and neutral forearm in sitting posture ($p = 0.169$), and wrist 45° extension and forearm 45° flexion ($p = 0.959$) in standing posture (Table 4.8–4.9).

4.2.1 *Influence of gender and age–group on grip strength*

The result related to GS analysis showed that GS of males in various body postures was higher than the GS of females. The apparent justification for this outcome was dissimilarity in the variety of tasks done by both genders. Men are usually more adept at physically intensive tasks. Also, usually men are more associated with weight handling activities compared to women.

GS among the age group 18–40 years was tested in the current research and higher GS values were found as compared to the values obtained by previous Indian studies (Dewangan et al., 2010; Patel et al., 2014). Furthermore, a broader exploration for the three age groups (18–25, 26–32, 33–40 years) was also done in the current research and the analysis of different age–groups shows that participants in the age group of 26–32 years have higher GS as compared to the other two groups. These results conform to the results reported by previous researchers (Massy–Westropp et al., 2011; Werle et al., 2009).

4.2.1.1 *Influence of various conditions on grip strength*

The outcomes concerning the impact of posture on GS in male and female participants specified that there was no substantial difference of GS among various conditions. However, the mean GS was marginally greater in standing posture than that of sitting posture. Richards (1997), who investigated the effect of various body postures on GS, also established that GS computed in standing position was the highest, whereas GS computed in supine position was the lowest, however, there is no significant difference. Liao et al., (2014) also verified that GS was higher in standing posture with elbow flexed at 90° as matched with the GS values in supine and sitting postures. The outcomes of the current research are also in line with these findings.

In the present study, the highest male GS value for various standard limb postures was found to be 399 ± 41.8 N; which is closer to the maximum GS value (436 ± 97.7 N) found in the previous meta–analytic review carried out by Roman–Liu, (2003).The maximum GS values for both postures in wrist and forearm neutral conditions determined for male participants in the current research also comply with the values obtained by equation generated by Roman–Liu, (2003) for finding maximum hand grip force in male workers using the GS value of female workers.

Liao (2014a) noticed in his research that GS is extreme when the wrist and forearm are in neutral position, which was also sustained by Shih et al., (2006). However, research carried out by Kong (2014) expounded that shoulder extension at 90° is more influential in the development of maximum GS than 45° flexion and neutral positions. As per the tests in the current research, GS in 45° flexed wrist/forearm position with a fixed orientation of two body postures has been laid in the mid position and novel results were obtained. Furthermore, the participants were comfortable in two–body postures with the shoulder in 45° forward flexion and elbow at 90° position during all distinctions of various upper body part positions. In the existing research, fairly neutral forearm position was discovered to generate quite good GS values as compared to flexion and extension of body parts. The increase in various angles of upper body parts were found to be directly associated with the GS values as stiffness was increased in upper body parts with increase in angle.

The wrist position was also found to impact GS. It was detected in the current research that the neutral wrist angle resulted in considerably greater GS than ulnar deviation. A decrement in GS was obtained with wrist flexion at various angles as depicted in the previous findings (Claudon, 1998; Khan et al., 2013; Liao, 2014a; 2014b; Roman–Liu et al., 2005; Shih et al., 2006).

CHAPTER 5

ERGONOMIC DESIGN, DEVELOPMENT AND EVALUATION OF HAND–OPERATED TOOL

With modernization, quality issues and reliability complications exist in farm machineries. From the investigation of manual agriculture activities it was confirmed that awkward postures, force and repetitiveness were the risk factors contributing for pains in various body parts, accompanied by other work–related health problems. Farm workers reported discomfort, or extreme fatigue in various body parts including low back, shoulders and hand regions mostly. To reduce the physical workload on upper extremity (mainly lower back) and make the work comfortable, a hand–operated tool for weeding was conceptualised for farm workers involved in manual agriculture activities.

Previous studies revealed that there is no versatile weeding tool available. However, weeding tool design depends on region specific attributes (i.e., soil type, crops grown, cropping pattern, etc.).Therefore, the effort has been made to develop a hand–operated tool for weeding to meet the demand of farm workers in Rajasthan (India) and it was tested in the field through ergonomic point of view for its effectiveness.

5.1 Designing of hand–operated tool

The methodology used for designing of hand operated tool is as follows:

- Studying the manual implements currently utilized in various farming operations.
- Finding other alternatives available in similar and other sectors for designing a new intervention/tool.
- Altering the equipment according to the risky farming operations and determining the specifications comprising weight, surface area, shape of handle and posture during intervention/tool use.
- Developing new model of tool as per the anthropometric dimensions and strength data of the Indian farm workers and design philosophies.
- Building physical model.
- Testing the model on the basis of the ergonomic evaluation and usability examination procedure.
- Finding the optimal parameters from the test results of prototype testing in real time environment.

5.1.1 Design philosophies: operation specific

Limitations of the current weeding tools are as following:

(a) Existing weeding machine are only available for particular type of crops or for particular type of row spacing among the crops. Therefore, hand–operated tool for weeding is developed for various type of crops.

(b) The dynamic load changed with pace of a farmworker during process which also influences the working of existing weeding tools. This problem is solved by fixing the handle for dynamic operation.

The following criteria were considered to design and develop a hand–operated tool for wide–row crops (greater than 220 mm row spacing upto 300 mm) to overcome the above limitations,

(1) Weeds can be destroyed simply when they are at initial stages of development.

(2) Physical methods of weeding i.e., chopping/slicing weeds were considered. The slicing operation was selected for removing the weeds to scratch their nods in its early phase.

(3) Ergonomic principles were considered for design and development of appropriate hand–operated tool for wide–row crops on flat fields.

(4) Push–pull method was selected for its action in the crop fields that helps farm worker to complete the task in lesser time.

(5) The cutting width of hand–operated tool was kept between 200 to 250 mm so that it can function well for various vegetable crops (cabbage, capsicum, cauliflower, chilly, French been, labia, okra, pea, etc.) transplanted at row spacing of 200 mm and above.

(6) Maintainable power of human was measured based on literature as below:

According to Campbell (1990), the power of convenient work done by human is

$$HP = 0.35 - 0.092 \log t$$

where, t=time in minutes

So, the power developed by the worker would be 0.10–0.13 HP ~ 0.11 HP or 80W for 3 to 4 hours non–stop work.

(7) Maximum depth of cut was kept 15–30 mm for chopping/slicing the weeds to use human power more efficiently.

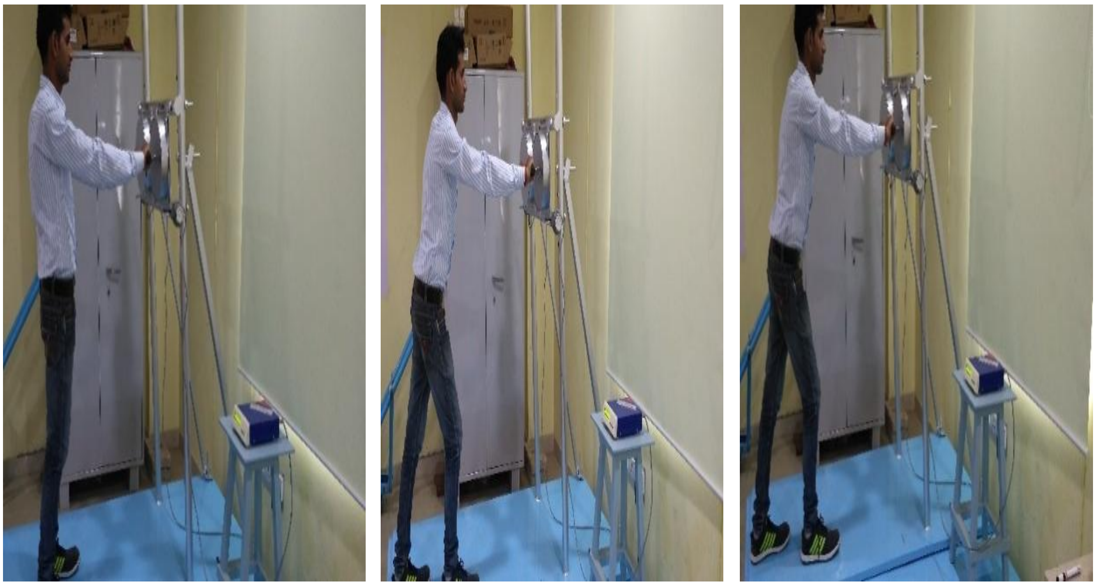
5.1.2 Calculation of parameters for hand–operated tool

The 'hand–operated tool for weeding' contained handle, rectangular tool bars, weeding blades and wheels. The design of these parts is described below:

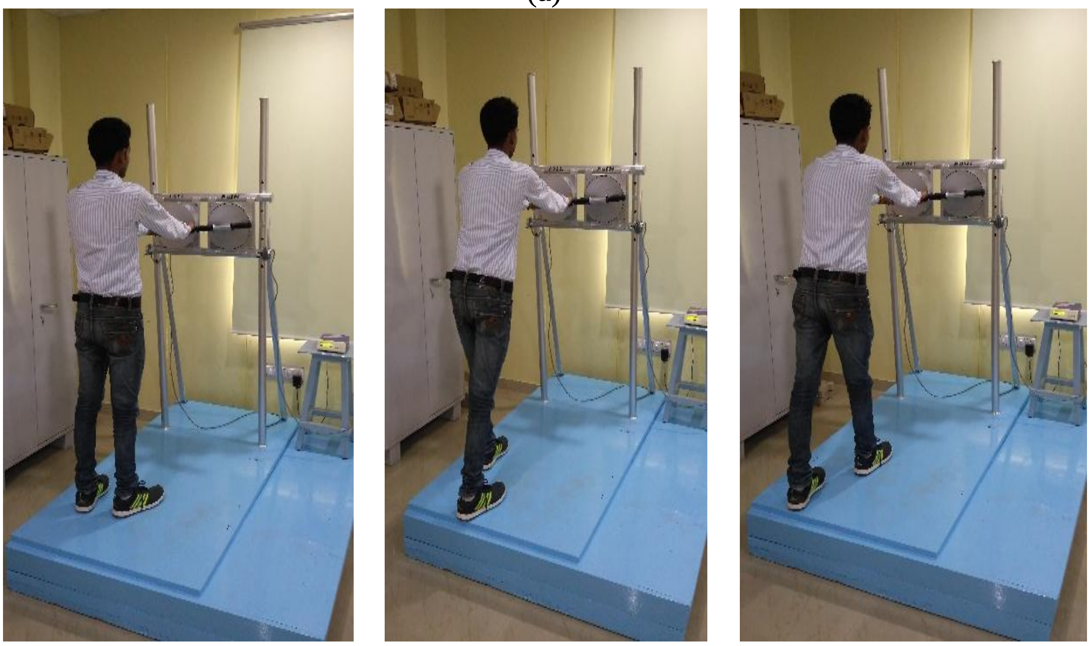
5.1.2.1 Maximum grip strength and push–pull isometric strength

The maximum grip strength in standing posture with both hands by a male and female worker are 489 and 312N respectively. However, for better muscular effectiveness, the dynamic strength for the cyclic work should not exceed 30 percent of the maximum push force (Grandjean, 1989).

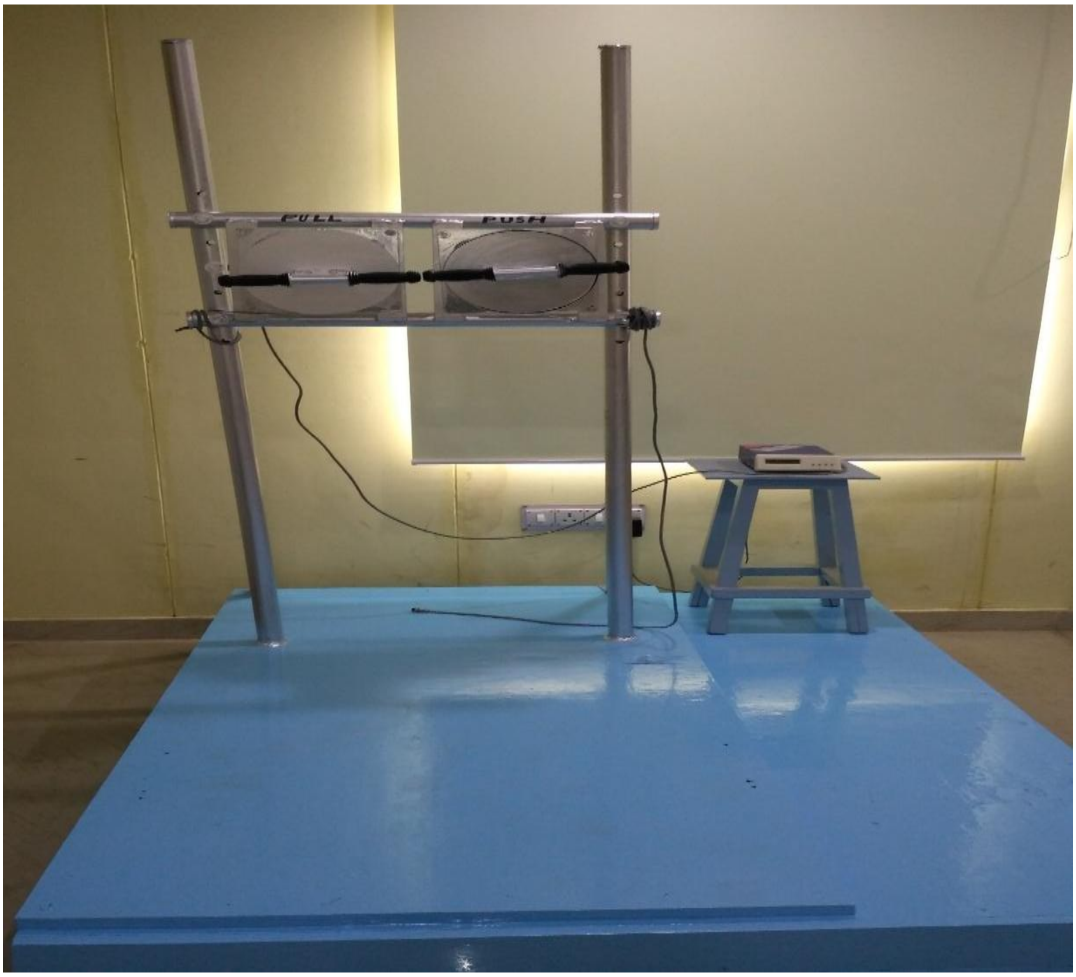
As, the planned hand–operated tool for weeding is push–pull type in operation, it is necessary to collect the push–pull strength data of workers (Refer Appendix–IV). Therefore, the data were collected using the equipment developed as shown in Figure 5.1 which is installed in ergonomics laboratory of the institute.



(a)



(b)



(c)

Figure 5.1: Strength data collection arrangements for (a) push force (b) pull force (c) main equipment

The values for push–pull force in standing postures were also calculated and presented in Table 5.1.

Table 5.1: Isometric push and pull strength of workers (N = 60)

Particulars	Male percentiles		Female percentiles	
	5th	95th	5th	95th
Push force by both hands in standing posture (in N)	182	339	127	233
Pull force by both hands in standing posture (in N)	176	314	132	244

The optimal push and pull strength values were 233 N and 244 N, which is appropriate for the 3–4 hour working operation (Singh et al., 2016).

5.1.2.2 Maximum width of operation

Relationship between mechanics of weeding operation and soil resistance could be expressed as below,

$$F\cos \emptyset_p = w \times d_w \times R_s$$

where, F = workable push force (i.e. 30 percent of 489N and 312N = 147N and 94N) $\emptyset_p$= Angle of operation for hand–operated tool by a manual worker (comfortable working angle 30–45 degree: Gite and Yadav, 1989)

w = Weeding width (in mm)

d_w = Weeding depth (in mm) (15–30 mm for the hand–operated tool for weeding)

R_s = Specific soil resistance (0.02 N/mm^2 for heavy soil up to 150 mm depth: Bernacki et al., 1972)

After computation, width for weeding came in the range of 351–430 mm and 263–322 mm at operation angle 45 and 30° by farm worker (man) for weeding depth of 15 and 30 mm, respectively. In the same way for female manual worker, resultant values for weeding width were 215–263 mm and 161–197 mm. To create it gender–responsive, width was chosen between 200 to 250 mm with a push–pull mode of process.

5.1.2.3 Cutting blades dimensions

Cutting blades were settled in triangular profile with 45° from line of action to allow better weeding operation. The cutting blade was made of mild steel having the specifications as: 150 mm (length) × 45 mm (width) × 4 mm (thick). A 20 mm cutting edge was provided along the length of cutting blade.

5.1.2.4 Rectangular tool post

A rectangular tool post section was provided for cutting blades mounting. Following theories were considered for designing of the tool post:

(i) The tool bar was exposed to torsion and bending moment due to push–pull mode of process and wheel support.

(ii) As maximum push force with both hands is 489 N. Half of the force, i.e. 244 N was considered for a tool bar.

(iii) Ultimate tensile stress of mild steel is 320 N/mm^2.

(iv) Draftability (specific soil resistance) for heavy soil up to 150 mm depth is 0.02 N/mm^2 (Bernacki et al. 1972).

(v) A numerical value between 1 and 4 is desirable for Factor of safety (Krutz et al. 1984). Since maximum depth of weeding operation is only 20 mm under friable moisture condition so uncertainties (risk) will be of moderate level. So factor of safety was kept 4.

(vi) Tool bar was considered as a simple supported beam due to its support on two wheels.

(vii) Few dimensions assumed are as follows:

Maximum depth of operation= 30 mm, Width of blade = 45 mm, Mounting of blade to tool bar = angled (45 degree), Ground clearance of tool bar = 160 mm, Width of tool bar = 200 mm

Weeding cross–section area by blade mounted on shank (mm^2)

= (length of blade (mm) × cos 45°) × maximum depth of operation (mm)

= (175× cos45°) × 30

= 3712.31 mm^2

Draft required for shank = Weeding cross–section area (mm^2) × Draftability (N/mm^2)

= 3712.31 × 0.02 = 74.24 N

Design draft for tool bar = draft × factor safety = 74.24× 4 = 296.96 N

Torque on tool bar by = Draft required by shank (N) each shank × Ground clearance (m)

= 74.2 × 0.160 = 47.52 N–m

In addition to torque on tool bar, bending moment would also be acting on simple supported beam. The maximum bending moment (BM_{max}) will be,

BM_{max} = total weight or force on the tool bar (w, N) × total length of tool bar (l, m)

= (296.96+244) × 0.6 = 324.58 N–m

Equivalent torque (T_e) to torsion and bending moment was calculated using following formula,

$T_e = \sqrt{M^2 + T^2}$, N–m$=\sqrt{327.48^2 + 47.52^2}$ = 328.1 N–m

The maximum shear stress developed on the tool bar frame was obtained using following formula,

$$f_s / R = T / J$$

where, f_s = Shear stress at any section, R = distance of the section from neutral axis = b/2, T = Equivalent torque (N–mm), J = Polar moment of inertia

Design stress = Ultimate stress/ Factor of Safety = 320 N/m^2/4 = 80 N/m^2

$80/ (b/2) = 328036/ (5b^4/96)$

$160/b = 328036 \times 96/ 5b^4$

$b^3 = 328036 \times 96 /800$

b = 34.01 mm ≈ 35 mm

Therefore, for better running of the equipment, the length will be considered 40 mm. The ratio of length and thickness in rectangular section was taken 1:5, means b= 5t. Therefore, thickness of mild steel rectangular section will be 8 mm.

Hence, design section of a mild steel tool post is 40 × 200 × 8 mm.

5.1.2.5 Handle length and height

Anthropometric data of nearby state Madhya Pradesh, India (Gite et al., 2009: Table 5.2) were used to calculate the handle length. For better efficiency, a grip strength analysis was done and the outcomes shows that the elbow flexion angle (β) should be 90 degree. Various researches have recommended a value of 50–60° for the angle between the hand–operated tool blades and handle (θ) (Rogan, 1992).

Table 5.2: Anthropometric dimensions used for design

Particulars	**Male percentiles**		**Female percentiles**	
	5^{th}	95^{th}	5^{th}	95^{th}
Shoulder height	1256	1468	1168	1353
Elbow–elbow breadth	297	452	286	413
Grip diameter (inside)	39	57	35	55
Middle finger palm grip diameter	18	38	20	31
Elbow height	938	1115	883	1037
Metacarpal III height	616	763	581	718
Metacarpal III to elbow height	322	352	302	319

After considering the elbow height (x) and knuckle to elbow height (y) from the anthropometric records of India, the optimum length of the handle (Z) could be easily found. The handle length can be given by

$$Z = \frac{X+Y\cos\beta}{\sin\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.1)$$

The calculated inclined handle length (Z) using equation (5.1) at different conditions are given in Table 5.3.

Table 5.3: Optimum handles length

Particulars	**Male percentiles**		**Female percentiles**	
	5^{th}	95^{th}	5^{th}	95^{th}
β= 90 degree, θ= 50 degree	1224.47	1455.53	1152.67	1353.71
β= 90 degree, θ= 60 degree	1083.11	1287.49	1019.61	1280.42

From Table 5.2 and Table 5.3, it is obvious that optimum handle length varied from 1019 to 1456. An optimum handle length was perceived to 1280 mm for both male and female manual workers.

5.1.2.6 Cross–bar handle length and type

As this operation is continuous work, the desirable position of holding the bar handle should be in the line of the arms, for least fatigue. Therefore, elbow–elbow breadth is to be considered for handle bar length. As the equipment is to be operated by both male as well as female workers, 95thpercentile elbow–elbow breadth of male workers was considered.

The 95thpercentile value of the elbow–elbow breadth for female and male workers is 413 and 452 mm, respectively. Therefore the handle bar length can be taken as 450 mm in cylindrical shape for better grip. Also, the diameter of the handle is 32 mm.

5.1.2.7 Wheel dimensions

On the basis of above design calculations, the hand–operated tool for weeding was developed. The ground clearance of 150 mm was considered on the basis of initial weeds height which was detected as maximum of 160 mm. In wide–row crops, usually weeding is desired up to one month and after that crops survive. After considering this thing, the wheel of 320 mm diameter was chosen. Both of the wheels were fixed independently so that effortless moving/turning can be made on both of the wheels.

5.1.2.8 Frame dimensions

The length of weeding blade assembly was retained in such a style that gap for hand breadth through thumb, i.e. 110 mm (95thpercentile of farmers) could be provided for easy assembling/disassembling of blades. Thus, length and width of assembly was kept 20 × (200 – 250 mm). Three (200 mm width) or four (250 mm) square holes of 10 mm diameter was made for mounting the blades. The wheel–base of the weeding tool was 300 mm.

The weeding blade was aimed for chopping/slicing the weed at narrow depth, i.e. 15–30 mm. The weeding blade was attached on the rectangular assembly at 90° with lower edge at 45° from line of action of hand–operated tool. Also, such types of weeding blades were jointed to make a double pointed tip at every blade. This type of double pointing blade enables to decrease the shearing force, necessitates less force/cm cutting width in this manner as compared to cutting in straight manner. The specification of every blade was 150 × 40 × 4 mm and its rake angle was 30°. The depth modification was provided by moving the blade up–down.

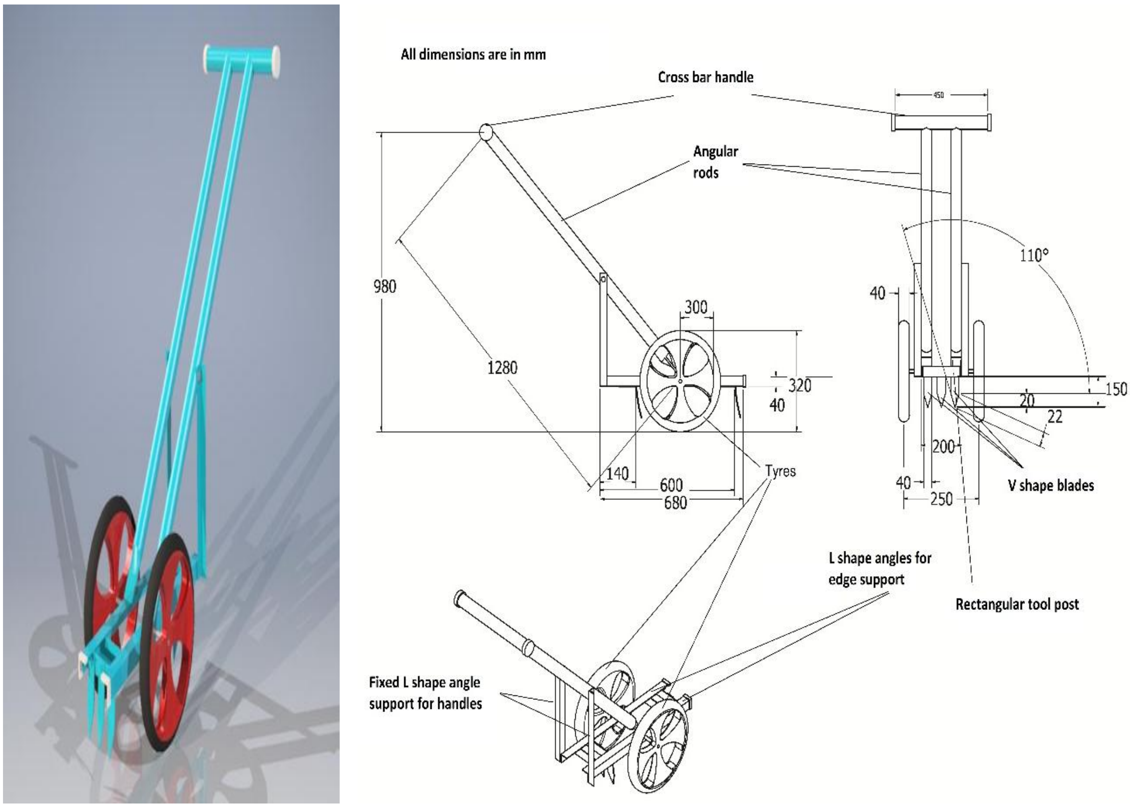
Handle was mounted with the tires on the 2^{nd} hole which is at 400 mm distance from the back end. The handle was fabricated utilizing two mild steel hollow pipes (1280 mm) parallel to each other. These pipes were further mounted on L–shape mild steel plate with another pipe on both corners (45 mm diameter) over it. Table 5.4 shows the technical specifications of proposed hand–operated tool for weeding.

Table 5.4: Technical specifications of the hand–operated tool for weeding

Particulars	Detail
Overall dimensions , (L × W × H), in mm	680 × 20 × 20
Weight, in kg	13
Size of wheel (diameter × width), in mm	300 × 25
Wheel base, in mm	300
Ground clearance, in mm	150
Size of weeding blade mounting, (L × W × T), in mm	40 × (200–250) × 20
Number of mounting	2
Handle dimension (L × W), in mm	1280 × 20
Size of cross bar handle, (diameter × L), in mm	32 ×450
Rake angle, in degree	30
Number of weeding blades	3 (200 mm row spacing), 4 (250 mm row spacing)
Size of weeding blade, (L × W × T), in mm	150 × 45 × 4
Length of sharpening in weeding blade, in mm	20

5.2 Digital human modeling of proposed dimensions

On the basis of technical specifications computed in the previous section a simulation model was developed in Autodesk inventor 2016 for checking the overview of the design. The developed design is presented in the Figure 5.2.



(a) (b)

Figure 5.2: Model designed in Autodesk inventor 2016: (a) physical view (b) orthographic views

For getting more clarity about the usability of the design in the field, feasibility of the proposed design was checked using ergonomic assessment method (RULA) in CATIA V5 and the results of the ergonomic assessment method is presented in Figure 5.3.

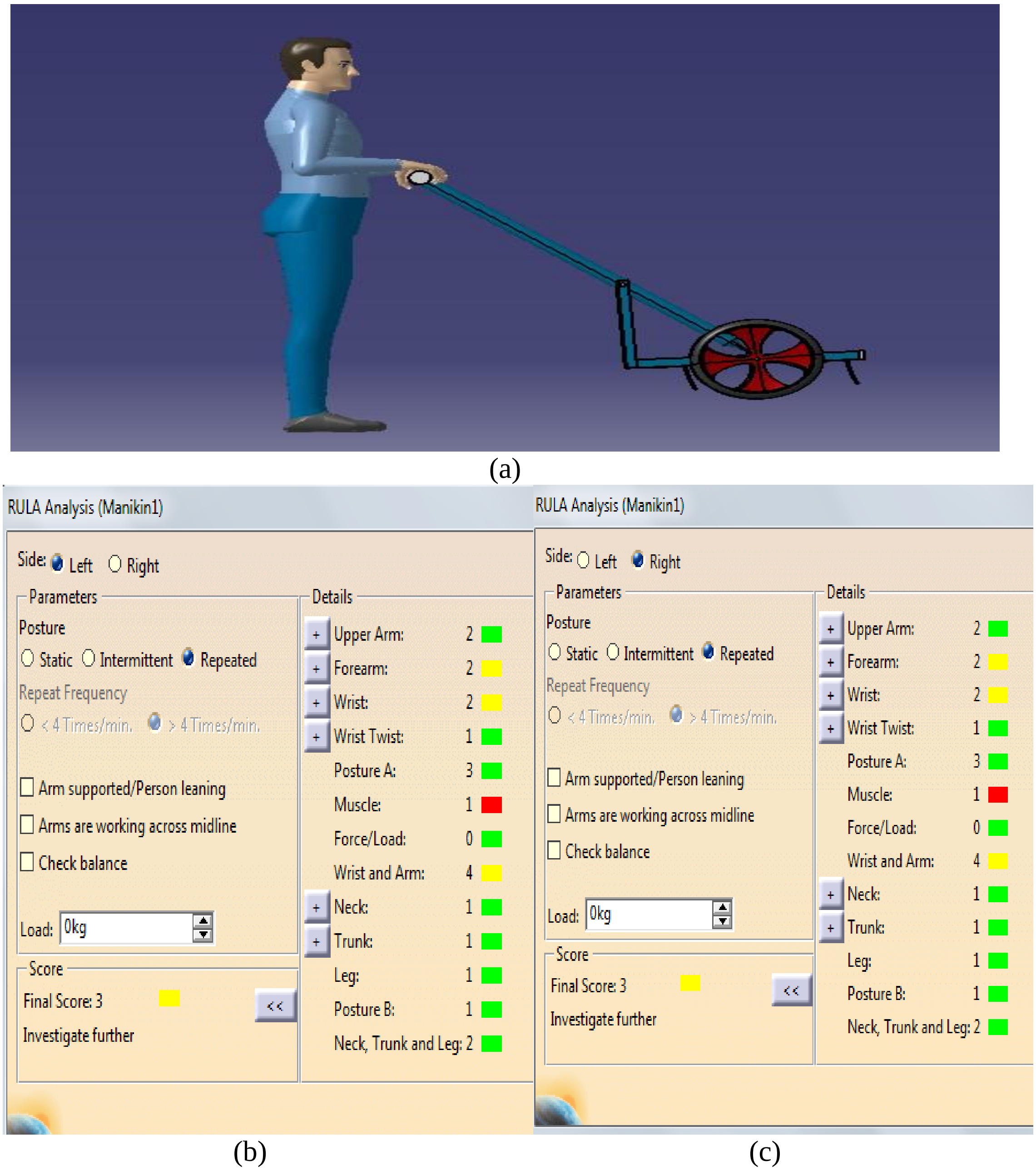


Figure 5.3: Ergonomic analysis in CATIA V5 (a) manikin with proposed model (b) RULA analysis left side (c) RULA analysis right side

5.3 Experimental testing and validation for proposed hand–operated tool

The functioning of the developed hand–operated tool was tested in the field as displayed in Figure 5.4.

Figure 5.4: Testing of the hand–operated tool in the field

The test was carried out in three series of short run tests. Speed of travel in km/hour was calculated using a stop watch. The field capacity in hectares/hour of the tool was calculated by fixing the area of 2000 m^2 (200m x 10 m).

The draft required by the hand–operated weeding tool was calculated using the equation (5.2).

$$D = W \times d_w \times R_s \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.2)$$

where, D = Draft of a tool, (kg), W = Width of cut, (cm), d_w = Depth of cut, (cm), R_s = Soil resistance, (kg/cm^2)

Weeding index can be calculated using the following equation (5.3) (Yadav and Pund, 2007).

$$\text{Weeding index (e)} = \frac{W1-W2}{W1} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.3)$$

where, W_1 = number of weeds per area before weeding, W_2 = number of weeds per area after weeding

The power input required for weeding operation was calculated by considering draft and traveling speed with equation (5.4)

$$\text{Power (hp)} = (D \times S) / 75 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.4)$$

where, D = Draft, (kg), S = Travelling speed, (m/sec)

Plant damage percentage is measured using the following equation (5.5) (Yadav and Pund, 2007).

$$Q = (1 - \frac{q}{p}) \times 100 \text{ ……………………………… } (5.5)$$

where, Q = plant damage, q = number of plant in a 6m row length after weeding, p = number of plant in a 6m row length before weeding

Field capacity of the tool was calculated using the below equation (5.6)

$$\text{Field capacity (a)} = \frac{A}{t} \text{ ………………………….. } (5.6)$$

where, A= area to be weeded (in ha), t = time taken for the weeding (in hour)

The hand–operated weeding tool performance was accessed through performance index (PI) by using equation (Yadav and Pund, 2007)

$$PI = \frac{aqe}{P} \text{ …………………………….. } (5.7)$$

where, a = field capacity of tool (ha/hr), q = plant damage (%), e = weeding index (%), P = Power input, HP

The hand–operated tool for weeding was evaluated by considering the following assumptions made in the previous findings by various researchers (Yadav and Pund, 2007; Singh et al., 2016):

(a) Travelling speed considered (0.6 m/s, 0.7 m/s and 0.8 m/s)

(b) Variable for operation: width of cut = 20–25 cm, depth of cut = 3 cm, Sand type: soft clay sand with soil resistance 0.02 kg/cm^2

(c) The plant damage index was considered as NIL. It is considered that the plants are seeded in a row and plants are not present between the rows.

On the basis of these assumptions, the following conditions were assumed for testing the hand–operated tool for weeding

(a) 20 cm width of cut achieved at three travelling speeds

(b) 25 cm width of cut achieved at three travelling speeds

For these conditions three levels of three parameters were developed using equations (5.2) – (5.7) which is presented in Table 5.5 and Table 5.6.

Table 5.5: Parameters used and their levels for 20 cm depth of cut

Symbol	Control parameters	Unit	Level 1	Level 2	Level 3
A	Weeding index	–	83.33	86.67	88.89
B	Field capacity	ha/h	0.025	0.0303	0.0313
C	Power input	HP	0.0096	0.0112	0.0128

Table 5.6: Parameters used and their levels for 25 cm depth of cut

Symbol	Control parameters	Unit	Level 1	Level 2	Level 3
A	Weeding index	–	83.33	86.67	88.89
B	Field capacity	ha/h	0.025	0.0303	0.0313
C	Power input	HP	0.012	0.014	0.016

On the basis of these conditions, the performed experiments are presented in Table 5.7 and Table 5.8.

Table 5.7: Experiments conducted for 20 cm depth of cut

Experiment number	Weeding index	Field capacity	Power input
1	83.33	0.0250	0.0096
2	83.33	0.0303	0.0112
3	83.33	0.0313	0.0128
4	86.67	0.0250	0.0112
5	86.67	0.0303	0.0128
6	86.67	0.0313	0.0096
7	88.89	0.0250	0.0128
8	88.89	0.0303	0.0096
9	88.89	0.0313	0.0112

Table 5.8: Experiments conducted for 25 cm depth of cut

Experiment number	Weeding index	Field capacity	Power input
1	83.33	0.0250	0.012
2	83.33	0.0303	0.014
3	83.33	0.0313	0.016
4	86.67	0.0250	0.014
5	86.67	0.0303	0.016
6	86.67	0.0313	0.012
7	88.89	0.0250	0.016
8	88.89	0.0303	0.012
9	88.89	0.0313	0.014

5.3.1 Optimization of selected parameters for operation of designed hand–operated tool

In the current research, the Taguchi method, a powerful tool to design for quality, was used to find the optimal process parameters for hand–operated tool for weeding that was used for manual working/manual weeding.

An orthogonal array, main effect, the signal–to–noise (S/N) ratio, and analysis of variance (ANOVA) were employed to investigate the selected parameters in order to achieve optimum performance of the tool so as to get maximum PI. Through the current research, not only the optimal process parameters for tool can be obtained, but also the main process parameters that affect the PI of the tool can be found. Experiments were carried out to confirm the effectiveness of this approach. From the results, it is found that operation parameters, i.e. plant damage, draft required and power input significantly affect the PI of the tool for different weeding indexes.

5.3.1.1 Analysis of signal to noise (S/N) ratio

PI were calculated using the experimental design for every group of the regulating factors using Taguchi methods, optimization of the calculated regulating factors were done using signal–to–noise (S/N) ratios. The higher values of PI was very significant for greater productivity for the weeding operation that's why the ''larger–the–better'' formula was utilized for the computation of the S/N ratio. Table 5.9 demonstrates the values of the S/N ratios for observations of the PI for both conditions.

Table 5.9: Outcome of investigations and S/N ratio values

Experiment no.	PI (at 20 cm)	S/N ratio for PI_{20}	PI (at 25 cm)	S/N ratio for PI_{25}
1	21700.52	86.7294	17360.42	84.7912
2	22543.74	87.0605	18034.99	85.1223
3	20376.79	86.1827	16301.43	84.2445
4	19345.98	85.7318	15476.79	83.7936
5	20516.41	86.2420	16413.13	84.3038
6	28258.03	89.0228	22606.43	87.0846
7	17361.33	84.7917	13889.06	82.8535
8	28055.91	88.9605	22444.73	87.0223
9	24841.58	87.9036	19873.26	85.9654

Means: PI_{20} = 22555.59, PI_{25} = 18044.47 $PI_{20-S/N}$ = 86.96, $PI_{25-S/N}$ = 85.02

At the end of the weeding operations, the mean values of the PIs were computed to be 22555.59 and 18044.47 respectively. Similarly, mean values of S/N ratio for PIs were computed to be 86.96 dB and 85.02 dB respectively.

Exploration of the effect of every regulating factor (plant damage, weeding index, power) on the PIs was done with a ''S/N ratio reaction table''. The reaction tables of S/N ratio for PIs are presented in Table 5.10.

Table 5.10: S/N ratios reaction table for PIs

Levels	Regulating factors					
	PI_{20}			PI_{25}		
	A	B	C	A	B	C
Level 1	86.66	85.75	**88.24**	84.72	83.81	**86.30**
Level 2	87.00	87.42	86.90	85.06	85.48	84.96
Level 3	**87.22**	**87.70**	85.74	**85.28**	**85.76**	83.80
Delta	0.56	1.95	2.50	0.56	1.95	2.50

The above table shows the optimal levels of regulating factors for the optimal PI values. The values of regulating factors for PIs given in Table 5.10 are presented by graphical formats in Figures 5.5 and 5.6.

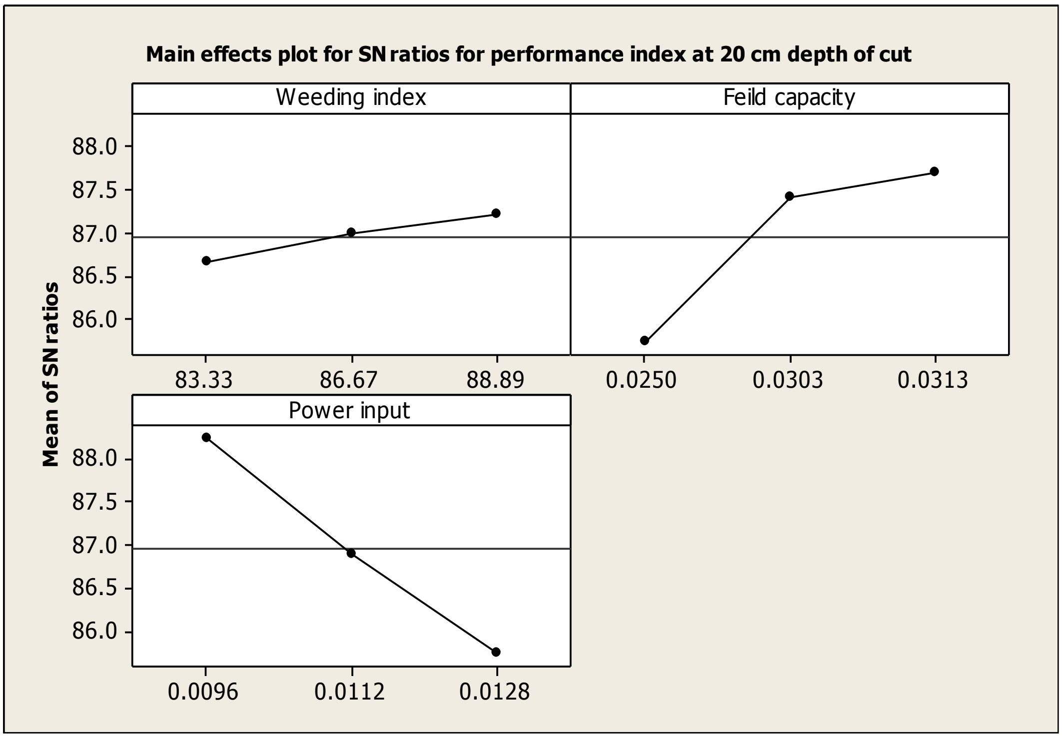


Figure 5.5: Effect of operating parameters on mean S/N ratio for PI_{20}

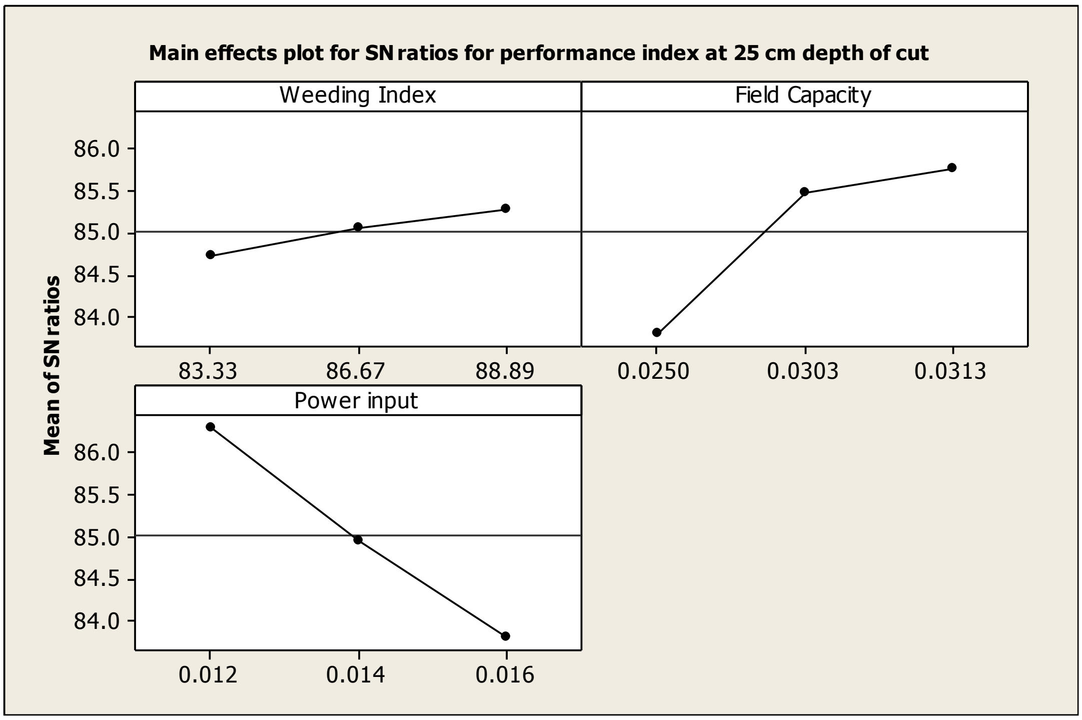


Figure 5.6: Effect of operating parameters on mean S/N ratio for PI_{25}

Optimal parameters of the regulating factors for maximizing the PI can be simply defined from this graphical representation. The greatest level for every regulating factor was discovered according to the peak S/N ratio in the levels of that regulating factor. As per the different levels and S/N ratios for all of the regulating factors giving the best PI_{20}

value were identified as factor A (Level 3, S/N = 87.22), factor B (Level 3, S/N = 87.70) and factor C (Level 1, S/N = 88.24). From Figure 5.5, it is clear that an optimum PI_{20} value was achieved with a weeding index of 88.89 (A3), at field capacity (B3) 0.0313ha/h and at a power input (C1) 0.0096HP. Similar type of conditions was obtained for PI value at 25 cm depth of cut.

5.3.1.2 Evaluation of investigational outcomes

The changes in the PIs which were obtained as the outcome of experimental investigation. Depending on the difference of the weeds in the field, there was not much change in the PI values. This may be a result of the rapid decrease in the productivity due to the lesser field capacity. The field capacity may also accelerate the increment of the productivity. However, for the lesser power input, the higher amount of field can be weeded at lesser field capacity, this will help to increase the PI of hand–operated tool for weeding.

It was noticed that the mostly affecting parameter in the increase of PI was field capacity. Because the PI is proportionately depends on the field capacity, an increasing rate of field capacity caused a significant increase in the PI values. Similarly, an increase in rate of field capacity had an important effect on the decrease of weeding index. This nature causes positive or negative effect on the productivity. Extremely high rate of field capacity and lesser power input were observed to be effective in the increase of PI. As a result, the lesser power input gained a benefit over the higher power input in gaining lower values of field capacity that will further provides better PI. The graphical figures presenting the effects of the regulating factors achieved through the Taguchi method (Figures 5.5 and 5.6) on the mean changes of PIs verify the outcomes obtained from the investigational studies.

5.3.1.3 ANNOVA analysis

ANOVA is a statistical technique which is utilized to determine the specific relations of all of the regulating factors in the experimental design. In the current research, ANOVA was utilized to examine the effects of various parameters used during weeding operation on PI of hand–operated tool. The ANOVA outcomes for the PI are presented in Table 5.11. The ANNOVA test was carried out at 95% confidence level. The significance of regulating factors in ANOVA test is found by assessing the F values of every regulating factor. The last column of the Table displays the percentage contribution of every parameter which specifies the degree of effect on the performance of process. From Table 5.11, it is clear that the percent contributions of the A, B and C factors on the PIs were found to be 4.7%, 38.1% and 56.6% respectively.

Table 5.11: ANNOVA Outcomes for PIs

Variation source	Degree of freedom (DOF)	Sum of squares (SS)	F ratio	Contribution rate (%)
PI_{20}				
A	1	5397519	41.51	4.7
B	1	43792266	336.79	38.1
C	1	65075786	500.48	56.6
Error	5	650131		0.6
Total	8	114915702		100
PI_{25}				
A	1	3454412	41.51	4.7
B	1	28027050	336.80	38.1
C	1	41648503	500.48	56.6
Error	5	416084		0.6
Total	8	73546049		100

Therefore, the most significant factor influencing the PIs were power input and field capacity (Factor C, 56.6% and Factor B, 38.1 %). The % of error was significantly low at 0.6 % for PIs respectively.

5.3.1.4 Regression analysis of various performance index

Regression analyses are utilized for the modelling and investigating of various variables where the association among a dependent variable and one or more independent variables was found. In the current research, the dependent variables are PIs, whereas the independent variables are plant damage, field capacity and power input. Forgetting analytical equations for the PI, regression analysis was utilized. These equations were made for normal linear regression models and all the equations are given below.

PI_{20} = – 6670 + 338.89 × (Weeding index) + 797935 × (Field capacity)–
2.05833e+006 × (Power input) …………………………….. (5.8)

R–Sq. = 99.43% R–Sq. (Adj.) = 99.09%

PI_{25} = –5336 + 271.112 × (Weeding index) + 638348 × (Field capacity) –
1.31733e+006 × (Power input) …………………………….. (5.9)

R–Sq. = 99.43% R–Sq. (Adj.) = 99.09%

Here PI_{20} and PI_{25} displays the analytical equations of PIs respectively. R^2 values of these equations which were achieved by linear regression model for PI_{20} and PI_{25}were found to be 99.43%for both.

5.3.1.5 Confirmation tests

Confirmation tests of the regulating factors were achieved for the Taguchi technique and regression equation at optimum and random levels. In Table 5.12, the comparison of test outcomes and the projected values achieved using the Taguchi technique and regression equations (Equations (5.8)–(5.9)) are provided. The projected and experimental values are very near to each other. The error values must be less than 20% for reliable statistical analyses (Cetin et al., 2011). Therefore, the outcomes achieved from the confirmation tests reveal effective contribution of the parameters.

Table 5.12: Projected values and confirmation test outcomes by Taguchi technique and regression equation

Level	Taguchi technique			Regression equation		
	Experimental	**Predicted**	**Error**	**Experimental**	**Predicted**	**Error**
PI_{20}						
$A_3B_3C_1$ (Optimum)	26367.5	25376.1	3.76	27090.85	25376	6.33
$A_1B_1C_2$ (Random)	17750.2	16818.3	5.25	17971.92	16818.1	6.42
PI_{25}						
$A_3B_3C_1$ (Optimum)	23461.2	22935.7	2.24	23169.49	22935.5	1.01
$A_1B_1C_2$ (Random)	16091.8	14772.31	8.20	15979.93	14771.8	7.56

From the outcome of Taguchi technique, optimal condition for operating the tool was identified as: weeding index – 88.89, field capacity – 0.0313 and power input of 0.17 HP. On the basis of the optimized parameter condition, it is easy to conclude that the travelling speed of 0.6 m/s is best for both the cutting width which results high PI, means higher productivity can be achieved at this speed.

5.4 Ergonomic evaluation of hand–operated tool

In entire intervention/tool development procedure participatory methodology was implemented, from the initiation of design idea to every concept making stages. A number of manual workers were taken into self–assurance that the new hand–operated tool for weeding would support them well and running on ease of comfort.

The below criteria were considered during the ergonomic testing of tool:

No. of participants: 30 workers (physical characteristics are presented in Table 5.13).

Table 5.13: Demographic characteristics of participants

Particulars	Mean (SD) or frequency
Age	29.6 (6.3)
Gender	10 Male, 10 Female
Weight	64 (6.2)
Stature	168.7(5.4)

No. of treatments 2 (With or without the new tool)

Parameters for comparison to evaluate benefits of using new device: MSDs (pain feeling) and usability scale (Appendix–III).

5.4.1 Subjective response of MSDs

On the basis of human body map of upper extremity for MSDs reporting, musculoskeletal difficulties were determined at two point scale as per method defined in earlier chapter. The results of MSDs reporting during the tool evaluation is depicted in Table 5.14.

Table 5.14: Musculoskeletal difficulties while performing weeding operation with and without intervention/tool (N = 30)

Body part	**With intervention**		**Without intervention**	
	Last 15 days	Last one month	Last 15 days	Last one month
Neck	6.67	16.67	33.33	50
Upper back	3.33	6.67	43.33	46.67
Shoulders	3.33	3.33	50	50
Lower back	3.33	6.67	66.67	73.33
Wrists/hands	10	6.67	56.67	66.67
Fingers	10	3.33	30	40
Elbows/forearms	10	13.33	26.67	33.33
Hips/thighs	0	0	6.67	13.33
Knees	3.33	0	6.67	10
Foots/ankles	3.33	3.33	10	10

Working with the new designed hand–operated tool for weeding produced significant decrease in pain concerning to fingers pain (10%) followed by hands/wrists pain (10%). There was significant reductions in lower back and shoulder were observed while weeding was performed with the newly designed tool. In case of elbow pain it was obtained more i.e. 13.33% (Table 5.14). Workers were not familiar to work with these type of tools and also the device firstly restricts free movements due to dryness of soil furthermore for day long work it work smoothly, these may be possible reasons for increment in pain.

5.4.2 Usability evaluation

Evaluation of hand–operated tool for weeding was also done using self–reporting tool questionnaire. The standard hand tools have the lowest rating of discomfort and other parameters, while newly designed tool ranked as the most favourite tool by all participants (see Table 5.15).

Few participants believed that newly designed hand–operated tool for weeding was less productive, while the large amount of the participants rated productivity at the same level using both type of tools. The newly designed tool required higher or equal amount of rest break as compared to traditional hand tool used by the farm workers. However, the working on existing tool was highly repetitive in nature.

Table 5.15: Outcomes of self–reported usability evaluation

Particulars	Existing intervention (Using Khurpa)	Newly designed hand–operated tool
Comfort	2.5	3.9
Force required	–	3.4
Ease of use	2.43	4.53
Hand discomfort	2.13	3.07
Productivity	2.97	3.96
Rest break	3.47	2.87

After usability evaluation, a solution was provided by the participants. For easy assembling and disassembling of the rectangular tool bar, the middle part of the cross bar handle length should be replaced with mix of circular and flat angle, so that adjustment of rectangular tool post can be done easily. The final specification of the tool is provided in the Table 5.16.

Table 5.16: Final specifications of the assembly

Particulars	Detail
Overall dimensions , (L × W × T), in mm	680 × 20 × 20
Weight, in kg	13
Size of wheel (diameter × width), in mm	300 × 25
Wheel base, in mm	300
Ground clearance, in mm	150
Size of weeding blade mounting, (L × W × T), in mm	40 × (200–250) × 20
Number of mounting	2
Handle dimension (L × W), in mm	1280 × 20
Size of circular bar for handle, (diameter × L), in mm	*32 × 40*
Size of the flat angle for supporting circular bar of handle (L × W × T), in mm	*20 × 410 × 20*
Rake angle, in degree	30
Number of weeding blades	3 (200 mm row spacing), 4 (250 mm row spacing)
Size of weeding blade, (L × W × T), in mm	150 × 45 × 4
Length of sharpening in weeding blade, in mm	20

5.5 Productivity evaluation

Rationally and hypothetically, the hand–operated tool for weeding was having capacity for chopping/slicing/weeding all the weeds same time which arrives under the blades of tool due to its chopping/slicing action. However, in all the experimentations, the weeding effectiveness fluctuated from 95–100% which was primarily due to downturns at some fields. The productivity/efficiency of newly designed tool was obtained for the ratio of actual and theoretical area handling which varied 79–96%. These variations were principally due to considered factors and losses. Manual operation data was also considered for comparing the investigational outcomes (Figure 5.7–5.9).

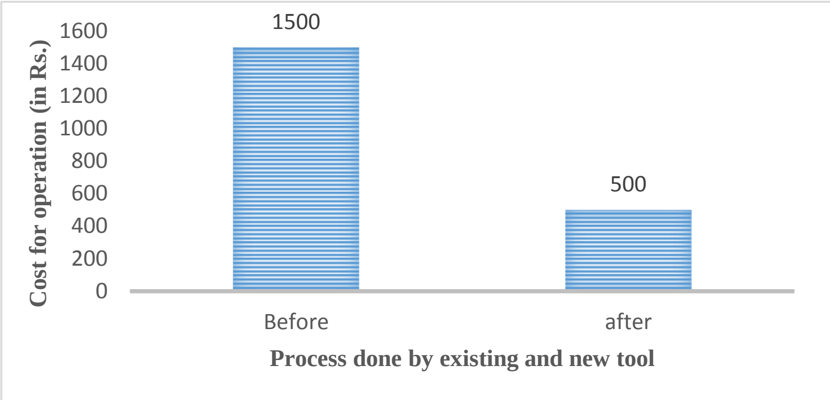


Figure 5.7: Comparison of cost for operation per BIGHA– before and after

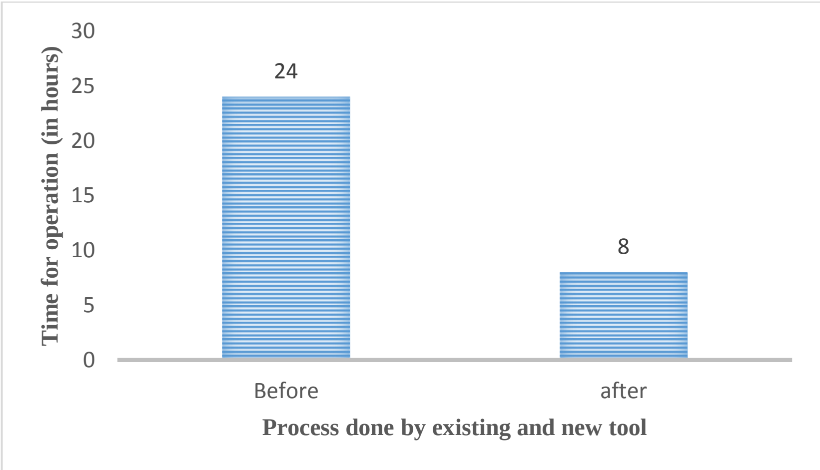


Figure 5.8: Comparison of time for operation per BIGHA– before and after

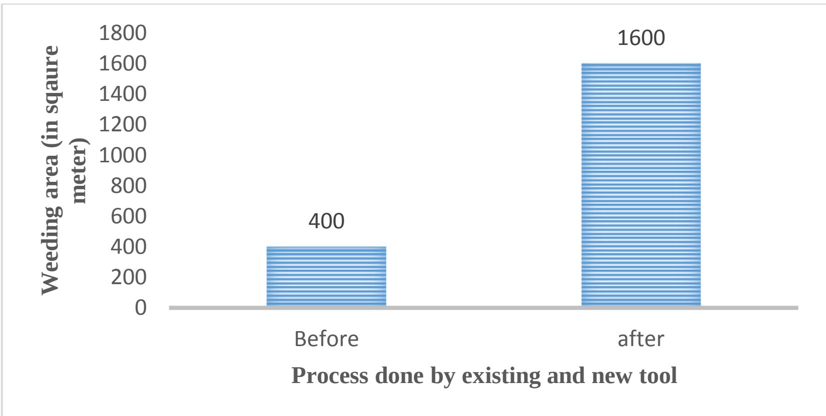


Figure 5.9: Comparison of weeding area covered by machines– before and after

At the time of manual weeding done using khurpa, weeding is performed inside the plant covering also with its removal from the field instantaneously. Therefore, it is reasonable to measure the productivity of farmer by expanding the area enclosed with khurpa, i.e. 50 m^2/h. Despite this estimate for traditional (manual) technique, the productivity of manual worker was 4 to 6 time higher with the newly designed hand–operated tool (Table 5.17). Therefore, the developed hand–operated tool for weeding enabled manual workers in finishing the weeding process timely with lessened drudgery and improved efficiency/productivity.

Table 5.17: Comparison of productivity

Particulars	Weeding operation without intervention (Manual khurpa)	Weeding operation with hand–operated tool
Weight	300 g	13 kg
Row to row spacing (in mm)	50–100	200–250
Weed count /m^2	50–100	100–300
Variations in weeds height, mm	100–150	100–200
Average width of weeding, mm	110	200–250
Average depth of weeding, mm	10–20	50–100
Soil type	Sandy clay	Sandy clay, hard clay
Posture	Squatting and Sitting	Standing
Effective weeding area, m^2/h	24.3	100–150
Weeding efficiency, %	99.8	81–90
Cost of equipment, in INR	150–300	1500–3000
Cost of operation (for 1 Bigha), in INR	1500	500

CHAPTER 6

CONCLUDING REMARKS

6.1 Summary of conclusions

In the current study, manual agriculture activities was ergonomically analysed and new ergonomic hand–operated tool was designed and developed which was further evaluated in the real field. Based on the study, the following conclusions can be made:

- Fifty percent of farm workers work in an awkward posture during different manual agriculture activities using un–ergonomic hand tools, which are exposed to MSDs in different body regions– specifically in the lower back, shoulders, fingers and hands/wrists.
- MSDs in one or more body regions were found to be associated with age, daily working in farms, farming experience, gender, hand dominance and perceived work fatigue. The age was majorly associated with MSDs in all body regions except the shoulder, lower back and neck as per the outcome of logistic regression.
- Postural analysis shows that 70 % farm workers are exposed to higher risk in operations like crop cutting/harvesting and weeding.
- The outcomes of grip strength measurement research showed that men participants had a highly GS as compared to women participants.
- For good performance and better force exertions, the tools should be used in the postures like, standing posture with a fixed forward flexed angle of 45° shoulder joint with elbow at 90° and, the forearm and wrist at neutral. The highest value of grip strength is achieved at 32 mm handle diameter.
- An ergonomic design of hand–operated tool for weeding was done for weeding of wide row–spacing crops with range of 200–250mm.
- From the outcome of Taguchi technique, optimal condition for operating the tool was identified as: weeding index – 88.89, field capacity – 0.0313 and power input of 0.17 HP.
- On the basis of the optimized parameter condition, it is easy to conclude that the travelling speed of 0.6 m/s is best for both the cutting width which results high PI, means higher productivity will be achieved at this speed.

- The usability and post assessment examination concluded that, newly designed hand–operated tool for weeding reduces the work–related health problems and improves comfort as well as productivity.
- Current research may be very supportive for Indian agriculture sector towards a better vision and managing the work–related health problems of farm workers.
- The results of the current research provided various strategies like MSDs assessment of upper extremity body parts, optimal posture for grip strength assessment and design strategies for developing the hand–operated tool in manual agriculture activities.
- The methodology developed in the current research can be utilized as an educational tool for improving health and safety status of the agriculture farm workers.
- The developed hand–operated tool can be a good alternative for many other manual activities like gardening (digging/slicing operations).

6.2 Limitations and scope for future work

The major manual working activity, the weeding operation is improved through designing of tool in the current research successfully. However, the current research has some limitations, which future investigators could consider.

- The individual factors (i.e., age, gender) have more significance as compared to the work–related factors, which can be treated as possible confounders in future investigation of MSDs among the farm workers.
- The current research was cross–sectional in design, which avoided an assessment of the connection between cause and effect. Therefore further longitudinal research is needed. In addition, more complex models considering other aspects (e.g., physical and psychological factors) are suggested.
- The sample size may be enlarged. The low number of female participants and their poor response are also limitations of the current research. Therefore, the current research has implications for future research by considering the suitable constraints of female workers.
- The low number of female subjects and their poor response is also the limitation of current study. Therefore, this study has implications for future research by considering the suitable constraints of female workers.
- The questionnaire can be further expanded as that it can be utilized for a global survey around various type of farmers by which the comparison can be done between Indian and farmers of other countries.

- In the current research, testing was done for short duration to assess the influences of the newly designed hand–operated tool for manual agriculture activity. Further examinations can be done to assess productivity in real time environments.
- Various other software may also be utilized for the analysis of biomechanics of the posture.
- The ergonomic design of hand–operated tool was tested in the simulated environment on the workers for finding the optimal conditions for usability of the equipment in the real time environment. The outcomes of the simulating environment were productive for testing the tool in the real time farm environment. Also, the developed tool can be a good alternative for the manual gardening activities. Overall, the tool is best option for manual digging/chopping/slicing operation.

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APPENDIX–I

Survey Questionnaire

The purpose of this questionnaire is to gain an insight from the different problem areas in the farmers of agriculture sector. You are requested to fill it and return back to me. We assure you that the information given by you will fully confidential and will be used for research purpose only.

Section A: Demographics information

The date of inquiry _________/_________/_________

Name: ______________________ Gender: Female/ Male

Marital Status: _________________ Qualification: __________________

What year were you born? ______________

From how many years and months you are doing present type of work? _____years +______ months

On average how many hours a week do you work? ________ Hours a week

How much do you weigh? ________kgs How tall are you? ________ cms.

Monthly Income: __________ Rs.

Are you satisfied with the income?

Strongly satisfied (SS)/ Satisfied(S) / Neither satisfied nor dissatisfied (NSND)/ Dissatisfied (D)/ Strongly dissatisfied (SD)

Are you right–handed or left–handed? 1 right–handed / 2 left–handed

Smoking Habit: Smoker / Non Smoker

Hand tools used:

Are you satisfied with existing tools?

Strongly satisfied (SS)/ Satisfied(S) / Neither satisfied nor dissatisfied (NSND)/ Dissatisfied (D)/ Strongly dissatisfied (SD)

Crop:

Problems in using Hand tools:

Activity:

Section B: Musculoskeletal Health

TROUBLE WITH LOCOMOTIVE ORGAN		
Body region	**To be answered only by those who have had trouble**	
	Have you at any time during the last 12 months been prevented from doing your normal work (at farm or away from farm) because of the trouble?	**Have you had trouble at any time during the last 7 days?**
Neck 1. No 2. Yes	1. No 2. Yes	1. No 2. Yes
Shoulder 1 No 2 Yes, in the right shoulder 3 Yes, in the left shoulder 4 Yes, in both shoulder	1. No 2. Yes	1. No 2. Yes
Elbows 1 No 2 Yes, in the right elbow 3 Yes, in the left elbow 4 Yes, in both elbow	1. No 2. Yes	1. No 2. Yes
Wrist/hands 1 No 2 Yes, in the right Wrist/hand 3 Yes, in the left Wrist/hand 4 Yes in both Wrist/hand	1. No 2. Yes	1. No 2. Yes
Upper back 1. No 2. Yes	1. No 2. Yes	1. No 2. Yes

Your cooperation and valuable participation for answering the questions is highly appreciated.

Thanking You! Name and Signature

APPENDIX–II

Survey Questionnaire: Evaluation of Manual Work

The purpose of this questionnaire is to gain an insight from the different problem areas in the farmers of agriculture sector. You are requested to fill it and return back to me. We assure you that the information given by you will fully confidential and will be used for research purpose only.

Section A: Demographics information

The date of inquiry _________/_________/_________

Name: ______________________ Sex: Female/ Male

Marital Status: _________________ Qualification: __________________

What year were you born? ______________

From how many years and months you are doing present type of work?___years +____ months

On average how many hours a week do you work? ________ Hours a week

How much do you weigh? ________kgs How tall are you? ________ cms.

Monthly Income: __________ Rs.

Income Satisfaction: 0–Satisfied 1–Dissatisfied 2– Neither satisfied nor dissatisfied

Tool Satisfaction: 0–Satisfied 1–Dissatisfied

Are you right–handed or left–handed? 1 right–handed / 2 left–handed

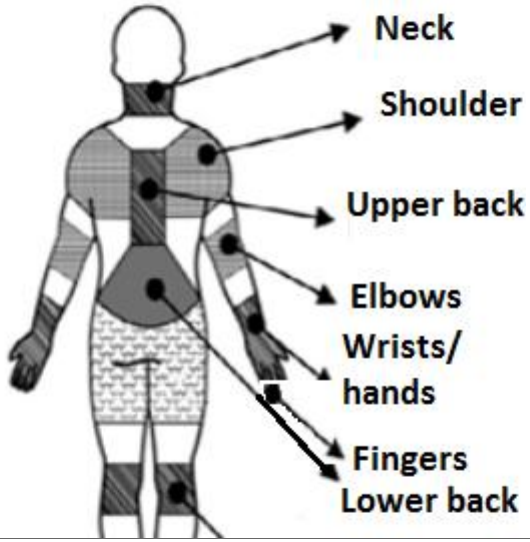
Smoking Habit: Smoker / Non–Smoker

Section B: Musculoskeletal Health

Please tell us about any musculoskeletal discomfort you have experienced in the last six months or musculoskeletal injuries (tick in the figure) you have incurred:

No discomfort (Proceed to next section)

Reporting pain in upper extremity



Body part	For each body area where there's been some pain in past six months (i.e. write '1' or '0' in the bracket below just opposite to the part in the left side)	
	Yes ('1')	No ('0')
Neck	( )	( )
Shoulders	( ) ( )	( )
Upper back	( )	( )
Elbows	( ) ( )	( )
Wrists/hands	( ) ( )	( )
Fingers	( ) ( )	( )
Lower back	( ) ( )	( )

Note– Shoulders, Elbows/forearms, Hands/wrists and fingers boxes provided two brackets. If pain is present in both side (left and right) write '1' in both brackets and if it is on one side write '1' and tick that part in the diagram.

Your cooperation and valuable participation for answering the questions is highly appreciated.

Thanking You! Name and Signature

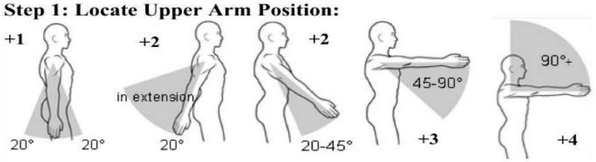
Section C: RULA Score Sheet

RULA Employee Assessment Worksheet

based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

A. Arm and Wrist Analysis

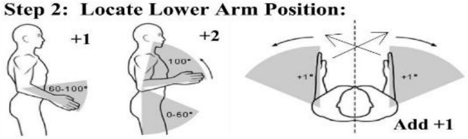
Step 1: Locate Upper Arm Position:



Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

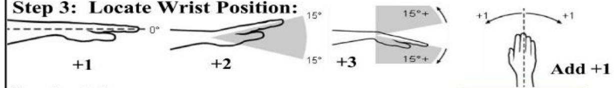
Step 2: Locate Lower Arm Position:



Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:



Step 3a: Adjust...
If wrist is bent from midline: Add +1

Wrist Score

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A
+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>[redacted] 1 min),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score
+

Step 7: Add Force/Load Score
If load < .4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score
=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in **Table C**.

Wrist & Arm Score

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	1 Wrist Twist 1	1 Wrist Twist 2	2 Wrist Twist 1	2 Wrist Twist 2	3 Wrist Twist 1	3 Wrist Twist 2	4 Wrist Twist 1	4 Wrist Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C: Neck, trunk and leg score

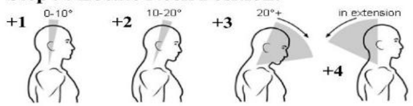
Wrist and Arm Score	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Final Score

B. Neck, Trunk and Leg Analysis

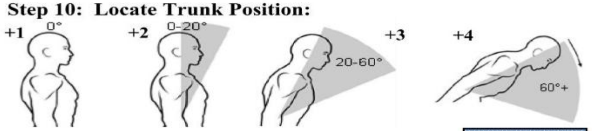
Step 9: Locate Neck Position:



Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:



Trunk Score

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B

Posture Score B
+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>[redacted] 1 min),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score
+

Step 14: Add Force/Load Score
If load < .4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score
=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in **Table C**.

Neck, Trunk & Leg Score

Task name: ______________________________ Reviewer:________________________ Date: _______/_____/_____

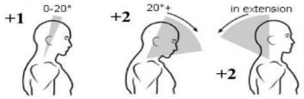
Section D: REBA Score Sheet

REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

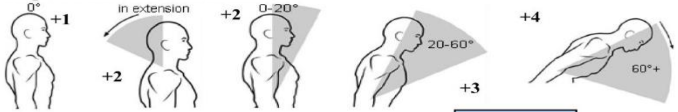
Step 1: Locate Neck Position



Neck Score

Step 1a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

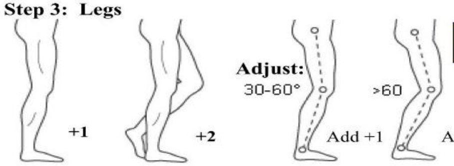
Step 2: Locate Trunk Position



Step 2a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs



Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score

=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A	Neck 1				Neck 2				Neck 3			
Trunk Posture Score / Legs	1	2	3	4	1	2	3	4	1	2	3	4
1	1	2	3	4	1	2	3	4	3	3	5	6
2	2	3	4	5	3	4	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm 1			Lower Arm 2		
Upper Arm Score / Wrist	1	2	3	1	2	3
1	1	2	2	1	2	3
2	1	2	3	2	3	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

Table C

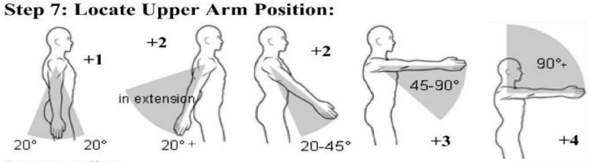
Score A (score from table A +load/force score) \ Score B, (table B value +coupling score)	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score

Final REBA Score

B. Arm and Wrist Analysis

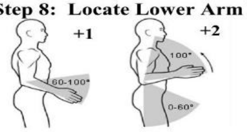
Step 7: Locate Upper Arm Position:



Step 7a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

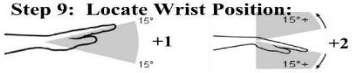
Upper Arm Score

Step 8: Locate Lower Arm Position:



Lower Arm Score

Step 9: Locate Wrist Position:



Wrist Score

Step 9a: Adjust…
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Task name: ________________________ Reviewer:________________________ Date: _______/_____/_____

APPENDIX–III

Tool Usability questionnaire

Please complete the following questions, trying to represent your true feelings for each topic as best as you can. Circle the number of your best answer; if you are unsure just estimate the level as closely as possible.

1. Rate the comfort of the intervention on the following scale.

1	2	3	4	5
Not comfortable	Low comfortable	Neutral	Comfortable	Very comfortable

2. Rate the level of push–pull force required to operate the intervention on the following scale.

1	2	3	4	5
Minimum	Not much	None	A few	Maximum

3. How easy was the tool to use?

1	2	3	4	5
Very, very difficult	Very difficult	Easy	Very easy	Very, very easy

4. Rate the level of hand/wrist discomfort on the following scale.

1	2	3	4	5
Almost none	Almost	A few	Few	Maximum

5. How productive do you feel using this tool?

1	2	3	4	5
Very, very unproductive	Very unproductive	Productive	Very productive	Very, very productive

6. Rate the level of rest required for the use of intervention on the following scale.

1	2	3	4	5
Almost none	A few	Few	More	Maximum

7. Please provide any additional comments regarding the use or comfort of this setup:

………
………
……………………………………………………………………………………………………

Your cooperation and valuable participation for answering the questions is highly appreciated.

Thanking You! Name and Signature

APPENDIX–IV

The collected data during the research work (Necessary dimensions and categorization defined in Chapter 3) are as follows:

1. Ergonomic evaluation of manual agriculture activities (N = 140)

A: Age	B: Gender	C: Body mass index	D: Hand dominance	E: Smoking
F: Schooling	G: Farming experience	H: Daily working time	I: Hand tool satisfaction	J: Salary satisfaction
K: Perceived work fatigue	L: RULA score A	M: RULA score B	N: RULA grand score	O: MSDs score
P: Finger pain	Q: Elbow/forearm pain	R: Neck pain	S: Upper back pain	T: Shoulder pain
U: Lower back pain	V: Hand/wrist pain			

Subject number	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Subject 1	18	1	3	0	0	1	3	1	1	2	1	0	0	0	0	0	0	0	0	0	1	1
Subject 2	18	1	1	0	0	1	5	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Subject 3	18	1	2	0	1	1	5	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1
Subject 4	19	1	2	1	1	1	2	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
Subject 5	19	0	2	0	1	1	5	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
Subject 6	21	1	3	1	1	1	6	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
Subject 7	21	1	4	1	0	2	7	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0
Subject 8	21	1	2	1	1	1	5	1	0	2	1	0	1	1	1	1	1	1	1	1	1	1
Subject 9	21	1	2	1	1	1	7	1	1	0	1	0	1	1	1	1	0	0	0	0	1	1
Subject 10	22	1	3	1	1	1	5	1	1	2	1	1	0	1	1	1	1	1	1	1	1	1
Subject 11	22	1	1	0	1	1	6	1	0	2	2	0	0	1	0	0	0	0	0	0	0	1
Subject 12	23	1	3	1	1	1	5	1	1	1	1	0	0	0	1	0	0	0	0	0	1	0
Subject 13	23	1	2	1	1	1	3	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1
Subject 14	23	0	1	1	1	1	6	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0
Subject 15	23	1	3	1	1	1	5	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1
Subject 16	24	0	2	1	0	0	2	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
Subject 17	24	1	3	1	1	1	2	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Subject 18	24	1	3	1	1	1	2	1	1	1	1	0	0	1	1	1	0	1	0	0	1	1
Subject 19	24	1	2	1	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0

Subject 20	24	1	2	1	1	1	5	1	0	1	1	0	0	1	1	0	0	0	0	0	1	1
Subject 21	24	0	3	1	1	2	3	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Subject 22	25	1	3	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
Subject 23	25	1	2	1	1	1	4	0	1	2	2	1	1	1	0	0	0	0	0	1	0	0
Subject 24	25	1	2	1	0	1	9	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0
Subject 25	25	1	3	1	1	1	6	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
Subject 26	25	1	2	1	1	0	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 27	26	1	3	1	1	1	5	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
Subject 28	26	1	2	1	1	1	7	0	1	2	2	0	0	1	1	1	0	1	0	1	1	1
Subject 29	26	1	2	1	1	1	4	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Subject 30	26	1	3	1	1	1	7	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
Subject 31	27	0	1	1	1	0	4	0	1	0	0	1	0	1	0	0	0	0	0	1	0	0
Subject 32	27	1	2	1	1	1	6	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0
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Subject 39	28	1	3	1	1	1	3	0	1	2	2	0	0	0	1	0	0	0	0	1	0	0
Subject 40	28	1	2	1	1	1	4	0	1	1	1	0	0	1	1	0	0	0	0	0	0	0
Subject 41	28	1	3	1	1	1	3	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1
Subject 42	28	1	3	1	1	2	2	0	1	2	2	0	0	0	1	0	0	0	0	0	0	1
Subject 43	28	1	2	1	1	1	2	0	1	1	1	1	0	1	1	1	1	1	0	1	1	1
Subject 44	28	1	3	1	1	1	8	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0
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Subject 63	33	1	2	1	1	1	9	0	1	0	0	0	0	0	1	1	1	1	1	1	1	1
Subject 64	33	1	1	1	1	1	11	0	1	2	2	0	0	0	1	1	0	1	0	1	1	0
Subject 65	34	1	1	1	1	1	10	0	1	1	1	0	1	1	1	1	0	0	0	0	1	1
Subject 66	34	1	2	1	1	1	13	0	1	0	0	0	1	1	1	1	1	1	1	1	1	0
Subject 67	34	0	2	1	1	1	13	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0
Subject 68	35	1	2	1	1	1	17	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1
Subject 69	35	1	1	0	0	1	12	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Subject 70	36	1	2	0	1	1	20	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1
Subject 71	36	1	2	1	1	1	11	1	1	1	1	0	1	1	1	1	0	0	0	0	1	0
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Subject 81	38	1	1	1	1	1	11	0	1	2	2	1	0	1	1	1	0	1	1	1	1	0
Subject 82	38	1	3	0	1	1	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 83	38	1	2	0	1	1	12	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1
Subject 84	38	1	3	1	1	1	14	0	1	2	2	0	1	1	1	0	0	0	0	1	0	0
Subject 85	38	1	2	1	1	1	12	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1
Subject 86	38	1	2	1	1	1	12	0	1	2	2	0	0	0	1	1	0	0	1	1	1	1
Subject 87	39	1	1	1	1	1	12	0	1	2	2	0	0	1	1	0	0	0	0	1	0	0
Subject 88	39	1	2	1	1	1	14	0	1	0	0	0	1	1	1	1	1	1	0	0	1	1
Subject 89	39	1	3	0	1	1	6	0	1	2	2	0	0	0	1	1	1	1	1	1	1	1
Subject 90	39	1	2	1	1	1	9	0	1	0	0	0	1	1	1	0	0	0	0	1	0	0
Subject 91	39	1	1	1	1	1	9	0	1	1	1	0	0	1	1	1	1	1	0	0	1	1

Subject 92	39	1	2	1	1	1	10	0	1	0	0	0	0	1	1	1	1	0	1	1	1	0
Subject 93	39	1	2	1	1	1	18	0	1	0	0	0	1	1	1	1	1	1	0	0	0	1
Subject 94	39	1	2	0	1	1	13	0	1	1	1	1	0	1	1	1	1	0	1	1	1	0
Subject 95	39	1	2	0	1	1	14	0	1	2	2	1	1	1	0	0	0	0	0	1	1	0
Subject 96	39	1	3	1	1	1	11	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Subject 97	39	0	1	1	0	1	12	0	1	0	0	1	1	1	1	0	0	0	0	1	1	0
Subject 98	39	1	2	1	0	0	13	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0
Subject 99	39	1	2	1	1	1	18	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1
Subject 100	40	1	2	1	1	1	11	0	1	2	2	0	0	1	1	1	1	0	0	1	1	1
Subject 101	40	0	2	0	0	1	12	0	1	2	2	0	1	1	1	0	0	0	0	0	1	0
Subject 102	40	1	2	1	1	1	19	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1
Subject 103	40	1	2	1	0	0	21	0	1	1	1	1	0	1	1	0	0	0	0	1	0	0
Subject 104	40	1	2	1	0	1	22	0	1	1	1	0	0	1	1	1	1	1	0	0	1	1
Subject 105	40	0	2	1	1	0	14	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1
Subject 106	40	1	2	0	0	1	12	0	1	0	1	1	1	1	1	0	0	0	0	0	1	0
Subject 107	40	0	2	1	0	1	12	0	1	2	2	0	1	1	1	1	1	1	1	1	1	1
Subject 108	40	1	1	1	0	0	14	0	1	0	0	0	0	1	1	1	1	0	0	0	1	1
Subject 109	40	1	2	1	1	1	13	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1
Subject 110	40	0	2	1	0	0	14	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0
Subject 111	41	1	2	0	1	1	22	0	1	2	2	0	1	1	1	1	1	1	0	0	1	1
Subject 112	41	1	1	1	1	1	14	0	1	0	0	0	0	1	1	1	0	0	1	1	1	0
Subject 113	42	0	2	0	0	1	10	0	1	1	1	1	0	1	1	1	0	1	0	0	1	1
Subject 114	43	1	2	1	0	1	20	0	1	1	1	0	1	1	1	1	0	0	1	1	1	1
Subject 115	43	1	1	1	1	1	14	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0
Subject 116	44	1	2	1	0	1	10	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1
Subject 117	45	1	2	1	1	0	14	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0
Subject 118	45	1	2	1	1	0	18	0	1	2	2	1	1	1	1	1	1	1	1	1	1	1
Subject 119	45	0	2	1	1	1	14	0	1	1	1	0	0	1	1	1	0	0	0	1	1	0
Subject 120	46	0	1	1	0	1	12	0	1	2	2	1	0	1	1	0	0	0	0	0	0	0
Subject 121	46	0	3	1	0	1	10	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1
Subject 122	47	1	2	1	0	1	19	0	1	0	1	0	0	1	1	1	1	0	0	1	1	1
Subject 123	47	0	3	1	0	1	11	0	1	0	0	1	0	1	0	1	0	0	0	0	1	0
Subject 124	48	0	2	1	0	1	12	0	1	2	2	1	0	1	1	1	1	1	1	1	0	1
Subject 125	49	1	3	1	1	1	13	0	0	2	2	1	1	1	1	0	0	0	0	0	1	1
Subject 126	50	1	1	1	0	0	15	0	1	0	1	0	0	1	0	1	1	0	0	0	1	0
Subject 127	50	0	3	0	1	1	14	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1

Subject 128	51	1	1	1	1	2	19	0	1	0	1	0	0	1	1	1	1	0	1	0	1	1
Subject 129	52	1	2	0	0	1	10	0	1	2	2	0	0	1	1	1	0	0	1	1	1	1
Subject 130	52	0	2	1	1	1	14	0	1	2	2	0	0	1	1	1	1	1	1	1	1	1
Subject 131	53	1	2	0	1	1	18	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1
Subject 132	54	1	2	1	0	0	18	0	1	0	0	0	0	1	1	1	1	0	0	0	1	1
Subject 133	54	1	1	0	0	1	20	0	1	2	2	0	0	1	1	1	1	1	1	1	1	1
Subject 134	55	0	2	1	0	1	12	0	1	1	1	0	1	1	1	1	1	0	0	1	1	1
Subject 135	55	1	2	1	0	2	19	0	1	0	0	0	0	1	1	1	1	0	1	1	1	1
Subject 136	56	1	2	1	0	1	13	0	1	2	2	0	1	1	1	1	1	1	0	0	0	1
Subject 137	56	1	2	1	1	1	14	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1
Subject 138	57	0	2	1	0	0	21	0	1	2	2	1	1	1	1	1	1	0	1	1	1	1
Subject 139	58	1	2	1	1	0	16	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Subject 140	58	1	1	1	1	1	15	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1

2. Grip strength data collection (N = 200)

Sitting		
GS1: Grip strength in neutral wrist position	GS2: Grip strength in 45° wrist extension	GS3: Grip strength in 45° wrist flexion
GS4: Grip strength in neutral forearm position	GS5: Grip strength in 45° forearm extension	GS6: Grip strength in 45° forearm flexion
Standing		
GS7: Grip strength in neutral wrist position	GS8: Grip strength in 45° wrist extension	GS9: Grip strength in 45° wrist flexion
GS10: Grip strength in neutral forearm position	GS11: Grip strength in 45° forearm extension	GS12: Grip strength in 45° forearm flexion

Subject number	**GS1**	**GS2**	**GS3**	**GS4**	**GS5**	**GS6**	**GS7**	**GS8**	**GS9**	**GS10**	**GS11**	**GS12**
Subject 1	44	36	33	38	29	34	43	31	34	39	37	42
Subject 2	38	32	39	37	29	31	45	31	33	39	40	41
Subject 3	39	32	39	31	29	33	40	35	39	35	36	34
Subject 4	39	30	36	38	31	38	45	33	37	43	35	34
Subject 5	40	34	36	32	33	40	38	32	33	42	36	33
Subject 6	44	30	35	33	29	35	38	38	41	34	36	42
Subject 7	35	34	39	34	35	31	33	37	34	34	38	36
Subject 8	41	30	34	39	31	40	36	31	40	38	39	37
Subject 9	35	35	36	33	31	40	43	37	40	45	39	33
Subject 10	37	35	33	36	35	38	34	31	39	44	35	33

Subject 11	42	32	37	32	35	33	39	38	36	48	39	36
Subject 12	33	31	33	41	33	31	43	33	38	42	40	40
Subject 13	36	36	38	38	33	34	40	34	38	36	37	37
Subject 14	36	35	35	39	33	30	38	35	38	35	33	39
Subject 15	41	34	38	35	29	37	33	36	37	39	34	35
Subject 16	40	32	37	38	34	33	37	33	40	40	35	41
Subject 17	36	32	36	34	34	39	40	36	38	43	38	40
Subject 18	37	32	39	36	35	34	36	36	41	36	38	42
Subject 19	41	32	33	40	31	34	41	34	34	34	38	39
Subject 20	32	34	32	31	33	33	43	33	36	37	39	42
Subject 21	35	31	38	33	33	40	41	32	39	35	33	36
Subject 22	39	34	37	33	35	32	45	37	38	37	40	36
Subject 23	37	31	37	41	32	32	39	36	36	48	33	37
Subject 24	43	35	37	39	32	39	38	32	37	47	40	38
Subject 25	38	36	35	38	30	39	42	36	33	45	36	39
Subject 26	36	31	35	32	29	33	43	36	35	40	33	35
Subject 27	39	36	39	34	31	32	34	34	36	43	38	39
Subject 28	35	36	37	40	32	34	43	34	34	40	35	41
Subject 29	32	36	38	37	33	31	36	34	34	39	35	40
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Subject 31	36	30	36	34	35	39	44	34	39	36	37	40
Subject 32	44	34	32	32	33	30	41	37	33	36	33	34
Subject 33	33	35	35	36	32	38	45	33	39	45	39	35
Subject 34	37	31	39	41	29	31	33	33	37	42	39	38
Subject 35	41	35	34	31	34	31	39	36	41	41	32	40
Subject 36	44	36	37	32	31	35	42	38	39	36	33	38
Subject 37	34	32	35	38	32	39	38	35	33	35	37	40
Subject 38	40	34	37	36	33	32	35	32	33	38	34	35
Subject 39	35	34	38	40	35	35	34	35	34	43	38	38
Subject 40	32	34	35	38	29	39	36	38	38	36	34	36
Subject 41	40	31	34	41	32	38	34	35	37	47	35	38
Subject 42	34	32	38	35	34	36	36	37	37	45	38	33
Subject 43	42	33	37	39	32	39	43	32	35	46	38	40
Subject 44	43	34	36	37	33	40	43	34	35	43	35	42
Subject 45	41	36	34	37	30	32	38	31	41	45	40	39
Subject 46	38	36	34	32	31	35	35	31	33	41	37	42

Subject 47	38	32	39	31	32	38	33	35	41	41	35	35
Subject 48	39	30	37	38	34	38	42	35	34	47	37	39
Subject 49	44	35	34	41	32	38	41	32	35	35	40	40
Subject 50	41	30	34	41	32	40	42	32	35	43	34	37
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Subject 52	44	32	39	34	31	33	45	33	40	41	39	41
Subject 53	42	34	35	39	34	32	43	35	33	39	39	35
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Subject 56	34	36	38	35	29	39	36	38	40	40	32	35
Subject 57	44	33	33	38	34	39	40	38	33	44	33	39
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Subject 62	38	32	38	32	29	32	45	32	34	48	33	41
Subject 63	39	31	33	33	34	40	36	35	38	35	37	42
Subject 64	35	33	38	41	30	40	41	34	40	39	36	34
Subject 65	43	31	32	39	29	32	45	38	34	42	36	33
Subject 66	35	34	35	41	29	34	33	34	40	34	40	36
Subject 67	36	30	38	41	31	36	35	38	35	44	32	40
Subject 68	39	34	38	38	29	40	39	37	40	46	32	40
Subject 69	33	34	38	35	34	36	37	33	36	36	36	36
Subject 70	39	32	36	37	29	31	39	35	38	47	40	35
Subject 71	38	35	34	37	35	37	44	34	34	45	32	37
Subject 72	43	35	35	33	35	36	40	31	38	39	39	37
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Subject 74	40	35	32	41	35	34	42	35	36	40	39	41
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Subject 77	37	35	35	40	35	39	44	37	38	43	39	39
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Subject 80	40	33	33	32	30	38	42	35	37	36	38	35
Subject 81	34	35	39	38	29	34	38	37	34	44	35	33
Subject 82	42	36	37	40	35	38	42	31	37	44	40	42

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Subject 161	37	29	34	36	33	34	33	35	33	34	30	35
Subject 162	36	34	36	31	33	29	38	31	31	37	36	32
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Subject 164	37	31	31	32	33	37	38	30	36	42	35	33
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Subject 166	42	33	30	30	28	35	38	35	32	34	31	36
Subject 167	39	32	32	37	28	31	38	36	31	43	36	35
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Subject 169	39	33	37	37	29	34	36	33	34	40	32	40
Subject 170	32	33	33	29	29	30	34	31	36	39	36	32
Subject 171	32	31	33	37	29	35	33	32	33	41	35	35
Subject 172	42	31	31	29	27	34	38	29	30	39	37	40
Subject 173	37	34	31	38	30	36	40	31	31	32	34	38
Subject 174	38	32	31	38	29	31	37	29	31	37	34	32
Subject 175	32	31	33	37	30	29	33	32	32	42	31	34
Subject 176	37	30	37	33	29	37	40	34	36	33	32	31
Subject 177	31	33	34	30	30	34	37	31	36	35	36	31
Subject 178	37	34	35	29	29	28	38	30	31	37	36	37
Subject 179	37	32	34	38	33	30	31	33	33	38	34	36
Subject 180	38	31	32	35	27	31	37	34	30	37	31	40
Subject 181	42	29	32	29	29	29	35	35	32	33	38	37
Subject 182	34	30	34	34	32	34	38	29	33	35	30	32
Subject 183	35	30	36	35	30	37	35	30	31	36	33	33
Subject 184	38	34	33	29	27	33	31	32	32	35	38	40
Subject 185	31	31	32	30	27	28	33	34	32	36	30	34
Subject 186	40	34	37	37	33	30	35	35	37	41	35	39
Subject 187	42	32	36	34	31	28	37	31	33	41	31	39
Subject 188	32	33	32	29	33	35	32	30	31	42	36	34
Subject 189	32	34	31	37	28	28	31	31	35	41	37	32
Subject 190	38	30	34	32	27	29	36	31	36	35	36	32

Subject 191	36	30	32	34	33	33	39	29	30	38	36	37
Subject 192	36	32	36	37	33	31	34	35	32	39	36	31
Subject 193	39	33	35	31	27	33	39	29	31	38	33	36
Subject 194	34	31	35	29	31	36	39	33	33	37	32	37
Subject 195	39	31	33	38	30	36	31	33	31	38	33	40
Subject 196	37	29	31	34	30	30	35	30	34	36	30	36
Subject 197	31	31	33	29	30	37	31	36	30	34	32	34
Subject 198	38	33	36	38	28	32	39	32	34	32	32	33
Subject 199	38	33	31	29	30	34	36	29	37	35	32	34
Subject 200	32	31	35	30	29	34	34	35	37	33	36	38

3. Push and pull strength data collection (N = 60: in kgs)

Subject number	Male (n = 30)		Female (n = 30)		Subject number	Male (n = 30)		Female (n = 30)		Subject number	Male (n = 30)		Female (n = 30)	
	Push	Pull	Push	Pull		Push	Pull	Push	Pull		Push	Pull	Push	Pull
Subject 1	24	22	25	18	Subject 21	33	31	16	27	Subject 41	35	26	17	17
Subject 2	25	33	17	19	Subject 22	28	19	19	15	Subject 42	18	29	17	19
Subject 3	27	19	15	20	Subject 23	27	29	19	14	Subject 43	23	28	16	13
Subject 4	22	21	14	21	Subject 24	27	19	24	23	Subject 44	27	26	18	12
Subject 5	26	26	19	17	Subject 25	28	28	21	19	Subject 45	23	21	21	16
Subject 6	31	13	19	16	Subject 26	41	24	19	20	Subject 46	24	20	20	18
Subject 7	28	32	24	17	Subject 27	20	23	18	22	Subject 47	28	33	21	18
Subject 8	18	21	15	22	Subject 28	32	25	22	24	Subject 48	24	29	15	17
Subject 9	29	29	19	24	Subject 29	22	26	16	15	Subject 49	34	19	16	18
Subject 10	20	30	15	22	Subject 30	28	30	23	21	Subject 50	22	26	14	20
Subject 11	20	23	26	25	Subject 31	22	23	17	22	Subject 51	27	23	19	17
Subject 12	28	22	18	23	Subject 32	33	21	17	19	Subject 52	30	18	18	19
Subject 13	27	29	15	22	Subject 33	31	26	18	21	Subject 53	28	25	27	15
Subject 14	29	25	21	23	Subject 34	32	23	24	14	Subject 54	24	24	15	14
Subject 15	32	26	12	20	Subject 35	27	29	17	18	Subject 55	27	18	18	21
Subject 16	20	30	21	25	Subject 36	20	27	17	17	Subject 56	30	24	15	20
Subject 17	27	23	17	18	Subject 37	15	23	16	14	Subject 57	33	22	15	18
Subject 18	27	22	19	20	Subject 38	27	27	25	20	Subject 58	25	30	15	17
Subject 19	25	27	16	19	Subject 39	30	27	16	27	Subject 59	34	26	19	17
Subject 20	25	33	19	25	Subject 40	20	26	18	19	Subject 60	24	20	16	14

4. Tool evaluation (N = 30)

4.1 MSD evaluation

A: Last 15 days	B: Last one month	N: Neck	UB: Upper back	S: Shoulders	LB: Lower back	0 = No
WH: Wrists/hands	F: Fingers	EF: Elbows/forearms	HT: Hips/thighs	K: Knees	FA: Foots/ankles	1 = Yes

Subject number	Existing tool																				Newly developed hand–operated tool																			
	N		UB		S		LB		WH		F		EF		HT		K		FA		N		UB		S		LB		WH		F		EF		HT		K		FA	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Subject 1	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 2	1	1	0	1	0	1	0	1	0	1	1	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	0	0	1	0	0	0	0	0	0
Subject 3	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 4	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 5	1	1	0	1	1	0	0	0	1	1	1	1	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0
Subject 6	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 7	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 8	0	1	0	1	1	1	1	0	0	1	0	1	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Subject 9	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 10	1	1	1	1	1	1	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Subject 11	1	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 12	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 13	1	0	0	0	1	1	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 14	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 15	1	0	0	1	0	1	1	0	1	1	0	1	1	1	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1
Subject 16	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 17	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 18	0	1	0	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 19	0	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 20	1	1	0	1	0	1	0	1	1	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0
Subject 21	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 22	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 23	1	0	1	1	1	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0
Subject 24	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 25	0	0	1	1	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 26	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 27	1	0	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0
Subject 28	0	1	0	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 29	1	0	0	1	1	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subject 30	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.2 Usability evaluation of newly developed hand–operated tool

Subject number	Comfort		Ease of use		Hand/wrist discomfort		Productivity		Rest/break		Force use in new tool
	Before	After	Before	After	Before	After	Before	After	Before	After	
Subject 1	3	4	5	2	2	2	4	3	4	3	2
Subject 2	4	1	5	4	3	2	2	4	2	3	2
Subject 3	3	4	4	4	4	3	4	2	2	2	3
Subject 4	5	3	5	1	3	2	2	4	2	3	4
Subject 5	3	2	4	3	2	2	4	2	4	4	3
Subject 6	3	4	5	2	5	3	4	4	2	4	4
Subject 7	4	1	5	1	3	2	4	2	4	5	3
Subject 8	5	2	4	4	2	3	5	4	3	4	3
Subject 9	4	1	5	3	2	2	4	3	4	5	4
Subject 10	5	4	4	2	5	2	4	3	2	2	4
Subject 11	3	3	4	4	2	1	5	4	3	3	4
Subject 12	3	1	4	2	3	3	3	3	4	2	2
Subject 13	5	1	5	1	3	3	5	2	2	5	4
Subject 14	4	3	4	2	5	3	5	2	4	3	3
Subject 15	5	1	5	3	4	2	3	2	3	3	4
Subject 16	4	1	5	1	3	3	5	3	2	3	5
Subject 17	3	3	4	4	4	2	2	4	2	5	5
Subject 18	3	2	5	3	2	3	4	3	4	4	2
Subject 19	5	2	4	2	3	2	5	4	2	5	5
Subject 20	4	4	5	2	5	1	4	3	2	2	5
Subject 21	4	4	4	2	2	3	5	2	2	3	2
Subject 22	3	3	5	3	4	2	4	3	3	4	3
Subject 23	3	4	4	1	2	1	3	4	2	3	4
Subject 24	5	2	5	3	3	1	4	2	4	5	4
Subject 25	5	3	4	3	2	1	5	2	3	2	3
Subject 26	5	4	5	2	3	1	4	4	3	4	2
Subject 27	4	1	5	2	2	1	3	2	3	3	3
Subject 28	3	1	4	3	3	3	4	2	4	2	4
Subject 29	4	2	4	3	4	2	5	4	3	3	4
Subject 30	3	4	5	1	2	3	4	3	2	5	2

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Academics

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2014	Post–Graduated from MNIT, Jaipur with a Master of Technology in Mechanical Engineering, Specialized in Manufacturing System Engineering.
2012	Graduated from University College of Engineering, Rajasthan Technical University, Kota, Rajasthan, India with a Bachelor's degree in Production & Industrial Engineering.

Experience

Research	July, 2012 – to date Five years at Malaviya National Institute of Technology, Jaipur
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Publications

More than 20 papers published in various International Journals and Conference proceedings which includes these popular journals like, "Archives of Environmental & Occupational Health", "International Journal of Occupational Safety and Ergonomics", “International Journal of productivity and Quality Management" and “Journal of Industrial Engineering International”.

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PUBLICATIONS FROM PhD WORK

International Journal Papers (Published/Accepted):

- **Jain R.**, Meena M.L., Dangayach G. S., and Bhardwaj, A. K., 2018. "Association of risk factors with musculoskeletal disorders in manual working farmers", *Archives of Environmental and Occupational Health*. 73(1), 19–28 **(SCI, Taylor and Francis Ltd.)**
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- **Jain R**., Meena M.L., and Dangayach G. S. "Interventions for injury prevention in manual farm work: a review", The International Journal of Occupational and Environmental Medicine. **(SCOPUS, NIOC Health Organization)**
- **Jain R**., Meena M.L., and Dangayach G. S. "Impact of posture choice and anthropometric features on two–handed push/pull strength variations at three handle

heights”, The International Journal of Occupational and Environmental Medicine. **(SCOPUS, NIOC Health Organization)**

Paper Presented in International Conferences:

- **Jain R.**, Meena M.L. and Dangayach G. S., “Impact of ergonomic interventions in agriculture sector: a short review”, Published in proceedings of *XVIIIth Annual International Conference of the Society of Operations Management* held at Department of Management Studies & Continuing Education Centre, **IIT Roorkee** during December 12–14, 2014. (ISBN: 978–93–84935–023)
- **Jain R.**, Meena M.L. and Dangayach G. S., “Investigating agriculture farmers working on hand tools in Rajasthan”, Published in proceedings of *HWWE 2015* held at **IIT Mumbai** during December 6–9, 2015. (ISBN: 978–93–5258–836–7)
- **Jain R.**, Meena M.L., Dangayach G. S., and Bhardwaj, A. K., “The effect of different hand positions on capability of hand–grip strength”, published in proceedings of *IJIE 2016* held in Seoul, **South Korea** during October 10–12, 2016. (**International Travel grant Sponsored by Science and Engineering Research Board, Department of Science and Technology, New Delhi**)
- **Jain R.**, Meena M.L., Dangayach G. S., and Bhardwaj, A. K., “Grip strength as a function of combined hand positions for agriculture farmers”, published in proceedings of *HWWE 2016* held at **NIT Jalandhar** during December 8–11, 2016. (ISBN: 978–93–83006–81–6)
- **Jain R.**, Meena M.L. and Dangayach G. S., “Isometric push/pull strength of Indian male participants at three handle heights”, Published in proceedings of *HWWE 2017* held at **AMU, Aligarh** during December 8–10, 2017. (ISBN: 978–93–86724–25–0)