Designing and Evaluating an Ergonomic Intervention to Minimise Risk of Musculoskeletal Disorders in Indian Small and Medium Scale Cashew Nut Processing Mills

A thesis submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

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Dedicated to

my parents and my teachers

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Declaration

I hereby declare that the work contained in this thesis entitled "Designing and Evaluating an Ergonomic Intervention to Minimise Risk of Musculoskeletal Disorders in Indian Small and Medium Scale Cashew Nut Processing Mills" is my own work and carried out under the supervision of Dr. Debayan Dhar, Assistant Professor, Department of Design, IIT Guwahati, and Dr. Swati Pal, Associate Professor, IDC School of Design, IIT Bombay. To the best of my knowledge, it contains no materials previously published or written by any other person or substantial proportions of material that have been accepted for the award of any other degree or diploma at IIT Guwahati or any other educational institution, except where due acknowledgment is made in the thesis. Any contribution made to the research by others with whom I have worked at IIT Guwahati or elsewhere is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the content that assistance from others in the project's design and conception or style, presentation, and linguistic expression is duly acknowledged.

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Certificate

This is to certify that the work contained in this thesis titled "Designing and Evaluating an Ergonomic Intervention to Minimise Risk of Musculoskeletal Disorders in Indian Small and Medium Scale Cashew Nut Processing Mills" submitted by Mr. Mallampalli K. Chaitanya (Roll No.: 176105103) to the Indian Institute of Technology (IIT) Guwahati for the award of the degree of Doctor of Philosophy has been carried out under our supervision. This work has not been submitted elsewhere for the award of any other degree.

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Abstract

India is one of the largest producers and processors of cashew nuts in the world. The vast export capabilities and local demand for cashew nuts are fuelling the growth of the cashew industry in India. There are nearly 3650 cashew nut processing mills that are spread across India. These mills are primarily labour-intensive and provide significant employment opportunities for rural people. However, the health and well-being of workers employed in these mills are highly compromised due to the use of traditional tools/equipment. Moreover, investigations related to occupational health, and ergonomic design and development of work equipment from an ergonomics perspective have barely been studied to date in Indian small and medium-scale cashew nut processing mills. Therefore, this research presents an assessment of existing working conditions in relation to the musculoskeletal health of cashew workers in Indian small and medium-scale cashew nut mills. Subsequently, it provides the design and evaluation of an ergonomic intervention to minimize the risk of musculoskeletal disorders in Indian small and medium-scale cashew nut processing mills from an ergonomics perspective. This entire research work was broadly divided into three phases.

In the first phase, a cross-sectional survey with 290 cashew workers across four different states in eastern India was conducted. Survey results showed that the awkward working postures were prevalent, and around 70.3 % of cashew workers suffered from prevalence of work-related musculoskeletal disorders (WMSDs). It was observed that workers engaged in shelling activity adopting poor working posture, performing repetitive actions, and using traditional hand-cum-pedal operated cashew nut sheller suffered more due to WMSDs. Information gathered during this first phase study and on-site observations informed the redesign of the existing cashew nut sheller, which could improve the working posture and reduce musculoskeletal load among workers. Thus, in the second phase, a participatory design process involving stakeholders' viewpoints and their feedback was used to redesign the existing traditional cashew nut sheller. A combination of steps, including identifying stakeholders' needs, concept generation, and concept screening sessions, were carried out to conceive a new ergonomic cashew nut sheller design. The redesigned sheller is hand-operated type, and thus it was named as a hand-operated

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cashew nut sheller in this thesis. The final phase of the study (phase 3) comprised of the development and field testing of hand-operated cashew nut sheller. Overall, a comparative study conducted between the old and the new designs highlighted that the proposed ergonomic design intervention effectively improved the working postures and provided sufficient confirmation of minimizing the risk of musculoskeletal disorders of cashew nut workers, specifically for shelling workers.

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List of Abbreviations

CEPCI	Cashew Export Promotion Council of India
Cr.	Crore
DCCD	Directorate of Cashew nut and Cocoa Development
DGCI&S	Directorate General of Commercial Intelligence and Statistics
DHM	Digital Human Modeling
DHMS	Digital Human Modeling and Simulation
IDC	Industrially Developing Countries
IEA	International Ergonomics Association
INC	International Nut and Dried Fruit Council Foundation
MT	Metric tonne
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
SME	Small and Medium-scale Enterprises
WMSD	Work-related Musculoskeletal Disorder
WHO	World Health Organization

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Working Definitions

Cashew nut Sheller: A mechanical device that is specifically used for cracking or breaking the hard shell of a roasted cashew nut.

Ergonomics: A multidisciplinary field of science that is concerned with the understanding of man-machine interactions and applies principles, theory, methods, and data to design in order to achieve better human well-being and overall performance of a system (Bridger, 2008).

Ergonomic intervention: It is defined as a change process initiated and implemented by stakeholders aiming to introduce measures to influence occupational exposure(s) to improve musculoskeletal health.

Small and medium-scale cashew nut processing mills: The mills having a raw cashew nut processing capacity not exceeding 100 kg per day or the capacity of steam cooker up to 45 kg per batch are stated as small and medium-scale mills (Jadhav, 2006).

Shelling efficiency: It is the percentage of the weight of shelled nuts to the total weight of nuts put into the machine.

Whole kernel recovery: It is the percentage of the weight of nuts shelled (unbroken kernels) to the total weight of nuts put into the machine.

Working condition: The term working condition is defined as a condition concerning working postures, the occurrence of work-related musculoskeletal disorders, and the association between work-related musculoskeletal disorders and potential risk factors (including demographic and work-related factors) in a workplace.

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Chapter – 1: Introduction

Chapter Abstract:

This chapter highlights research issues that are being investigated in this thesis work. It presents the background of the study—highlights present scenario of cashew nut processing in India and the need for ergonomic based investigation in the Indian cashew industry. Subsequently, the chapter explains the scope and rationale of the thesis work, and it specifically focuses on addressing ergonomic issues in manual cashew nut shelling activity and highlights the need for ergonomic design intervention. Then, the present chapter stated the aim and objectives, the research questions, and a research plan for the study. This chapter also included summaries of all chapters.

1.1. Global cashew nut industry

Cashew (Anacardium Occidentale Linn) is an extremely important evergreen tropical crop and a valuable agricultural commodity worldwide. It occupies a significant position among edible tree nuts in the world. It ranked third in the world edible tree nut production, after almonds and walnuts (INC, 2019). The growing interest in the cashew crop is primarily due to its cashew kernel. It is the main commercial product of cashew crop (Azam-Ali & Judge, 2001), and whose production values and trade have been growing steadily over the past ten years (Dendena & Corsi, 2014; INC, 2019). With a fast-growing market in the USA and Europe, and also the new markets opening in some parts of the world, such as Japan, there is a high expectation that the cashew market will remain strong in the future (Dendena & Corsi, 2014).

At present, around 31 countries, primarily low-income and middle-income countries, are producing cashew nuts worldwide (de Oliveira Galvão et al., 2014). Presently, the world's leading commercial cashew producers are India, Vietnam, Brazil, Nigeria, and Indonesia (CEPCI, 2019; INC, 2019). During 2020-21, a total of 0.83 million MT of cashew nuts (kernel basis) were produced globally. This is equivalent to 20% of world edible tree nut production (INC, 2019). Further, cashew production plays a crucial role in creating revenues, employment, and small and medium-scale industrialization in low-income and middle-income countries. Another important reason for the significant interest in cashew nuts is their nutritional value. They are rich in crude fat (47.8 g), carbohydrate (29.9 g), protein (16.8 g), and gives

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574 kcal of energy per 100 g of intake (Brufau, Boatella, & Rafecas, 2006). Also, cashew is a good source of iron, phosphorus, and calcium (Ghosh & Bose, 1986). It was found that regular consumption of cashew nuts leads to the reduction of coronary heart diseases (Kris-Etherton, Zhao, Binkoski, Coval, & Etherton, 2001). In fact, it is considered to be an esteemed food item in many customs and cultures globally because of its pleasant taste and flavour (Irtwange & Oshodi, 2009). According to Azam-Ali & Judge (2001), 60% of cashew kernels are consumed in snacks, and the remaining (40%) are used in confectionery bakery products.

1.2. Indian cashew industry: an overview

Historically, cashew is native to South America, and it was introduced to the Goa region of India in 1598 AD by Portuguese travellers (Johnson, 1973; Mohod, Jain, Powar, Rathore, & Kurchania, 2010). Initially, it was grown primarily to prevent soil erosion and enhance dry-land agriculture for economical use. However, cashew cultivation has spread across both India's east and west coastal regions over the years. Although cashew has been produced traditionally and consumed for centuries, the first commercial cashew trade started in the 1920s. India was the first country to introduce commercial cashew processing in the world, and the USA was the sole importer of processed cashew from India during that time (Harilal, Kanji, Jeyaranjan, Eapen, & Swaminatha, 2006). Currently, India is the top producer of cashew nuts in the world. According to the DCCD report 2019-20, the current production of raw cashew nuts in India was 8.17 lakh MT (DCCD, 2019). At the same time, India imports raw cashew nuts from different countries. During 2018-19, it imported and processed 6.49 lakh MT of raw cashew nuts (CEPCI, 2019; DCCD, 2019). In total, India produced 1.98 lakh MT of cashew nuts (kernel basis) globally, which was equivalent to 24% of the world’s production (INC, 2019). The leading cashew-producing states and production figures are Maharashtra (269440 MT), Andhra Pradesh (116960 MT), Orissa (98585 MT), and Karnataka (89447 MT) (CEPCI, 2019).

Though the Indian cashew industry is almost a century old, it is still regarded to be a small and medium-scale industry. There are over 3650 cashew nut processing mills in the country. Mostly were unorganized in nature and mainly spread across coastal regions of the country (Anonymous, 2009). As per the available data, there was a rapid increase in the number of units established from 1959 to 2008. The

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number of units increased from 170 to 3650 during the same period (Swain, 2005). At present, the Indian cashew industry is growing at a faster pace and focusing on regionalized production centres with a view to increase domestic raw cashew nut production. In addition, one more advantageous factor for the Indian cashew industry is the skilled labour force (Harilal et al., 2006). Therefore, it is imperative that for India to increase its global share from 24% presently and thus the domestic processing capacity of units could significantly increase.

Additionally, the cashew industry is one of India's economically and socially important industries. The production and processing of cashew nuts is a major source of foreign exports revenue in India. This industry is popularly known as a dollar-earning industry. According to DGCI&S (2019) data, India earned 5870.97 Cr. (USD 911 million) of foreign exports revenue by exporting 0.84 lakh MT of processed kernels during 2019-20. Indian cashew industry ranked sixth among India's total agro-export earnings, and it accounted for 0.30% of total foreign exchange earnings in the country (CEPCI, 2019). This industry employs nearly 0.5 lakh people (Anonymous, 2009), and most of them belong to socially and economically backward classes. Besides the significant economic importance, the Indian cashew industry plays a key role in providing social and financial support to the workers and their families.

However, despite its tremendous growth potential and socio-economic significance, the current dominance of India in the international trade of cashew nuts may not last long due to various reasons. One of the important reasons was increased competition from Vietnam and Brazil, affecting international exports of India. On the other hand, the increasing market interest in other tree nuts like almonds, hazelnuts, pistachio, and macadamia is challenging the Indian cashew nut industry. Moreover, the Indian cashew nut processing industry is primarily confined to the rural sector. Even today, the conventional processing methods use manual equipment rather than automated machines. It was evident that manual equipment output is meagre, and the rural processors have limited exposure to the latest technology. So, the limited production capacities can be attributable to low technology use and appear to be the primary factor preventing the Indian cashew industry from meeting the quantity and quality of cashew kernel production. In addition, the scarcity of investments in new technology is preventing this industry from innovations. The introduction of technology applications in processing industries has been limited by lack of

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knowledge, technical support, and services. Altogether, these factors make India's small and medium-scale cashew nut processing sector labour-intensive. Furthermore, the low productivity is also attributable to working conditions in the industry. The manual tasks are tedious, time-consuming and workers have exposure to various occupational health problems from an ergonomics point of view.

1.3. Cashew nut processing in India–Present scenario

Cashew nut processing is defined as the recovery of edible cashew kernel by a series of unit operations. Commonly, the unit operations include sun-drying, pre-treatment, shelling, peeling, grading, and packing. Importantly, pre-treatment of raw nuts and shelling are the two most important operations that require more attention because they determine the whole kernel recovery. The type of shelling depends upon the method of pre-treatment. In India, the steam roasting method is most widely practiced (Fitzpatrick, 2011; Mohod et al., 2010). In this method, the out turn and appearance of kernels are better (Ajav, 1996) when compared to other roasting methods (such as drum roasting and oil roasting) (Azam-Ali & Judge, 2001).

During the steam roasting process, the raw cashew nuts are initially sun-dried for two to three days to reduce their moisture content from 25 % to 7 – 8% (Asogwa, Hammed, & Ndubuaku, 2008; Mohod, Khandetod, Sengar, & Shrirame, 2012). After this, the primary steps involve (1) Pre-treatment of raw cashew nut, which is done to increase the brittleness of outer shell and loosen kernel from the shell walls. Usually, the nuts are treated in a stationary steam cooker for 15 to 25 minutes (Fitzpatrick, 2011; Mohod et al., 2010) and then cool for 12 hours at room temperature. During this step, the nuts attain moisture content between 15 and 25 %. (2) Extraction of cashew kernel from the shell, the shelling is performed to separate the shell from the kernel. It is usually done using either a manually operated mechanical device or a semi-automated/automated device. Manual shelling coupled with steam roasting has been found to give high shelling efficiency (up to 99%) (Dendena & Corsi, 2014). Manual shelling has been the traditional method and is widespread in most of the small and medium-scale cashew nut processing mills in India (Ajav, 1996; Dendena & Corsi, 2014; Mallampalli, Dhar, & Pal, 2020; Ojolo, Olatunji, & Orisaleye, 2016). (3) Peeling is performed to remove a thin layer (testa) on dried cashew kernel. (4)

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Grading of cashew kernels is done according to international standards. In the final step (step 5), packing is done according to customer requirements and standards.

Traditionally, all these activities are manually performed by workers. These manual operations are very tedious, time-consuming, and labour-intensive. Workers get easily exposed to health-threatening working conditions during cashew nut processing. These manual operations are often regarded as the source of drudgery and often increase postural stress that is potentially harmful to workers' health and well-being (Borah, 2015; Mallampalli & Pal, 2021). Workers in boiling, shelling, peeling, and grading tasks often adopt unnatural postures while performing processing activities. The predominant postures involved in cashew processing activities are squatting, stooping, and twisting. These typical working postures may lead to pain or discomfort in different body regions. Cashew nut shelling is one of the important operations in cashew nut processing, wherein a majority of the workforce is chiefly engaged in manual shelling operation. This shelling is very tedious and monotonous in operation. Workers commonly use conventional hand-cum-pedal operated cashew nut sheller for shelling roasted cashew nuts. The typical operation of this conventional machine involves: placing the nut by one hand in-between two sharp contour-shaped blades, pushing the hand lever by another hand, and exerting pressure on the foot pedal, simultaneously. By applying controlled pressure on the foot pedal and coordinating the hand lever, the shell portion is split apart without damaging the kernel. Generally, the output in this method is between 25 – 30 kg per day. The disadvantages of this shelling method are listed below:

a) While the exiting sheller is manually operated using both hands and leg, the awkward posture of hands and leg can contribute to disorders in arms and legs.
b) The fixed height of sheller table forces the workers to often bend their trunk and head to have good vision during the shelling.
c) The radial and cylindrical sheller handle is attached to the sheller unit. The orientation of the handle is not in line with the forearm and thus may cause wrist disorders. Here, it is essential to highlight that the handle is often made from iron, making it difficult to hold, especially during the winter season.
d) Due to the unavailability of the seat in the existing sheller, a worker had to stand throughout the shelling operation. This prolonged standing may cause lower back disorders.

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In light of these issues, there is a need to conduct ergonomic investigations in Indian small and medium-scale cashew nut processing mills. Identifying musculoskeletal problems (if any) and finding ways to prevent those occupational health problems among workers is highly required in the context of Indian small and medium-scale mills. Specifically, a systematic ergonomic evaluation of the existing sheller and ergonomic design intervention (if any) can address ergonomic issues in the current shelling method.

1.4. Musculoskeletal disorders and ergonomic intervention

Work-related musculoskeletal disorders (WMSDs) are important occupational health problems among workers. WMSDs have become a global phenomenon that is affecting almost all countries and all categories of workers (Acaröz Candan, Sahin, & Akoğlu, 2019; Kumar, Chakrabarti, Patel, & Chowdhuri, 2016; Ncube, Kanda, & Sanyanga, 2019; Thetkathuek, Meepradit, & Sa-ngiamsak, 2018). In normal circumstances, these work-related disorders can decrease the normal functioning of musculoskeletal structure (Muhamad Ramdan, Candra, & Rahma Fitri, 2018). These disorders among workers also result in reduced productivity of workers and sickness absenteeism (Dianat, Afshari, Sarmasti, Sangdeh, & Azaddel, 2020; Niu, 2010). A strong relationship also exists between workers' productivity and WMSDs (McPhee, 2005). Various ergonomic risk factors contribute to WMSDs and result in worker fatigue, discomfort, and reduced efficiency (Chakrabarti & Bhattachheriya, 2012; Kumar et al., 2016). In addition, other workplace factors such as body postures, exertions, rapid movements, work methods, poor design of work equipment, the mismatch between body dimensions and equipment, and unbalance between worker performance and job demands play a role in the occurrence of WMSDs (Muhamad Ramdan et al., 2018; Patel et al., 2017; Sanjog, Patel, Chowdhury, & Karmakar, 2015).

Ergonomics is the scientific discipline concerned with understanding man-machine interactions and applies principles, theory, methods, and data to design to achieve better human well-being and overall system performance (Bridger, 2008). Ergonomists and occupational health researchers apply ergonomic principles and guidelines in designing and evaluating tasks, products, and workstations according to humans' needs, abilities, and limitations. However, despite the attention to

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ergonomics, the problem of musculoskeletal disorder has been one of the persistent problems in many occupations (Acaröz Candan et al., 2019; Anton & Weeks, 2016; McPhee, 2005). At the same time, vast research efforts have been carried out to understand causative factors (including physical and psychosocial) for different musculoskeletal problems and to provide workplace interventions (Bhattacharyya & Chakrabarti, 2012; Choobineh, Tosian, Alhamdi, & Davarzanie, 2004; Mukhopadhyay & Ghosal, 2008).

Ergonomic intervention (or prevention) for improving the work-related musculoskeletal has been reported in numerous papers (Gangopadhyay & Dev, 2014; Rai, Gandhi, Kumar, Sharma, & Garg, 2012; Westgaard & Winkel, 1997). An ergonomic intervention is defined as a change process initiated and implemented by stakeholders aiming to introduce measures to influence occupational exposure(s) to improve musculoskeletal health. Basically, ergonomic interventions can be classified as (1) primary intervention: an intervention against specific occupational exposure factors (e.g., modifying the workstation design) (2) secondary intervention: an intervention directed towards the individual workers to develop resistance to harmful exposures (e.g., physiotherapy or exercise or work technique training). Many studies have reported that designing workstations or work equipment according to ergonomic principles effectively reduces musculoskeletal problems and increases user comfort, satisfaction, and productivity (Choobineh et al., 2004; McNeill & Westby, 1999; Sharma, Tiwari, Thakur, & Ganguli, 2021). For example, Patel et al. (2017) developed a paddy thresher adaptable to the agricultural needs of north-eastern and recommended that improved design of agricultural equipment can reduce discomfort among agricultural workers. Another study by Singh, Singh, & Singh (2012) designed a hand-operated maize dehusker-sheller using ergonomics and reported that physiological workload was reduced over the traditional method. McNeill & Westby (1999) redesigned and evaluated the cassava chipping machine and found that redesigned chipper reduced discomfort and drudgery among workers. Umar, Ahmad, Halim, Lee, & Hamid (2019) reported noticeable improvement in working postures of technicians in manual material handling operation with ergonomic design of trolley-lifter. Kushwaha & Kane (2016) designed a crane cabin workstation and recommended that intervention of ergonomics in workplace could reduce mismatch between man and machine. Sanjog, Patel, & Karmakar (2019) implemented a

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contextual design intervention from an occupational ergonomics perspective and reported that reduction in operator cycle time compared to traditional operations. Jadhav, Arunachalam, & Salve (2019) designed an ergonomic stitching workstation in the footwear industry based on user requirements and ergonomic guidelines of workstation design. They found that the workstation design was effective in reducing postural workload. Overall, these studies highlighted that the ergonomically designed work equipment is advantageous in terms of improving work and work methods, providing comfort to the user, reducing their postural stress, and enhancing productivity.

1.5. Aim and objectives

This research work aims to design and evaluate an ergonomic intervention to minimize the risk of musculoskeletal disorders in Indian small and medium-scale cashew nut processing mills. In order to achieve the stated aim, the following objectives were laid down:

Obj. 1 To investigate the current working conditions in small and medium-scale cashew nut processing mills in terms of: (a) investigation of the prevalence of WMSDs among cashew nut processing workers, (b) risk assessment of awkward working posture among cashew nut processing workers, and (c) examination of the relationship between WMSDs, and demographic and work-related risk factors.

Obj. 2 To identify specific activity that gives high potential for the improvements of the existing method and to reduce musculoskeletal disorders in small and medium-scale cashew nut processing mills.

Obj. 3 To devise possible ergonomic intervention using participatory design approach for minimising musculoskeletal problems taking into consideration: (a) Identification of ergonomic design needs. (b) Generation and evaluation of design alternatives. (c) Pre-testing of the proposed intervention using digital human modeling.

Obj. 4 To introduce a novel shelling method/style for shelling activity.

Obj. 5 To evaluate the developed intervention in comparison to existing one using field testing.

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1.6. Scope and rationale behind present research

The cashew nut processing industry is one of the crucial industries in the agro-processing sector in India. There are approximately 3650 cashew nut processing mills across the country. Moreover, cashew occupied the sixth position with a 6.65 % share in total agricultural commodities exports from India (DGCI&S, 2019). In 2019, this industry earned USD 911 million, which accounted for 0.30% of total foreign exchange earnings (DGCI&S, 2019). It also contributes to the generation of employment. Half a million workers are employed in the Indian cashew industry, and a large extent of this workforce is manual labour, specifically from rural areas and economically backward sections of the society. Both male and female genders are involved in cashew nut processing in India. However, despite its tremendous growth potential and large employment opportunities, cashew nut processing is quite laborious and hazardous due to the way it is being processed, and that is primarily because of the peculiar shape of the nut. Cashew workers in small and medium-scale cashew nut processing mills may suffer from different work-related risk factors due to traditional methods of working conditions. Among many, some of the causative factors may include faulty work methods, awkward posture, unusual workload, work fatigue, lack of rest pauses, job-related stress, fast work pace and etc. Several researchers have reported that demographic (gender, age, educational level, etc.) and work-related factors (work experience, duration of work, work pace, etc.) can significantly contribute to WMSDs (Das, Kumar, & Sharma, 2021; Iman Dianat, Kord, Yahyazade, Karimi, & Stedmon, 2015). Besides this, the health and safety of cashew workers have been neglected time and again by industry management due to lack of awareness and financial sources. Though several reasons can be attributed to negligence towards health problems of cashew workers by managements, short-term benefits such as cost reduction, increasing production, and profits are mainly attributable. In this context, therefore, evaluating the current working conditions of Indian cashew nut processing mills is deemed necessary. The present research work initially focused on evaluating the current working conditions in common activities of cashew nut processing among Indian small and medium-scale cashew nut mills.

Among all operations that are conducted in the cashew mills, the shelling of roasted cashew nuts is an important task in cashew nut processing mills. It deals with the recovery of the whole cashew kernel by separating the tough outer shell. This

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method is very tedious and time-consuming. A hand-cum-pedal operated sheller is commonly used for this task. Workers adopt complex work postures such as bending and twisting postures during the shelling for prolonged hours. These are harmful to the health of workers from an ergonomics point of view. The shelling workers are compelled to adopt awkward posture. As mentioned earlier (Section 1.3), the design of the existing sheller seems to have ergonomic issues that impose postural stress on the workers and may result in musculoskeletal problems in different body regions. Thus, the existing shelling equipment should be evaluated from an ergonomic point of view. The necessary modifications/redesigning should be adopted so as to minimise the risk of musculoskeletal disorders. The present study primarily emphasizes the current cashew nut shelling activity to address any postural stress that may exist resulting in musculoskeletal problems. All efforts have been made to propose an ergonomic intervention according to the requirements of end-users. A systemic approach complying with ergonomic design needs of users was considered for addressing ergonomic and design issues in existing sheller design.

1.7. Research questions

The following are the research questions (RQs) that have been answered during the course of this thesis work:

RQ1. What are the current working conditions in Indian small and medium-scale cashew nut processing mills, and does it warrant an ergonomic design intervention?

RQ2. What would be the appropriate technology that can reduce the ergonomic risk associated with cashew nut shelling activity?

RQ3. Does the workers' comprehensive participation contribute to the conceptualization of an ergonomic intervention?

RQ4. Does the proposed ergonomic intervention minimise the risk of musculoskeletal disorders?

1.8. Research plan

The entire research work was divided into three separate phases:

Phase I: Evaluation of current working conditions.

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i. The present study has been carried out a cross-sectional study design in the different states of India to ascertain the seriousness of the current issue.
ii. Four common work activities (i.e., boiling, shelling, peeling, and grading) were investigated during the study.
iii. Questionnaire survey and field observational methods were used to collect details related to cashew workers to identify the specific problem area.

Phase II: Ergonomic design and simulation-based evaluation.

i. Cashew nut shelling activity was chosen for further investigation. An ergonomic cashew nut sheller (CAD model) was designed through a participatory approach.
ii. Simulation-based evaluation of new cashew nut sheller was performed using digital human modeling.

Phase III: Development and evaluation.

i. A full-scale fully-functional model of a new cashew nut sheller was developed using relevant anthropometric data.
ii. The developed model was tested in the field by the users. Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) methods were used.

1.9. Organization of the thesis

In this thesis, the whole research has been organized into five chapters. Following are the summaries of each chapter.

Chapter 1, the present chapter, presents the study's background, scope, and rationale. It outlines the present scenario of Indian small and medium-scale cashew nut processing and specifically focuses on addressing ergonomic issues in manual cashew nut shelling. It highlights the need for ergonomic design intervention to improve the working conditions in cashew nut shelling. In the final sections of this chapter, the research questions, aim and objectives, and research plan of the study have been stated.

Chapter 2 presents the detailed observation of current working conditions in Indian small and medium-scale cashew nut processing mills. The prevalence of WMSDs was

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determined using a Nordic musculoskeletal questionnaire. The level of ergonomic risk was determined using the rapid entire body assessment (REBA) method. The logistic regression analyses were used to assess the association between potential risk factors and reported WMSDs.

Chapter 3 presents a systematic approach for ergonomic design intervention in cashew nut shelling activity. This chapter includes the need for modifications in existing sheller, review of existing sheller design, identification of problems, concept generation and screening (CAD model), and pre-testing a finalized model using a digital human modeling approach.

Chapter 4 presents the development of a new cashew nut sheller. Then, it presents a test evaluation of the new cashew nut sheller in comparison with the traditional existing sheller.

Chapter 5 summarizes and concludes the complete research work carried out in this thesis. The contributions of the thesis, limitations, and suggestions for future work were described in the final sections of this chapter.

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Chapter – 2: Evaluation of Working Conditions in Small and Medium Scale Cashew Nut Processing Mills in Eastern India

Chapter Abstract

This chapter examines the current working conditions in relation to the work posture, the prevalence of WMSDs, and associated risk factors among workers in Indian small and medium-scale cashew nut processing mills. The present chapter reports a cross-sectional study that was conducted across four states in the eastern region of India. The prevalence of WMSDs and the awkward working postures among study population were determined. Furthermore, results of logistic regression that were performed to determine the association between WMSDs and potential risk factors (including demographic and work-related factors) have been highlighted.

2.1. Introduction

The work activities carried out by cashew workers are mostly manual in nature. These are potentially dangerous and complex tasks involving fine manipulative skills, hand-eye coordination, congested workplace, harmful postures (forward inclined trunk and neck positions), and strong visual demands. Due to such nature of the job activities, workers are susceptible to WMSDs. The prevalence of WMSDs among cashew workers have been reported by different researchers (Oliver Raj & Narsia, 2020; Girish, Ramachandra, Arun, & Asha, 2012). However, their studies were limited by small sample size and single study location. So, considering the tremendous growth potential of Indian cashew processing industry, evaluating the current working conditions is the need of the hour. Therefore, an attempt was made in this research investigation to examine work posture, to examine prevalence of WMSDs, and to identify associated risk factors among cashew workers in small and medium-scale cashew nut processing mills in (eastern) India.

2.2. Work-related musculoskeletal disorders and associated risk factors

Work-related musculoskeletal disorders (WMSDs) is one of the important occupational health issues in both industrially developed and developing countries (Brooks, 2006; Iman Dianat & Karimi, 2016; Punnett & Wegman, 2004). WMSDs are primarily responsible for reduced quality of life, short/long-term sickness absence, and loss of productivity (Das et al., 2021; Dianat, Bazazan, Azad, & Salimi, 2018;

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Tebyetekerwa, Akankwasa, & Marriam, 2017). Furthermore, costs (direct and indirect) associated with WMSDs in industrially developing countries (IDCs) are very high (Brooks, 2006). It is worth noting that globalization and rapid industrial growth are contributing to the emergence of occupational health problems such as WMSDs among working populations in developing countries like India (Saiyed & Tiwari, 2004). These problems were prevalent across different sectors in India. For example, agriculture (Kumar et al., 2016), manufacturing (Sanjog et al., 2015), construction (Parida & Ray, 2015), office work (Alavi, Makarem, Abbasi, Rahimi, & Mehrdad, 2016), health care (Anap, Iyer, & Rao, 2013), etc. Especially, WMSDs have been the prominent problems in Indian agro-related industries, like tea leaf pluckers (Bhattacharyya & Chakrabarti, 2012), pineapple peeling workers (Kumar et al., 2016), Anola pricking (Rai, Gandhi, & Sharma, 2012), etc. Ergonomists and healthcare researchers report that short and/or long-term exposures to ergonomic risk factors cause ill health of workers and contribute to WMSDs. Awkward working posture, long hours of static sitting, repetitive actions, and manual carrying/lifting are associated with WMSDs (Dianat et al., 2020; Meksawi, Tangtrakulwanich, & Chongsuvivatwong, 2012; Ncube et al., 2019; Niu, 2010). Many studies also report various occupational factors, including individual (e.g., age, gender), organizational (e.g., job stress, working hours), and environmental (e.g., air quality, temperature) factors that contribute to the occurrence of WMSDs in many small and medium-scale enterprises in India (Das et al., 2021; Kumar et al., 2016; Nag & Nag, 2007; Sanjog et al., 2015). Furthermore, WMSDs have a negative impact on individuals' health and companies' performance. Therefore, its prevention in the workplace is of utmost importance. A systematic analysis of workplace conditions in the industry is essential to identify WMSDs and devise interventions to minimise them.

2.3. Tool for subjective assessment of musculoskeletal disorders

There are various techniques that are widely used to evaluate self-reported musculoskeletal pain/discomfort and are suitable to assess workplace conditions and evaluation of ergonomic interventions to identify exposures related to occupational risks (Sauter, Swanson, Waters, Hales, & Dunkin-Chadwick, 2005). The most common tools are the University of Michigan Upper Extremity Questionnaire (UMUEQ) (Franzblau, Salerno, Armstrong, & Werner, 1997), NIOSH musculoskeletal discomfort surveys (Stanton, Hedge, Brookhuis, & Salas, 2004),

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Cornell musculoskeletal questionnaire ("Cornell University Ergonomics Web," 2003), Dutch Musculoskeletal Questionnaire (DMQ) (Hildebrandt, Bongers, Van Dijk, Kemper, & Dul, 2001), and standard Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al., 1987). On examining these tools, NMQ was found to be the most widely used tool to identify musculoskeletal disorders in different body regions (Sauter et al., 2005).

NMQ can be self-administered or used in interviews to analyze musculoskeletal disorders among occupational groups (Andersson, Karlehagen, & Jonsson, 1987; Kuorinka et al., 1987). While assessing work environment or workstation design, the NMQ tool is one of the best diagnostic tools for screening WMSD, and it is not intended for clinical diagnosis. A study by Deakin, Stevenson, Vail, & Nelson (1994) showed that NMQ is sensitive enough to distinguish the patterns of reported injuries in industrial settings after two different workstations were evaluated. The authors also stated that such a characteristic of NMQ is useful for comparing different workstations and identifying more problematic ones so that workstation design or man-machine interface can be improved. NMQ is found to be a screening tool that is sensitive and repeatable (Crawford, 2007). Further, the NMQ is a validated and reliable tool (Dickinson et al., 1992; Kuorinka et al., 1987). The NMQ is a standardized instrument that can be applied across different occupational groups to determine musculoskeletal complaints in the ergonomic and occupational health context. The results of test re-test reliability of NMQ after one-week, two-week, and three-week showed identical response rates (ranging 70 % to 100%) across questions (Dickinson et al., 1992; Kuorinka et al., 1987). De Barros & Alexandre (2003) evaluated a version of the Nordic general questionnaire (i.e., Brazilian Portuguese version) by test-retest reliability procedure with one-day interval and reported substantial reliability (Kappa values between 0.88 and 1) of the questionnaire. In a NMQ, questions about the ache or pain or discomfort are asked for nine different body regions. This approach enabled the wide application of this tool across various work environments. A large number of workers can be surveyed quickly and cheaply. Besides the advantages, the NMQ has some limitations while administering. The limitations of the NMQ include: (a) the interviewer bias that may affect results, and (b) participants ability to recollect—mostly they remember most recent or more serious MSDs (Kuorinka et al., 1987).

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2.4. Postural evaluation tool for entire body assessment

Awkward working posture is one of the important ergonomic risk factors that contribute to the development of musculoskeletal disorders. Hence, postural analysis can be a powerful technique to assess musculoskeletal injuries associated with working postures in specific work activities. Most commonly, working postures are measured by using observational techniques. These observational techniques do not interfere with the job or process. Furthermore, there is no requirement of any additional equipment to be placed on the subjects' bodies that might cause worker discomfort (Genaidy, Al-Shedi, & Karwowski, 1994). Based on the visual perception, this observational technique is applied in different ways: (a) direct observation of the job/task or (b) posture video recording and analysis (Genaidy et al., 1994).

For evaluating the entire body, an observational technique, the Rapid Entire Body Assessment (REBA) tool, was designed (Hignett & McAtamney, 2000). It is a task-sensitive observational/field technique developed for assessing unpredictable working postures found in healthcare and other service industries. In this technique, the body is divided into individual segments and is coded with respect to movement planes. A specific coding system is provided for muscle activity caused by static, dynamic, rapid changes, or unstable postures. In addition, the coupling factor (human-load interface) is also incorporated. Finally, this tool provides action levels based on the final score, indicating urgency. The results of the inter-observer reliability test of fourteen participants showed that REBA is a reliable (62 - 85 % agreement) tool (Hignett & McAtamney, 2000). Many postures were examined across different sectors (viz. health-care, electricity, and manufacturing) using REBA, and its face validity has also been established (Hignett & McAtamney, 2000; Stanton et al., 2004).

Other postural analysis techniques such as Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett, 1993), Quick Exposure Checklist (QEC) (Li & Buckle, 2005), Ovako Working Posture Analysis System (OWAS) (Karhu, Kansi, & Kuorinka, 1977), Strain Index (SI) (Moore & Garg, 1995), and Occupational Repetitive Action Method (OCRA) (Occhipinti & Colombini, 1996) are generally used for upper limb assessment.

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2.5. Materials and methods

2.5.1. Description of work activities

The major work activities commonly observed in small and medium-scale cashew nut processing mills are *boiling, shelling, peeling,* and *grading* (Azam-Ali & Judge, 2001; Mohod et al., 2010). All of these tasks are manually performed by workers. Figure 2.1 shows the work activities assessed in the present study. *Boiling* is about heating the raw cashew nut using a steam cooker where workers carry and lift cashew bags. This task is commonly carried out on raised shoulders and with bending trunk. The primary purpose of *shelling* is to crack the roasted cashew nuts, which is performed using conventional cashew nut shelling equipment. This activity involves prolonged standing, bending, and twisting the trunk for long hours. *Peeling* activity is about removing the thin layer on the cashew kernels, and *grading* is to sort the kernels by size. In these two activities, workers commonly adopt different floor-sitting postures, including sitting with cross-legs, squatting, and legs folded at knees.

Figure 2.1 Typical work activities of small and medium-scale cashew nut processing mills: (a) boiling, (b) shelling, (c) peeling, (d) grading.

2.5.2. Study design

This study was conducted across four major cashew processing states (i.e., Andhra Pradesh, Assam, Meghalaya, and Orissa) of eastern India. According to the (CEPCI,

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2019), these states nearly produce 30.07 % of total cashew in India. In these states, a total of sixteen mills (i.e., Andhra Pradesh (6), Assam (1), Meghalaya (1), and Orissa (8)) were visited. As mentioned earlier, four major processing activities, namely *boiling, shelling, peeling, and grading,* were examined during the study of WMSD risk.

The cross-sectional study design was carried out with 290 randomly selected cashew workers from (eastern) India. The inclusion criteria were: workers with work experience of 12 months in the current job, age greater than 18 years, and giving their individuals' consent to participate in the study. The workers reporting pain due to injuries, accidents, or any other diseases were excluded. All the participants were informed about the purpose of the study in layman's terms. Participation was voluntary.

2.5.3. Instruments

A questionnaire survey was carried out to collect details related to cashew workers in small and medium-scale cashew nut processing mills. The questionnaire consisted of three parts, as shown in Appendix I. The first part of the questionnaire collected data on demographic details (gender, age, height, weight, marital status, education level, work activity, and smoking habit). In the second part, work-related details such as work experience, daily working hours, the perceived speed of work, perceived work fatigue, job satisfaction, current health status, and stress level were collected. The third part of the questionnaire included the standard Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al., 1987). Using NMQ, participants were interviewed about the prevalence of WMSDs during the past 12 months. A body map indicating the nine different body regions (i.e., neck, shoulders, elbows, hands/wrists, upper back, lower back, hips/thighs, knees, and ankles/feet) was shown to the participants (Appendix I). Subsequently, they were asked to identify those body parts that they had experienced any pain or discomfort in the past 12 months. A 5-point scale (1= very mild pain to 5 = very severe pain) pain rating scale was used to record the severity of pain. Additionally, any disruption of normal activities due to WMSDs was also recorded.

The working postures of cashew workers were assessed, and it was observed that the whole body of workers is involved in most of the tasks. Therefore, the

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analysis of different working postures of cashew workers was performed using the Rapid Entire Body Assessment (REBA) method (Hignett & McAtamney, 2000) for quantifying the risk of WMSDs. According to this method, a special scoring method is employed based on the range of motion of body parts. The body parts are divided into two groups as group A (neck – trunk – legs) and group B (shoulders – elbows – wrists). Load coupling and static/dynamic nature of activity parameters are also included. All the scores are combined to give a final or grand REBA scores and five action levels, as shown in Figure 2.2. Based on the deviation of body posture from the neutral position, the final REBA score increases, and the checklist can be seen in Appendix II.

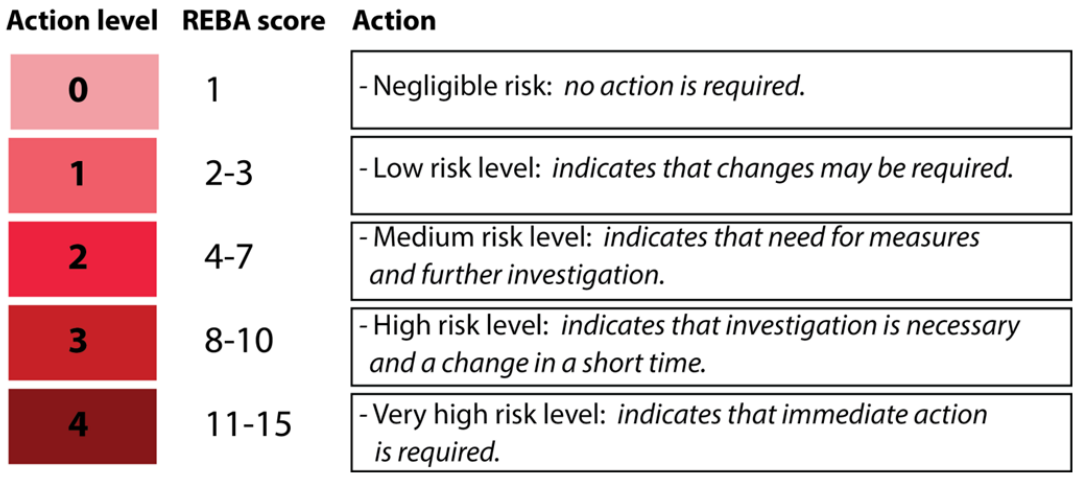

Figure 2.2 REBA scores and corresponding action levels.

During the study, working posture of cashew workers was photographed and video recorded. The most engaging and frequent work postures observed in all the activities were taken into consideration. Later on, stick diagrams were prepared, and the REBA employee assessment sheet (Appendix II) was used to determine scores, risk levels, and action levels for each work activity. REBA scores and risk levels were categorized activity-wise: *boiling, shelling, peeling, and grading*.

2.5.4. Statistical analysis

Statistical analysis of the data was performed using SPSS v20.0 (IBM Corp., Armonk, NY, USA). Kolmogorov-Smirnov test was used to check for normality of data. Demographic and work-related characteristics of the study population were reported as Mean (Standard Deviation), frequencies, and percentages (%). Multivariate logistic regression analysis (backward stepwise) was performed to predict the influence of risk

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factors on occurrence of WMSDs among different body regions. According to Hair, Tatham, Anderson, & Black (2006), multivariate logistic regression is a well-known statistical modelling method for understanding relationships between independent and dependent variables. In the present study, the dependent variables were neck, shoulders, elbows, hands/wrists, upper back, lower back, knees, and ankles/feet disorders. Independent variables include demographic and work-related characteristics. The odds ratios (ODs), p-value, and 95 % confidence intervals (95 % CIs) were used for the description of association between the prevalence of WMSDs and study variables. The assumptions of logistic regression models (presence of outliers and collinearity) were checked, and the model's fit was checked by the Hosmer-Lemeshow goodness-of-fit test. P <0.05 was considered statistically significant.

2.6. Results

2.6.1. Demographic details

Table 2.1 presents the demographic details of the study population. A total of 290 (female = 73.4 %; male = 26.6 %) cashew workers from four different work activities such as boiling (11.4 %), shelling (51.8 %), peeling (22.0%), and grading (14.8 %) participated during the study. Participants age ranged between 19 and 65 years (mean = 35.0; SD = 9.1), with around 79 % participants were married. The mean BMI of participants was 24.2 kg/m^2 (SD = 2.5). Around 57.9 % of participants were illiterate, and only 12.8 % were educated up to secondary school. The majority (88.6 %) of participants were non-smokers.

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Table 2.1 The demographic characteristics of study population (n = 290).

Variables	Boiling (n = 33)		Shelling (n= 150)		Peeling (n= 64)		Grading (n= 43)		Total (n= 290)	
	n	%	n	%	n	%	n	%	n	%
Gender										
Male	26	78.8	51	34.0	0	0.0	0	0.0	77	26.6
Female	7	21.2	99	66.0	64	100.0	43	100.0	213	73.4
Age (years)										
< 30	13	39.4	58	38.7	24	37.5	14	32.6	109	37.6
> 30	20	60.6	92	61.3	40	62.5	29	67.4	181	62.4
Mean (SD)	33.2 (7.6)		34.8 (9.3)		35.9 (9.3)		35.7 (8.9)		35.0 (9.1)	
Body mass index (kg/m^2)										
< 25	27	81.8	107	71.3	34	53.1	27	62.8	195	67.2
> 25	6	18.2	43	28.7	30	46.9	16	37.2	95	32.8
Mean (SD)	23.5 (1.4)		23.8 (2.4)		25.0 (2.5)		24.6 (2.9)		24.2 (2.5)	
Material status										
Single	7	21.2	31	20.7	14	21.9	9	20.9	61	21.0
Married	26	78.8	119	79.3	50	78.1	34	79.1	229	79.0
Educational level										
Illiterate	19	57.6	85	56.7	37	57.8	27	62.8	168	57.9
Primary school	11	33.3	42	28.0	19	29.7	13	30.2	85	29.3
Secondary school	3	9.1	23	15.3	8	12.5	3	7.0	37	12.8
Smoking										
Yes	12	36.4	18	12.0	2	3.1	1	2.3	33	11.4
No	21	63.6	132	88.0	62	96.9	42	97.7	257	88.6

2.6.2. Work-related details

Table 2.2 shows the work-related details of the study population. The participants' work experience ranged between 1 and 30 years (Mean = 8.5; SD = 5.8), and their mean daily working time was reported to be 9.6 hours per day. Among them, one-third of the participants had perceived a high level of work fatigue, and around 42.4 % of participants reported that they work very fast. More than fifty percent of participants were fully satisfied with their work, and around 26.2 % of participants had high job stress.

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Table 2.2 The work-related characteristics of the study population (n = 290).

Variables	Boiling (n = 33)		Shelling (n= 150)		Peeling (n= 64)		Grading (n= 43)		Total (n= 290)	
	n	%	n	%	n	%	n	%	n	%
Work experience										
≤ 5	14	42.4	70	46.7	17	26.6	15	34.9	116	40.0
> 5	19	57.6	80	53.3	47	73.4	28	65.1	174	60.0
Mean (SD)	6.6 (2.7)		8.5 (6.5)		9.5 (5.7)		8.3 (5.1)		8.5 (5.8)	
Working hours/day										
≤ 8	33	100.0	31	20.7	63	98.4	43	100.0	170	58.6
> 8	0	0.0	119	79.3	1	1.6	0	0.0	120	41.4
Mean ± SD	8.0 (0.0)		11.1 (1.6)		8.0 (0.5)		8 (0.0)		9.6 (1.9)	
Working very fast										
Yes	7	21.2	111	74.0	38	59.4	11	25.6	167	57.6
No	26	78.8	39	26.0	26	40.6	32	74.4	123	42.4
Work fatigue										
Low	8	24.2	42	28.0	26	40.6	22	51.2	98	33.8
Moderate	6	18.2	48	32.0	28	43.8	13	30.2	95	32.8
High	19	57.6	60	40.0	10	15.6	8	18.6	97	33.4
Job satisfaction										
Low	6	18.2	16	10.7	7	10.9	2	4.7	31	10.7
Moderate	9	27.3	65	43.3	23	35.9	12	27.9	109	37.6
High	18	54.5	69	46.0	34	53.1	29	67.4	150	51.7
Current health status										
Good	24	72.7	113	75.3	51	79.7	32	74.4	220	75.9
Moderate	7	21.2	23	15.3	12	18.8	10	23.3	52	17.9
Bad	2	6.1	14	9.3	1	1.6	1	2.3	18	6.2
Job stress										
Low	13	39.4	51	34.0	32	50.0	16	37.2	112	38.6
Moderate	13	39.4	55	36.7	18	28.1	16	37.2	102	35.2
High	7	21.2	44	29.3	14	21.9	11	25.6	76	26.2

2.6.3. Prevalence of WMSDs

Prevalence of WMSDs among different body regions as reported by the cashew workers is presented in Table 2.3. A total of 70.3 % of the cashew workers (females = 71.3 %; males = 67.5 %) had experienced discomfort in at least one body region during the past 12 months. Shoulders (52.4 %), lower back (51.4 %), hands/wrists (43.4 %), and knees (35.9 %) were the most commonly affected body regions of

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discomfort. As it can be seen from the Table 2.3, lower back (Mean = 4.3; SD = 0.88), knees (Mean = 4.0; SD = 1.1), hands/wrist (Mean = 3.9; SD = 1.0) and shoulders (Mean = 3.8; SD = 1.1) were found to be high and very high pain severities. This indicates that the risk of WMSDs is higher among cashew workers. Table 2.3 also shows the disruption of normal activities due to WMSDs. Around 44.1 % of the participants' normal activities were distrusted due to WMSDs. The lower back (17.2%), shoulders (16.9 %), and hands/wrists (13.4%) were the most common body regions that contributed to the disruption of normal activities.

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Table 2.3 The prevalence of WMSDs among cashew workers (n = 290).

	Prevalence of WMSDs			**Disruption of normal activities due to WMSDs**			**Severity of pain (Scale 1-5)**		
	Males	**Females**	**All**	**Males**	**Females**	**All**	**Males**	**Females**	**All**
	n (%)	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**M (SD)**	**M(SD)**	**M (SD)**
Body region									
Neck	29 (37.6)	67 (31.4)	96 (33.1)	13 (16.8)	20 (9.3)	33 (11.4)	3.0 (1.14)	3.5 (1.17)	3.3 (1.18)
Shoulders	43 (55.8)	109 (51.1)	152 (52.4)	13 (16.8)	36 (16.9)	49 (16.9)	4.3 (1.02)	3.7 (1.12)	3.8 (1.13)
Elbows	30 (38.9)	56 (26.3)	86 (29.7)	12 (15.5)	17 (8.0)	29 (10.0)	3.6 (1.09)	3.6 (1.00)	3.6 (1.02)
Hands/wrists	34 (44.1)	92 (43.2)	126 (43.4)	11 (14.2)	28 (13.1)	39 (13.4)	4.2 (0.99)	3.7 (1.02)	3.9 (1.03)
Upper back	7 (9.0)	24 (11.2)	31 (10.7)	3 (3.9)	3 (1.4)	6 (2.1)	3.1 (1.06)	2.7 (1.16)	2.8 (1.13)
Lower back	30 (38.9)	119 (55.9)	149 (51.4)	9 (11.6)	41 (19.2)	50 (17.2)	4.5 (0.77)	4.2 (0.90)	4.3 (0.88)
Hips/thighs/buttocks	8 (10.4)	22 (10.3)	30 (10.3)	2 (2.6)	7 (3.2)	9 (3.1)	2.3 (1.18)	2.5 (1.00)	2.5 (1.04)
Knees	23 (29.8)	81 (38.0)	104 (35.9)	8 (10.3)	22 (10.3)	30 (10.3)	3.7 (1.25)	4.0 (1.15)	4.0 (1.18)
Ankles/feet	13 (16.8)	42 (19.7)	55 (19.0)	5 (6.5)	13 (6.1)	18 (6.2)	3.0 (1.44)	3.7 (0.92)	3.6 (1.09)
Any region	52 (67.5)	152 (71.3)	204 (70.3)	32 (41.5)	96 (45.0)	128 (44.1)	-	-	-

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Figure 2.3 shows the prevalence of WMSDs among cashew workers activity-wise. The study showed that shoulders, lower back, hands/wrists, and knees were the worst affected body regions among cashew workers. The study further showed that most of the cashew workers activity-wise experienced shoulders pain: 62.7 % (shelling), 57.6 % (boiling), 48.8 % (grading), and 28.1 % (peeling). Lower back pain is the second most affected body region among cashew workers: 59.3 % (shelling), 48.5 % (boiling), 41.8 % (grading), and 40.6 % (peeling). Hands/wrist is the main body region of the upper extremities that was affected among cashew workers: 48.7 % (shelling), 43.7 % (peeling), 33.3 % (boiling), and 32.6 % (grading). Knees were the most affected body region of shelling workers. 57.3 % of shelling workers had experienced knee pain due to shelling activity, whereas 42.6 % of boiling workers suffered from neck pain due to working in a bent neck posture for long hours.

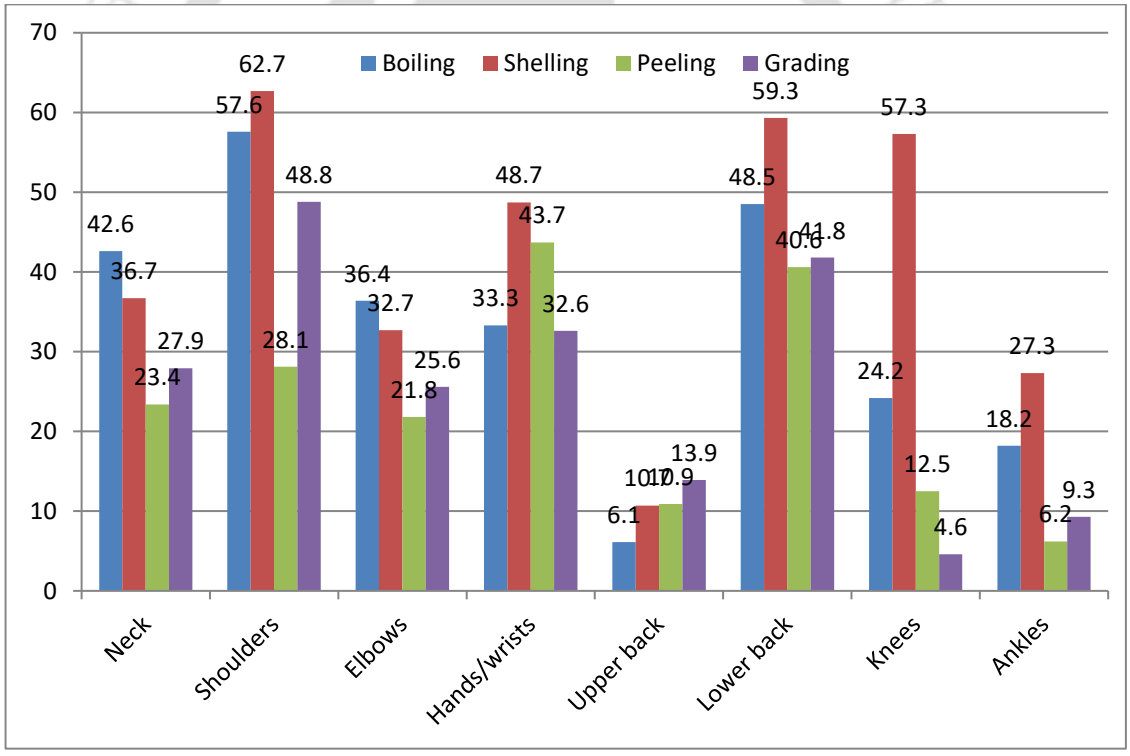

Figure 2.3 Prevalence of WMSDs among workers in boiling, shelling, peeling, and grading activities.

2.6.4. Working posture assessment

Table 2.4 shows the postural analysis by the REBA method. From the analysis of working postures of cashew workers, it was identified that most of the workers' postures were at high and very high risk and required immediate investigation and change according to REBA action levels.

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Table 2.4 The working postures analyses using REBA method.

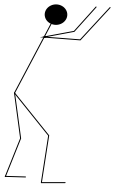
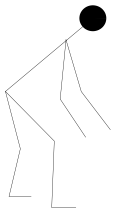
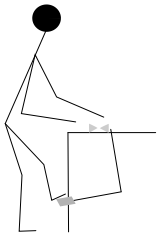
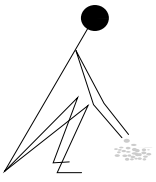
Type of work	Activity	Posture	REBA score	Risk level	Action level	Recommended action
Boiling	Carrying cashew-nut bag		10	High	3	Investigate and implement change
	Loading cashew-nut bag into a cocker		9	High	3	Investigate and implement change
	Unloading cashew-nut from cocker		10	High	3	Investigate and implement change
Shelling	Cashew nut shelling using hand-cum-pedal operated tool		10	High	3	Investigate and implement change
	Cashew kernel separation from shell		9	High	3	Investigate and implement change

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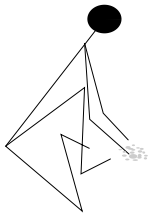
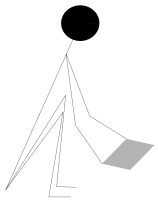
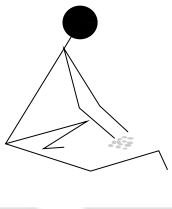
Table 2.4 The working postures analysis using REBA method (continued).

Type of work	Activity	Posture	REBA score	Risk level	Action level	Recommended action
Peeling	Peeling cashew kernels one by one		8	High	3	Investigate and implement change
Grading	Grading using hand sieve		9	High	3	Investigate and implement change
	Grading manually by hands		8	High	3	Investigate and implement change

2.6.5. Risk factors for WMSDs

Table 2.5 and Table 2.6 present the logistic regression analyses of risk factors associated with WMSDs in different body regions. The multivariate logistic regression analysis showed that the females were most likely to suffer from lower back (odds ratio (OR) = 3.0, 95 % confidence interval (CI): 1.58 – 5.68, $p < 0.01$) disorder than males. The prevalence of upper back (odds ratio (OR) = 3.48, 95 % confidence interval (CI): 1.29 – 9.37, $p < 0.05$), and neck (odds ratio (OR) = 2.52, 95 % confidence interval (CI): 1.37 – 4.63, $p < 0.05$) disorders increased with age greater than 30 years. Marital status was associated with shoulder (odds ratio (OR) = 3.46, 95 % confidence interval (CI): 1.43 – 8.35, $p < 0.05$), lower back (odds ratio (OR) = 3.59, 95 % confidence interval (CI): 1.36 – 9.47, $p < 0.05$), knee (odds ratio (OR) = 2.77, 95 % confidence interval (CI): 1.19 – 6.42, $p < 0.05$) disorders. The educational level associated with shoulder (odds ratio (OR) = 0.28, 95 % confidence interval (CI): 0.14 – 0.57, $p < 0.001$), elbow (odds ratio (OR) = 0.23, 95 % confidence interval (CI): 0.07

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– 0.72, $p < 0.01$), hand/wrist (odds ratio (OR) = 0.30, 95 % confidence interval (CI): 0.12 – 0.71, $p < 0.01$), and lower back (odds ratio (OR) = 0.22, 95 % confidence interval (CI): 0.07 – 0.72, $p < 0.05$) disorders.

The prevalence of shoulder (odds ratio (OR) = 0.29, 95 % confidence interval (CI): 0.10 – 0.81, $p < 0.05$), and knee (odds ratio (OR) = 5.34, 95 % confidence interval (CI): 2.12 – 13.44, $p < 0.001$) disorders was associated with peeling and shelling work activities, respectively. The prevalence of ankle/feet (odds ratio (OR) = 2.79, 95 % confidence interval (CI): 1.19 – 6.52, $p < 0.05$) disorder was increased with work experience more than 5 years. Job stress was associated with lower back (odds ratio (OR) = 3.51, 95 % confidence interval (CI): 1.68 – 7.34, $p < 0.01$) disorder. The prevalence of neck (odds ratio (OR) = 2.65, 95 % confidence interval (CI): 1.51 – 4.67, $p < 0.01$), and ankle/feet (odds ratio (OR) = 3.71, 95 % confidence interval (CI): 1.85 – 7.47, $p < 0.001$) disorders were increased with daily working time of more than 8 hours. Work fatigue was associated with shoulder (odds ratio (OR) = 3.37, 95 % confidence interval (CI): 1.61 – 7.04, $p < 0.01$), elbow (odds ratio (OR) = 2.49, 95 % confidence interval (CI): 1.23 – 5.06, $p < 0.05$), lower back (odds ratio (OR) = 2.41, 95 % confidence interval (CI): 1.12 – 5.17, $p < 0.05$), knee (odds ratio (OR) = 3.62, 95 % confidence interval (CI): 1.63 – 8.03, $p < 0.05$), and ankle/feet (odds ratio (OR) = 3.74, 95 % confidence interval (CI): 1.41 – 9.91, $p < 0.05$) disorders.

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Table 2.5 Logistic regression analyses of risk factors associated with the neck, shoulders, elbows, and hands/wrists.

Variables	Neck	Shoulders	Elbows	Hands/wrists
	OR [95% CI]	**OR [95% CI]**	**OR [95% CI]**	**OR [95% CI]**
Age				
≤ 30	1	1	1	1
> 30	2.52 [1.37 - 4.63]*	ns	ns	ns
Material status				
Single	1	1	1	1
Married	ns	3.46 [1.43 - 8.35]*	ns	ns
Educational level				
Illiterate	1	1	1	1
Primary school	ns	0.28 [0.14 - 0.57]***	0.29 [0.14 - 0.60]**	0.27 [0.15 - 0.50]***
Secondary school	ns	0.72 [0.25 - 2.04]	0.23 [0.07 - 0.72]*	0.30 [0.12 - 0.71]*
Type of work				
Boiling	1	1	1	1
Shelling	ns	1.36 [0.55 - 3.33]	ns	ns
Peeling	ns	0.29 [0.10 - 0.81]*	ns	ns
Grading	ns	0.86 [0.28 - 2.55]	ns	ns
Work experience				
≤ 5	1	1	1	1
> 5	3.18 [1.72 - 5.90]***	ns	ns	ns
Working hours/day				
≤ 8	1	1	1	1
> 8	2.65 [1.51 - 4.67]**	ns	ns	ns
Work fatigue				
Low	1	1	1	1
Moderate	ns	2.46 [1.25 - 4.84]*	1.27 [0.61 - 2.63]	ns
High	ns	3.37 [1.61 - 7.04]**	2.49 [1.23 - 5.06]*	ns

Note: OR = odds ratio; ns = no significant difference ($p > 0.05$).

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

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Table 2.6 Logistic regression analyses of risk factors associated with the upper back, lower back, knees, and ankles/feet.

Variables	Upper back	Lower back	Knees	Ankles/feet
	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
Gender				
Males	1	1	1	1
Females	ns	3.00 [1.58 - 5.68]**	ns	ns
Age				
≤ 30	1	1	1	1
> 30	3.48 [1.29 - 9.37]*	ns	ns	ns
Material status				
Single	1	1	1	1
Married	ns	3.59 [1.36 - 9.47]*	2.77 [1.19 - 6.42]*	ns
Educational level				
Illiterate	1	1	1	1
Primary school	ns	0.47 [0.23 - 0.95]*	ns	ns
Secondary school	ns	0.22 [0.07 - 0.72]*	ns	ns
Type of work				
Boiling	1	1	1	1
Shelling	ns	ns	5.34 [2.12 - 13.44]***	ns
Peeling	ns	ns	0.61 [0.19 - 1.97]	ns
Grading	ns	ns	0.20 [0.03 - 1.11]	ns
Work experience				
≤ 5	1	1	1	1
> 5	ns	ns	ns	2.79 [1.19 - 6.52]*
Working hours/day				
≤ 8	1	1	1	1
> 8	ns	ns	ns	3.71 [1.85 - 7.47]***
Work fatigue				
Low	1	1	1	1
Moderate	ns	2.26 [1.12 - 4.56]*	2.52 [1.14 - 5.56]*	1.45 [0.53 - 3.98]
High	ns	2.41 [1.12 - 5.17]*	3.62 [1.63 - 8.03]*	3.74 [1.41 - 9.91]*

Note: OR = odds ratio; ns = no significant difference ($p > 0.05$).

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

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Table 2.6 Logistic regression analyses of risk factors associated with the upper back, lower back, knees, and ankles/feet (continued).

Variables	Upper back	Lower back	Knees	Ankles/feet
	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
Job stress				
Low	1	1	1	1
Moderate	ns	2.31 [1.20 - 4.46]*	ns	ns
High	ns	3.51 [1.68 - 7.34]**	ns	ns

Note: OR = odds ratio

*p < 0.05, **p < 0.01, ***p < 0.001.

2.7. Discussion

The study findings provide a systematic analysis of the current working conditions of small and medium-scale cashew nut processing mills in (eastern) India. This study was carried out to examine the prevalence of WMSDs and contributing risk factors among different sections of cashew workers involved in *boiling, shelling, peeling,* and *grading* activities. The study findings indicated that the current situation in Indian small and medium-scale cashew nut processing mills share many similarities of poor unregulated working conditions. Perhaps, this study is the first of its kind to the best of our knowledge in the country about the working conditions of cashew workers in Indian small and medium-scale cashew nut processing mills. The information presented in this chapter would be valuable to industry management, workers, and healthcare providers. Overall, the present study highlights the poor working conditions of cashew workers that urgently need to be addressed so that workers' health and productivity can be improved.

2.7.1. Prevalence of WMSDs

The prevalence of work-related WMSDs during the past 12 months was found to be 70.3 % among the study population, which is relatively high when compared with (Oliver Raj & Narsia, 2020), 36.2 %, and (Girish, Ramachandra, Arun, & Asha, 2012), 28.5 % from Kerala. The high prevalence of shoulders, lower back, hands/wrists, and knees disorders found in this study were generally in agreement with previous studies in Kerala state (Girish et al., 2012; Oliver Raj & Narsia, 2020; Satheeshkumar, 2018). The reported pain severity was high and very high, especially

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in the lower back and knees. Dianat et al. (2020) highlighted that the prevalence of WMSDs may significantly impact the workers' health and well-being.

2.7.2. Factors associated with WMSDs

i. ***Gender:*** With regard to reported discomfort, the most commonly affected gender was female (71.3 %), as shown in Table 2.3. These results are in line with previous studies (Girish et al., 2012; Satheeshkumar, 2018). The gender difference observed in the occurrence of WMSDs may be attributable to the high number of female workers in this study. Usually, the management of small and medium-scale cashew nut processing mills largely employs female workforce because their wages are lower than males (Girish et al., 2012; Harilal et al., 2006).

This study also showed a significant association of female gender with their lower back disorder with an odds ratio of 3.0. This result may be due to heavy physical workload since most of the females were employed in physically demanding work activities such as *shelling*, *peeling*, and *grading*. In general, the body size and dimensions of females are smaller than males, and their physical capacities are also low (Nag, Vyas, & Nag, 2010; Tebyetekerwa et al., 2017). In a case where the males and females perform a similar physical activity, a female will tend to experience more physical workload. This may also be another possible reason for more reported discomfort by females in our study. In addition, females also perform different household activities. The more discomfort experienced by females than males in this study may also be due to various physical activities, including household work and these results are in line with ones reported in literature (Das, 2015; Thetkathuek et al., 2018).

ii. ***Age:*** The average age of workers was 35.0 years and ranged between 19 to 65 years. Around 62.5 % of the workers were above 30 years of age (Table 2.1). In this study, we showed that the workers who were greater than 30 years had a risk of developing neck and upper back disorders with an odds ratio (OR) of 2.52 and 3.48, respectively. This observation may be attributable to the physiological function decline of workers. This is one of the reasons that the occurrence of WMSDs is more often seen in the elderly due to decreased muscle strength and resiliency (Muhamad Ramdan et al., 2018). Previous had

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studies also reported that age is an independent physiological risk factor that is associated with the prevalence of WMSDs among various occupations (Girish et al., 2012; Kumar et al., 2016).

iii. ***Educational level:*** The education levels of cashew workers included: never educated, educated up to primary school, and secondary school education. The educational backgrounds of cashew workers were dominated by illiterate (57.9 %). In general, there is no requirement of basic education to work in small and medium-scale cashew nut processing mills in India. Therefore, the majority of workers were illiterate, and many cashew workers may lack basic skills, experience, training, and awareness of occupational safety and health rules.

The present study showed that education level was significantly associated with WMSDs in shoulders, elbows, hands/wrists, and lower back. This finding is in line with other similar studies that reported significant relationship between education background and WMSDs (Das et al., 2021; Muhamad Ramdan et al., 2018). It is to be noted that better education leads to logical and rational thinking among workers, and they can easily accept any new improvement or experience. In this case, the cashew workers required training to understand the risk of WMSDs. Previous studies reported that ergonomics training programs for workers could reduce WMSDs (Robertson & O'Neill, 2003).

iv. ***Marital status:*** More than three-quarters (79.0 %) of the study population were married in the present study. Married workers had experienced higher disorders (OR = 2.77 – 3.59) than unmarried workers. It can be understood from this finding is that most of the workers performed their work activities with responsibility and as the majority being female, they were also involved in household activities. These results showed consistency with the studies conducted in similar jobs (Anjali Nag, Vyas, Shah, & Nag, 2012; Soe, Laosee, Limsatchapanich, & Rattanapan, 2015).

v. ***Type of work:*** The work activities and percentage of workers involved in each activity are *boiling* (11.4 %), *shelling* (51.8 %), *peeling* (220.0 %), and *grading* (14.8 %). This study showed that more than fifty percent of the study population was involved in shelling activity. As shown in Figure 2.3, the shelling workers are the most affected by WMSDs, followed by boiling workers. Shoulder, lower back, and knees were common disorders among

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shelling workers. This result is supported by a previous study by Girish et al. (2012). Further, the results of logistic regression analysis also indicated that a significant association exits between knee disorders and shelling work. These results provide extra evidence that WMSDs are the most serious disorders among shelling workers. Lack of ergonomically designed shelling equipment might be the most blameable factor for disorders among workers in shelling activity.

vi. ***Work experience:*** This study showed that the average work experience of workers was 8.5 years, and around 60 % had more than five years of work experience. The results of the study indicated that work experience was associated with neck and ankles/feet disorders. This finding is in accordance with a previous study that was reported from Kerala (Girish et al., 2012). This finding may be attributable to sustained and monotonous work activities.

vii. ***Work duration:*** In the present study, the average duration of work was 9.6 hours/day, particularly shelling workers carry their activity for long hours (11.1 hours/day). This is relatively high when compared with other similar studies like fruit farming workers (Thetkathuek et al., 2018) and pineapple peeling workers (Kumar et al., 2016). Kumar et al. (2016) report that duration of work is an ergonomic risk factor that is associated with WMSDs. In this study, we found a significant association between work duration and disorders occurring in the neck and ankles/feet with an odds ratio of 2.65 and 3.71, respectively. This finding may be attributable to poor organization of jobs and high job demands. Activities such as *shelling*, *peeling*, and *grading* were more time-consuming, and their productivity was also low. Therefore, the workers perform their tasks for long hours to attain target production and to earn enough money for the day. Extended work duration has been previously reported to contribute to the development of WMSDs among various working groups (Kumar et al., 2016; Thetkathuek et al., 2018).

viii. ***Work fatigue:*** It was observed that most workers are working for long hours and hardly take few minutes for a lunch break during the afternoon. Work was not shift-based, and there were no evening work shifts. It indicates that workers were expected to perform their activities all day. This condition may result in work fatigue and may cause serious injuries.

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This study showed that work fatigue is associated with disorders in shoulders, elbows, lower back, knees, and ankles/feet. The long hours of work and very few rest pauses might result in work fatigue among cashew workers. In addition, they were often required to perform the task very fast due to tight delivery schedules. Kumar et al. (2016) mentioned continuous work activities without rest pauses are known to be associated with the prevalence of WMSDs. Rest breaks at regular intervals will provide enough time for workers to recover their energy and also reduce discomforts (Chakrabarty et al., 2016).

ix. ***Job stress:*** Some studies showed a significant statistical relationship between job stress and WMSDs in various body parts (Sakthi Nagaraj, Jeyapaul, & Mathiyazhagan, 2019). In the present study also, there is a significant association of job stress with lower back disorders with an odds ratio of 3.51. The workers work in the congested workplace, and the adopted postures were uncomfortable. Moreover, workers had limited time, and they often required to hurry for completing their tasks. All these factors might have led to stress among workers. Michie (2002) showed that job stress might also lead to aggression and fatigue.

2.7.3. Postures

The working posture of cashew workers in different work activities was assessed via the REBA method. In the posture analysis, it was found that most of the postures adopted by cashew workers were highly risky and required immediate corrective measures. It is not shocking because most of the industry activities such as *boiling*, *shelling*, *peeling*, and *grading* are characterized by forward inclined trunk and neck postures, long hours of sitting and standing periods, unnatural upper limb postures, and repeated use of hand which in turn impose unergonomic postural loading on the workers' body. Especially, during shelling activity strenuous postures were prevalent, and the workers worked for prolonged hours in awkward standing positions. In particular, shelling workers adopt forward bending of trunk posture in single-leg stance position while operating the typically designed conventional shelling equipment. This condition imposes a static load on the lumbar region, which may cause lower back injuries. During *boiling*, workers carry heavy loads on their heads, which many induce compressive force on the intervertebral discs. This shows that the lower back problem is the most common problem among cashew workers. This result

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coincided with the response from questionnaire study, which also showed that lower back disorder is second most prevalent among cashew workers and all the work activities were strenuous. These findings were supported by Das, (2014) and Das & Gangopadhyay, (2015). They highlighted that prevalence of poor working conditions involving exposure to ergonomic risk factors such as awkward posture leads to work-related MSDs.

Overall, the poor working conditions witnessed in these small and medium-scale cashew processing mills not only affect the health of workers but also can lead to reduced productivity of enterprise and revenues. This study's findings warrant an ergonomic design intervention to improve working conditions of small and medium-scale cashew nut processing mills.

2.8. Chapter 2 summary

This chapter presented the findings of a cross-sectional study performed to assess the current working conditions in Indian small and medium-scale cashew nut processing mills. It reported a high level of ergonomic risk and musculoskeletal problems in all examined activities of cashew workers.

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Chapter – 3: Design and Simulation-based Evaluation of Cashew Nut Sheller

Chapter Abstract

In Indian small and medium-scale cashew nut processing mills, cashew nut shelling is a major activity where workers commonly use hand-cum-pedal operated cashew nut sheller for shelling roasted cashew nuts. In this activity, workers are required to adopt awkward working postures for prolonged periods, which contributes to WMSDs. However, no formal investigation has been conducted on working postures and (re)design of shelling equipment in India so far. Therefore, this chapter presents a systematic process of conceiving an ergonomic design intervention to address the issues in cashew nut shelling activity.

3.1. Introduction

In the previous chapter, an assessment of current working conditions in Indian small and medium-scale cashew nut processing mills was reported, and the findings were discussed. It was identified that workers in cashew nut shelling had suffered more due to WMSDs as compared to other activity workers (Figure 2.3). The working postures adopted during cashew nut shelling operation were also at a high-risk level (REBA score: 10) (Table 2.4). The use of conventional cashew nut sheller was mainly attributed to disorders among shelling workers. These findings highlighted the need for further investigation and the necessitated improving the working conditions in cashew nut shelling activity. Therefore, further study was carried out to conceive an ergonomic design intervention of the cashew nut sheller. It is also important to highlight that the users' perspective is crucial while developing context-specific ergonomic design intervention. Therefore, we made an effort to engage the local population in the design process to conceive an appropriate design solution that ensures users' comfort and safety.

3.2. Cashew nut shelling activity and shelling equipment

Cashew nut shelling is a major activity in the cashew nut processing mills in India. This activity mainly deals with shelling hard-shelled cashew nuts in order to extract the cashew kernel. The peculiar curvature, brittleness of cashew nut, and slippery nature of the shell make cashew nut shelling tedious and also pose a great difficulty in

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removing outer shell without damaging the cashew kernel. Shelling equipment is commonly required to break the cashew nut. Based on various requirements, namely shelling rate, the efficiency of shelling, minimum damage of cashew kernels, cost of shelling, and type of industry (such as small, medium, or large), a great number of shelling equipment have been developed by researchers worldwide, including India (review on shelling equipment was given in following *Section 3.3*). However, equipment that is predominantly seen in India is the traditional hand-cum-pedal operated sheller (Figure 3.1). Cashew nuts are manually fed one at a time in between the blades. The pedal pressed using foot brings the blade closer and penetrates into cashew nut. At this condition, the hand lever has to be lifted upwards to shear the shell into two halves. In practice, the existing sheller seems to have several shortcomings in terms of user comfort and safety while shelling. Whilst operating this equipment, shelling workers adopt awkward standing posture throughout the duration of work. Studies have shown that prolonged standing is one of the important risk factors for developing WMSDs (Ncube et al., 2019; Sakthi Nagaraj et al., 2019). Furthermore, the typical operation of pedal-cum-hand operated sheller forces workers to operate using both hand and foot simultaneously. The repetitive foot pedalling in an awkward position of leg further increases discomfort among shelling workers. While standing, workers excessively bend their trunks and neck for better vision at shelling activity. The posture of shoulder and forearm remain awkward and twisted dramatically. Consequently, these poor working postures impose a postural load on the body and eventually lead to WMSDs among shelling workers. According to the study reported in *chapter 2*, workers of shelling activity had suffered more due to WMSDs compared to other activity workers. The WMSDs among shelling workers were found to be the most prevalent. Knee, lower back, and shoulder disorders were more common among shelling workers. Previous authors such as Girish et al. (2012) and Oliver Raj & Narsia (2020) also highlighted that the awkward postures and repetitive actions mainly attributed to WMSDs among shelling workers.

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(a) Right side

(b) Backside

Figure 3.1 The existing cashew nut sheller. (a) Right side view (b) Back side view.

The occupational health of workers should be of foremost importance in every industrial work environment. Work equipment designed in accordance with recommended standards improves workers' satisfaction, well-being, and productivity at workplace. In an unorganized SME context, most of the ergonomic investigations are often reactive as the industry owners pay little attention to man-machine

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compatibility before installing and commissioning the work. The work activities in the industry commonly involve highly repetitive actions, awkward postures, and forceful exertions (Kumar et al., 2016; Niu, 2010; Qureshi, Manivannan, Khanzode, & Kulkarni, 2019; Sakthi Nagaraj et al., 2019). Workers are often characterized by varied anthropometry and physical capacities, and they perform the same task thousands of times in a day. As a consequence, workers often suffer from musculoskeletal disorders. In such a scenario, the ergonomics perspective is of great importance in modern industrial settings when designing work equipment and assessing the improvements.

However, investigations on redesigning existing cashew nut sheller to improve the health and productivity of shelling workers are scarce in Indian scenario. The study reported in this chapter proposes a redesigned cashew nut sheller. A combination of methods, including a postural assessment tool, interviews, questionnaire study, virtual prototyping, and digital human modeling and simulation (DHMS), were used to achieve the stated aim.

3.3. Cashew nut sheller design – A review

Many researchers from India as well as from abroad have designed and developed a good number of cashew nut shellers so far.

Somyot & Sermpol (1985) constructed a centrifugal cashew nut sheller to break cashew nut using optimum kinetic energy. It consists of a rotating shaft with a centrifugal disk, feeder, sheller bin, and discharger. The shaft, which is placed vertically at the center of sheller, is rotated by the electric motor. The cashew nuts fed from the top-feeder passes through the centrifugal disks. Due to centrifugal force, the fed cashew nut impacts the casing of sheller bin. The performance of centrifugal sheller was evaluated at 800 rpm, 900 rpm, 1000 rpm, and 1100 rpm. The shelling efficiency was 51.3 % to 58.3 % for cashew nuts above 7 g weight and 21.8 % to 25.9 % for cashew nuts below 7 g weight. The shelling capacity of this sheller was found to be 200 kg per hour.

Kumar (1989) designed a cashew nut sheller where cashew nut strikes the hard surface of sheller casing under centrifugal force. The main component of this centrifugal sheller is the impeller. This generates the necessary impulse force to hit the

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cashew nuts against the hard surface of sheller. It also has the arrangement for collecting shelled nuts.

Thivavarnvongs, Okamoto, & Kitani(1995) designed two types of manual cashew nut sheller models (AE (KKU) 1 and AE (KKU) 2), and one semi-automated sheller model (AE (KKU) SA 1). The working principle of both manual shellers was based on press-twist movement of hand lever. In AE (KKU) SA 1, the cashew nut feeding is manual, and shelling is automatic. Thivavarnvongs, Sakai, & Kitani(1995) evaluated manual and semi-automated shellers. They reported that The AE (KKU) 2 was easy to operate and had a whole kernel recovery of 79.3 %, whereas automatic model (AE (KKU) SA 1) had a whole kernel recovery of 80.0%.

Ajav (1996) developed a low-cost manual cashew nut cracker. It consists of frame, pillar pole, cracking jug assembly, cutting case, blades, hand lever, and spring. The efficiency of this machine when tested with small, medium, and large size nuts was reported to be 69.4 %, 75.5 %, and 75.7 %, respectively.

Jain & Kumar (1997) developed a power-operated cashew nut sheller. It consists of different sections for feeding, shelling, discharge, power supply, and transmission. The sheller mainly consists of two round wooden disks of 25 mm thickness. One disk is fixed to the sidewall of the sheller, and the other disk is a spring-loaded rotating one. The cashew nuts that are fed into the sheller are compressed and subjected to shearing by rotation of disk. The shelled nuts are collected at the discharge section.

Bulaong, Gregorio, & Jallorina (2000) designed an automated cashew nut sheller. It consists of two blades (upper blade and lower blade) with a contour shape of cashew nut. Using micro switch, the lower blade is penetrated into cashew nut up to desired thickness, and the upper blade is twisted to shear the cashew nut. In this process, one nut is shelled at a time.

Swain (2005) developed manual and power-operated shellers. The maximum shelling efficiency of manual sheller was 84.0 %, whereas power-operated sheller was 77.6 %. Considering performance evaluation the use power-operated sheller was suitable for effective improvement of cashew nut shelling task.

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Osunde & Oladeru (2006) designed a manual cashew nut sheller. It works in the press and twist principle. The test results indicated that the shelling efficiency and whole kernel recovery were 80% and 66.7 %, respectively.

Ojolo & Ogunsina (2007) designed a box-type cashew nut shelling machine. It consists of a hinge and a spring-loaded cracking lid. The cashew nuts are placed in the round grooves and pressed gently using the spring-loaded lid. At a time, 25 roasted cashew nuts can be cracked using this box-type sheller.

Ojolo, Damisa, Orisaleye, & Ogbonnaya (2010) developed an impact shelling machine. It consists of an impeller which is rotated by an electric motor. The cashew nuts are cracked by impact force by the impeller. Machine throughput, shelling efficiency, and whole kernel recovery was 15.57 kg/hr, 95%, and 70 %, respectively.

Balsubramanian (2011) presented a radial arm type manual cashew nut sheller. During shelling operation, the cashew nut is subjected to cutting-shearing action to extract the kernel. This is done in a single operation, and the shelling rate is considerably low.

Uchiyama, Ho, Yamanaka, Sano, & Tran (2014) developed an automated cashew nut shelling system that consists of a vibrating cashew feeder, conveyor belt, rollers, cashew milling cutters, and cashew shell splitter. In this sheller, the force controller attached to the cashew milling cutters can accommodate variance in cashew nut size.

Fu et al. (2016) developed an automated cashew nut sheller. It consists of adaptive cashew nut shelling cutters, a support frame cutter, and a scraper. The cashew nut is placed on a V-shaped groove, and the scraper is used to drag the cashew nut against adaptive cutters. Particularly, the spring-loaded upper blade can move up and down in order to accommodate the size variance of cashew nuts.

Oluwaseun Kilanko et al. (2018) designed and constructed a centrifugal cashew nut sheller. It mainly consists of a hooper, impeller, shaft, and electric motor. It works on optimal kinetic energy for breaking the cashew nuts. The whole kernel recovery for large, medium, and small cashew nuts was reported to be 65.4 %, 51.62 %, and 37.95 % at 3110 rpm, 3487 rpm, and 3487 rpm, respectively.

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Kilanko et al. (2019) designed a shelling machine using the impact method. The sheller was evaluated using three different sized nuts (small, medium, large) and three levels of impeller speeds. The results showed that the large-sized nuts exhibited higher whole kernel recovery (82.0 %) compared to small and medium nuts.

These research works carried out by different researchers on the development of cashew sheller were briefly discussed in this section. Though a good number of cashew nut sheller designs were reported, however, most of the researchers worked on shelling principle, shelling efficiency, whole kernel recovery, and performance of sheller. There is a paucity of research on sheller design that considers ergonomic aspects in design and the occupational health of workers.

3.4. Considerations for a design intervention – An ergonomic perspective

Design of work equipment and characteristics of work determine the body posture of workers (Dellerman, Haslegrave, & Chaffin, 2004). The working posture adopted by the workers in any activity is directly determined by the equipment design. Further, factors like the position of machine controls, work surface height, the field of view, reach distance, and free movement of body parts are also in relation to equipment design (Dellerman et al., 2004). According to Keyserling (1998), workstation layout, worker anthropometric measurements, work methods, and visual demands govern the working posture of worker while performing a task. Primarily, poor design of work equipment and incompatibility of anthropometric needs of workers lead to undesirable postures. For example, standing or sitting without proper support, resting elbows on a high working surface while sitting, extended arms, head bending, raised elbows, wrist flexion, and extension, rotation of forearm (outward/inward), raised shoulders, trunk bending or twisting, shoulder abduction, radial or ulnar deviation are some of the indicators of awkward working postures (Genaidy et al., 1994). Deviation of body parts from neutral position results in pain and discomfort. It is known that work-related MSDs occur in a variety of ways among workers. Typically, workers that assume awkward postures frequently for long hours and even for months or years results in serious musculoskeletal injuries, and also leads to permanent disability and increased compensation (Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991). In a study by Simonsen et al. (2018), the assessment of physical workload in sonography task, reported that a high proportion of time spent in awkward posture resulted in

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work-related MSDs among sonographers. Therefore, elimination or reduction of awkward working posture should be the primary objective of workplace ergonomic interventions in order to prevent work-related MSDs (Keyserling, 1998; Punnett et al., 1991).

Ergonomics is the scientific discipline that is concerned with the understanding of man-machine interactions and applies principles, theory, methods, and data to design in order to achieve better human well-being and overall performance of system (Bridger, 2008). The ergonomic principles and guidelines help to provide a better understanding of the physiological and psychological requirements of the operator. Essentially, design is a compromise between operator's biological requirements and physical requirements of the equipment. In general, design is majorly determined by the mutual effect of location of work equipment elements and anthropometry on parameters like working posture, reach, vision, strength, clearance, and interfacing of body parts with the work equipment elements. Mostly, all of these design factors largely contribute to determining postural requirements of an operator while performing a task.

Consideration of ergonomics in the development of work equipment has been effective in reducing WMSDs (Dianat, Nedaei, Nezami, & Ali, 2015; Ghasemi, Hosseinzadeh, Zamani, Ahmadpoor, & Dehghan, 2017; Labbafinejad et al., 2019; Mukhopadhyay & Ghosal, 2008). Special care should be taken while designing manually operated equipment as it involves direct interaction of man-machine. Design of work equipment should be in a way that working posture in neutral position as long as possible. Design of machine controls should be close to workers' bodies and below their shoulder level (Kushwaha & Kane, 2016). Specifically, designing control elements between shoulder and hip height minimize awkward posture of hands/arms and shoulders (Reilly, 2020). The neck and trunk postures should be vertical with minimal bending and twisting movements. Minimal deviations of trunk from a neutral position help reduce lower back injuries. The height of the working surface needs to be designed nearer to elbow level either in standing or sitting position. Depending on type of work to be performed, the height of the working surface should have a definite relationship with the elbow height of the operator. According to Konz (1967), the height of working surface should be ± 5 cm to that of the elbow level. The working surface should not cause a significant effect on task performance as the proper

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working height provides a comfortable working posture. Adjustability is a crucial factor in the design of equipment because this feature allows accommodation of a wide range of people as well as the adoption of the desired posture by the workers (Dellerman et al., 2004; Sauter, Schleifer, & Knutson, 1991).

Anthropometry is a branch of ergonomics that deals with the measurement of human body dimensions. It assists the designer in determining the physical characteristics of work equipment and workstation design. So, anthropometric data should be considered in the ideal design process because the fit between human and designed equipment is always not optimal, and in many cases, it leads to WMSDs (Motamedzade, Choobineh, Mououdi, & Arghami, 2007). The design of components should be easily reachable and should satisfy the anthropometric characteristics of a wide range of people. It is to be noted that minute changes in equipment dimensions were found to have a greater result on occupational health and productivity of a worker. Changing location of machine components, altering heights, providing inclined seating surface, designing power grip handles, modifying equipment layouts, changing orientations, and hand actions may help to improve the human-machine interaction. Therefore, designing work equipment based on ergonomics and anthropometric data is highly required (Sharma et al., 2021). Particularly, implementing modifications/redesign of work equipment in order to eliminate awkward postures and safeguarding the health of workers in unorganized SME sectors were not generally observed (Dianat & Salimi, 2014; Sanjog, Patnaik, Patel, & Karmakar, 2016). In such cases, the role of a designer is crucial to formulate ergonomic design interventions and obtain acceptable solutions from an ergonomics point of view. It is worth noting that existence of un-ergonomic tools or work equipment is one of the major causes of WMSDs, which is highly prevalent in developing countries (Das et al., 2021; Kumar et al., 2016; Muhamad Ramdan et al., 2018). Though some efforts have been made to improve the working conditions of SME workers (Mukhopadhyay & Ghosal, 2008; Sanjog et al., 2016), much is required in agro-related processing industries like cashew processing SMEs.

3.5. Participatory approach and computer-based simulation tools

Participation at work is one such approach that gives end-users an opportunity to design workplace or tools according to their work activities. It is considered that end-

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users know better about their workplace and work activities than anyone else does, and their knowledge helps in developing comprehensive solutions to their workplace hazards (Hess, Hecker, Weinstein, & Lunger, 2004). It is the fundamental benefit of the participatory approach. The overall focus of this approach is to encourage end-users to participate in assessing, designing, and evaluating the tools and workplaces by applying different participative techniques and methods (Garmer, Ylvén, & Karlsson, 2004). Most often, the feasible methods that are used in order to include end-users perspectives in design process are brainstorming, focus group interviews, observations, and questionnaires (Wulz, 1990). Focus group interviews allow a group of individuals to collectively discuss the problems and brainstorm solutions to the problems (Dasgupta, Punnett, Moir, Kuhn, & Buchholz, 2016; Hess et al., 2004). The focus group meetings in a participative manner have been conducted in various industries in order to develop useful solutions for reducing musculoskeletal exposures and have been documented by many previous researchers (Dasgupta et al., 2016; Earle-Richardson et al., 2005; McNeill & Westby, 1999; Umar et al., 2019).

It is extremely important to incorporate ergonomic requirements in the early stages of a new product design and production planning. This can be seen as a holistic approach at the product design level where the changes are less costly and easier compared to late changes to work methods and workplace design. Based on these reasons, computer-based ergonomics simulations have been commonly performed to predict ergonomic issues even before any product or workstation is physically developed (Chaffin & Nelson, 2001). One of the important reasons for ergonomics simulations is to assess the physical workload acceptability by applying biomechanical models and data. Subsequently, the workstation design can be changed to improve the ergonomic conditions at the workplace.

In recent years, the advancement of powerful computer-based simulation tools has made it possible to execute testing of workstations in modern computer desktops, thus allowing the application of cost-effective simulations in the industry. One of the main aspects of the new computer-based simulation tools is that they encompass ergonomics knowledge to be used during the early stages of design. It is helpful to make better decisions while making products. Some of the other important benefits include: (a) designers may eliminate time, and expensive design changes during initial design stage, (b) Simulations also helps to eliminate costly and time-consuming

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physical mock-ups, (c) The issues related to ergonomics, anthropometry, and physiological can be analyzed and addressed while the workstation is in still design stage, (d) When the workstations are validated digitally, the production engineers can reduce time-to-market durations,

Nowadays, a good number of commercial software tools are available for ergonomics simulation and analysis to make faster and more efficient product design. These tools replace humans with virtual/digital model of humans known as a manikin. These virtual manikins are a changeable and controllable version of humans. Presently, several commercial software such as SANTOS (Abdel-Malek et al., 2007), ANYBODY (Rasmussen et al., 2003), SAMMIE (Porter, Case, Summerskill, & Marshall, 2009), RAMSIS (Human Solutions, 2010), DELMIA HUMAN (Dassault Systèmes, n.d.), JACK (Siemens, 2011), which support digital human models (DHMs). DHMs are capable of interacting with virtual workstations and evaluating workstation layout, assembly accessibility, workflow simulations, reach analysis, vision analysis, clearance analysis, safety analysis, posture and movement analysis, comfort analysis, the center of gravity analysis, biomechanical analysis, and etc. The DHMs have scientific validity (Chaffin, 2005). Some researchers assured good face validity of DHM after testing the effectiveness of design interventions (Jadhav et al., 2019; Kushwaha & Kane, 2016; Sanjog et al., 2016).

The application of DHM for the evaluation of virtual workstations and associated tasks was reported by some researchers in Indian scenario. For instance, evaluation of ingress-egress of an army vehicle (Karmakar, Majumdar, Pal, & Majumdar, 2011), vision analysis of jet aircraft (Karmakar, Pal, Majumdar, & Majumdar, 2012), workstation evaluation in plastic processing industry (Sanjog et al., 2016), evaluation of postures in handicraft polishing work (Mallampalli & Pal, 2021), postural assessment a submersible pump (Binoosh et al., 2017), evaluation of paddy thresher (Patel et al., 2017), working posture analysis in foundry (Qureshi & Solomon, 2021), evaluation of crane cabin (Kushwaha & Kane, 2016), stitching workstation evaluation (Jadhav et al., 2019), etc.

During the literature review, it was observed that the use of DHM in investigations of small and medium-scale cashew nut processing mills is scarce. It would be beneficial to use low-cost virtual technology for the ergonomic assessment

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of manual activity in unorganized small and medium-scale cashew nut processing mills.

3.6. Redesign of existing cashew nut sheller

Redesign of the existing cashew nut sheller started with defining the Design brief. Later, a participatory approach was adopted to involve end-users perspectives while designing the solution. The following sections present the steps taken to conceive the ergonomic design intervention in detail.

3.6.1. Design brief

The entire focus of the design activity is to address postural issues during the shelling activity where both upper and lower limbs are extensively used while operating existing hand-cum-pedal operated sheller. This activity exposes workers to the risk of WMSDs in different body regions. Thus, the objective of this phase was to modify the existing sheller design by engaging stakeholders in a participatory approach and to find a feasible solution to reduce the postural workload of shelling workers.

3.6.2. Study location and participant recruitment

The study was conducted in the Vetapalem cashew nut cluster. This study location is one of the oldest commercial cashew nut clusters in Andhra Pradesh, India. On this site, there are nearly fifty small and medium-scale cashew nut processing mills, and approximately 200-250 cashew nut shelling workers were engaged in these mills. This phase of the study was conducted on-site during 2020-21.

A total of thirteen potential workers voluntarily participated in the study. The participants include shelling workers, supervisors, technicians, and owners. Table 3.1 shows the demographic details of participants.

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Table 3.1 The demographic details of study participants.

Participant	Role	Gender	Age (yr.)	Height (mm)	Weight (kg)	Work experience (yr.)
1	Shelling worker	Male	35	1653	68	6
2	Shelling worker	Male	43	1668	65	10
3	Shelling worker	Male	45	1724	60	12
4	Shelling worker	Female	32	1556	55	5
5	Shelling worker	Female	34	1588	45	8
6	Shelling worker	Female	29	1547	45	5
7	Supervisor	Female	35	1606	52	12
8	Supervisor	Male	32	1689	70	10
9	Technician	Male	26	1655	65	8
10	Technician	Male	30	1682	55	8
11	Technician	Male	25	1698	58	6
12	Owner	Male	48	1655	68	20
13	Owner	Male	50	1678	70	25

3.6.3. Introductory meeting

An introductory session was conducted with the participants to briefly explain the concept of ergonomics. The main goal of the briefing is to enhance workers' knowledge in recognizing musculoskeletal exposure during cashew nut shelling and to make them aware of their health issues related to the shelling activity. Figure 3.2 shows a glimpse of the introductory meeting conducted with the participants. During the same meeting, all the participants were informed about the objectives of this study and were explained about the possible discussions in the participatory design sessions. They were made aware that this study was aimed to identify ergonomics issues, generate several interventions concepts, and propose an ergonomic design intervention collaboratively to address those issues. This introductory session lasted for 30 minutes. After the introductory meeting, two participatory sessions were held with the users.

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Figure 3.2 Introductory meeting with the stakeholders.

3.6.4. Reasons for not using semi-automated and automated equipment

As mentioned in the previous Section 3.3, there was a good number of cashew nut shelling equipment available in the market. However, commercial use of semi-automated and automated shelling equipment was scarce. During the meetings, an effort was made to find out the reasons for not using semi-automated and automated machinery in shelling operations. Some of the important reasons identified are as follows:

1. **Large capital investment:** Mostly, the small and medium-scale mills run with small capital resources. The installation of automated machinery requires large capital investment, and being a small and medium-scale industry with limited financial resources, owners cannot afford these costly pieces of machinery.
2. **Contractual nature:** Most of these small and medium-scale mills run their business on the basis of commission. They take orders from big players and supply the kernels after processing. When demand is high, they receive huge orders. When demand is low, they receive fewer orders. As the demand for the product varies, investing a huge amount in machinery does not seem profitable to the owners.
3. **Seasonal nature of the industry:** Cashew nut processing is a seasonal-based industry. Generally, production is done between 6 and 8 months in a year based on the availability of raw nuts. The machinery remains idle during the

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seasonal break, and as such, the owners are reluctant to invest in costly machinery.

4. **Electricity:** Mostly, cashew nut processing mills are established in rural areas. In rural areas, continuous supply of electricity is commonly not available. In this condition, running the machinery without any break is difficult, and as such, it may affect production.
5. **Lack of effective operational knowledge and technical support:** Even though mills purchase new technologies, there is a lack of workforce with technical knowledge. The maintenance and repair costs then seem to be an extra burden to the industry.
6. **Whole kernel recovery:** It is very important to extract the cashew kernels intact and as a whole which has a high value in the market. But with most of the semi-automated/automated machinery, 25% to 40% of kernels get damaged. Generally, the improper position of nut in between blades causes the nut damage. On the other side, the manually operated machinery gives almost 90% whole kernels (Ajav, 1996; Jain & Kumar, 1997; Oluwaseun Kilanko et al., 2018; Ojolo & Ogunsina, 2007). This is one of the main reasons that most of the small and medium-scale processors refrain from adopting automated machinery.

Along with the reasons for not adopting semi-automated or automated shelling equipment, the participants' preference regarding appropriate sheller design (manually operated/semi-automated/automated) was also collected. All the participants (13/13) preferred design of manually operated shelling equipment.

3.6.5. Identification of user requirements

After introducing ergonomics as a concept during the introductory meeting, the first participatory session was conducted with volunteered participants (Figure 3.3). In the first stage of this participatory session, a brief overview of existing knowledge about musculoskeletal exposure during cashew nut shelling was given based on published literature. The observations about the shelling activity made during initial studies were shared with the workers to facilitate discussions on possible modifications of existing equipment. The participants were encouraged to discuss the pros and cons of using the existing sheller. While individual workers explained negative aspects about the

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existing sheller, other co-workers were asked about the same to cross verify, and their insights were recorded.

Figure 3.3 Interaction with users during participatory session 1.

All comments from participants were recorded and transcribed. After analysis of data, a total of 45 user requirements were initially described. Table 3.2 shows the initial user requirement descriptors.

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Table 3.2 The description of initial user requirements related to use of cashew nut sheller.

Initial user requirements description					
1.	100% shelling	2.	Save space	3.	Provide seating
4.	Prevent slipping	5.	Easy assembling structure	6.	No pain
7.	Reasonable scale/dimension	8.	Avoid foot use	9.	Provide comfort
10.	Parts can be replaced	11.	Working surface should be plane	12.	Low cost
13.	Light weight	14.	Strong materials	15.	Beautiful appearance
16.	Fit for varied cashew nut sizes	17.	Easy to carry	18.	Avoid standing
19.	Allow left or right hand use	20.	Easy to transport	21.	Blades can be easily replaced
22.	Sufficient leg space	23.	Handle fit the hands	24.	No fatigue
25.	Good friction between hand and handle	26.	Superior quality	27.	Good control over cutting
28.	Provide enough gap between blades	29.	Provide good vision	30.	No vibrations
31.	Provide storage/collection bin	32.	Nice color	33.	Easy operation
34.	Good durability	35.	Blades can be easily cleaned	36.	Maintain stability during operation
37.	Provide adequate handle grip	38.	Blades can be reused	39.	Easy to clean dirt on the surfaces
40.	Suitable placing shelled cashew nuts	41.	Stool not integrated with table	42.	Easy repair
43.	Good force transmission	44.	Simple construction	45.	Good shape

These 45 initial user requirements were pre-screened and classified under meaningful categories. The pre-screening was carried out using grouping/combining/eliminating procedure. The criteria followed for performing this procedure were based on relevancy, redundancy, dependency, and similarity. As a result, a total of 15 pre-screened user requirements were identified and defined, as shown in Table 3.3.

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Table 3.3 The pre-screening of initial user requirements.

User requirements	User requirement definition	
1. Good cutting	The sheller provides good shelling of cashew nuts	1;16;28;29
2. Comfort	The sheller is comfortable to use; cause pain as low as possible during operation	6;9;22;23;24
3. Cleanable	Dirt on the sheller table and shelling blades are cleaned; surfaces are smooth	11;35;39
4. Durable	The sheller has strong materials and superior quality	14;26;34
5. Appearance	The sheller has beautiful appearance and nice color	15;32;45
6. Portable	The sheller is light weight; can be easily carried/transported	13;17;20;41
7. Stable	The sheller has good rigidity; has shock resistance	30;36
8. Maintenance	The sheller is easy to assemble; disassemble; repair	5;10;21;42
9. Easy to use	The sheller provides simple operation	8;19;27;33
10. Save space	The sheller has proper volume; reasonable scale/dimension; save space	2;7;44;
11. Storage and collection	The sheller has a collection bin for collecting shelled cashew nuts	31;40
12. Affordable price	The cost of the sheller is low; affordable	12
13. Sit	The sheller has comfortable seating arrangement	3;18
14. Recyclable	The sheller blades are recycled/reused	38
15. Handle anti-slip	The handle of the sheller has slip-resistance property; has good friction between handle and hand to transmit the required force	4;25;37;43

A survey questionnaire consisting full list of pre-screened user requirements was developed. A total of thirty workers from the local population had volunteered to evaluate the priorities of 15 user requirements. The relative importance of each user requirement was rated on a 5-point linear numeric rating scale (1 = extremely unimportant to 5 = extremely important) (Appendix III). The internal consistency reliability of the questionnaire was checked using Cronbach's alpha. The computed Cronbach's alpha was 0.75, which indicated acceptable reliability of the survey questionnaire.

Data collected during the first participatory session were processed using quality function deployment (QFD) tool. This is one such tool that explicitly translates customer needs into design/engineering characteristics. QFD is also a mostly used tool by various industries around the world (Demirbilek & Demirkan, 2004; Marsot, 2005;

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Zadry, Susanti, & Rahmayanti, 2017). Using QFD, design requirements were determined from final user requirements. Fifteen user requirements were translated into 29 design requirements, as shown in Table 3.4. The correlation matrix was built to find existing relationship between user requirements and design requirements. The user requirements-design requirements correlation was evaluated using rating scale (0 = no relation, 1 = weak relation, 3 = moderate relation, and 9 = strong relationship). It should be noted that this step (construction of QFD) is not a participatory act as no user was directly involved. It is an act of representation by the designers because the designers represent users by interpreting their real needs/expectations and matching them with their previous knowledge and interaction with users. Figure 3.4 illustrates QFD for ergonomic cashew nut sheller.

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Table 3.4 The user requirements and identification of design requirements.

User requirements		Design requirements
1. Good cutting	→	Blade shape
		Gap between blades
		Vision
		Blade rigidity
2. Comfort	→	Handle direction
		Height adjustment pin
		Position of cutting unit
		Seat cushioning
3. Cleanable	→	Smooth surfaces
4. Durable	→	Strong materials
		Superior quality
5. Appearance	→	Color variations
6. Portable	→	Weight
		Ease of carrying
7. Stable	→	Structure rigidity
		Shock damping/spring system
8. Maintenance	→	Easy repair
9. Easy to use	→	Low gripping force
		Handle inclination
		Seat forward inclination
10. Save space	→	Table size
		Seating surface
11. Storage and collection	→	Collection bin
		Dropping channel
12. Affordable price	→	Material and Manufacturing methods
13. Sit	→	Seating structure
14. Recyclable	→	Hardness of blade
15. Handle slip resistance	→	Handle grip
		Rough texture on handle

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Customer importance rating	Design Requirements → / Customer Requirements ↓	Blade shape	Gap between blades	Vision	Blade rigidity	Handle direction	Height adjustment pin	Position of cutting unit	Seat cushioning	Smooth surfaces	Strong materials	Superior quality	Color variations	Weight	Ease of carrying	Structure rigidity	Shock damping/spring	Easy repair	Low gripping force	Handle inclination	Seat forward inclination	Table size	Seating surface	Collection bin	Dropping channel	Material and Manufacturing	Seating structure	Hardness of blade	Handle grip	Rough texture on handle	Weighted Score
4.63	Good cutting	9	3	9	3	1		3				3				3	3											3	3		199.09
4.77	Comfort		3	9	3	9	9	9	9						3					9	3		3				9		3		386.37
3.53	Cleanable	9	9			1				9												3	1								112.96
3.70	Durable										9	9														3		9			111
2.90	Appearance	1											9																		29
3.37	Portable										9			9	9												3				101.1
3.43	Stable				9									1		9	9					1					3				109.76
2.43	Maintenance									1					3			9									3				38.88
3.80	Easy to use			3	9	9	1	3												9	3							3	1	155.8
2.87	Save space							1														9	3	1	1		3				51.66
4.20	Storage and collection																					1		9	3						54.6
2.83	Affordable price										3	3						9								9					67.92
4.17	Sit			1			9		9												3	1	9				9				170.97
3.30	Recyclable	9									3	3														1		3			62.7
2.57	Handle slip resistance					9	3	9				3							9	3						3			9	9	146.49
	Technical importance score	106	59.97	100	93.3	108.4	92	94.2	80.5	34.2	82	73.3	26.1	33.8	51.9	44.8	44.8	47.3	23.1	84.8	38.2	48.2	64	40.7	15.5	47.6	117	57.1	62.7	26.9	1798.3
	Importance %	6%	3%	6%	5%	6%	5%	5%	4%	2%	5%	4%	1%	2%	3%	2%	2%	3%	1%	5%	2%	3%	4%	2%	1%	3%	6%	3%	3%	1%	100%
	Priorities rank	3	14	4	6	2	7	5	10	24	9	11	27	25	16	20	20	19	11	8	23	17	12	22	29	18	1	15	13	26	

Degree of correlation: 0-No correlation; 1-Weak correlation; 3-Moderate correlation; 9-strong correlation.

Figure 3.4 The construction of QFD for new cashew nut sheller.

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3.6.6. Generation and screening of design alternatives

Based on the information extracted from the matrix, preliminary concept sketches were generated during participatory session 2 (Figure 3.5). Different ideas were generated in order to crack the cashew nut in various ways. Several ideas were explored by referring various similar tasks from the literature. The handle orientation was taken as the basis for generating various concept sketches. The handle was oriented in three directions, namely Horizontal, Inclined, and Vertical. Different concepts were generated for each category. A total of three preliminary concepts were sketched. Figure 3.6 – 3.8 shows the generated computer sketches of cashew nut sheller. It should be noted that the generation of concepts was done based on interview sessions with the stakeholders, review of ergonomics literature, and on-site observations of the shelling activity. The computer-drawn sketches were presented to the users in the second participatory session. Copies of drawings were circulated among all the participants, and they were asked to provide their feedback about the concept sketches. Also, the description of each concept sketch was presented to the participants in order to avoid any misunderstanding. The concepts then underwent screening by all the participants. The participants reviewed the concepts and were screened down to one. The criteria considered were: the orientation of handle, ease of operation, mechanism as well as availability of materials. Among the three design concepts presented to the participants, the vertically oriented handle concept was preferred by all the participants and hence selected as the final concept.

Figure 3.5 Interaction with users during participatory session 2.

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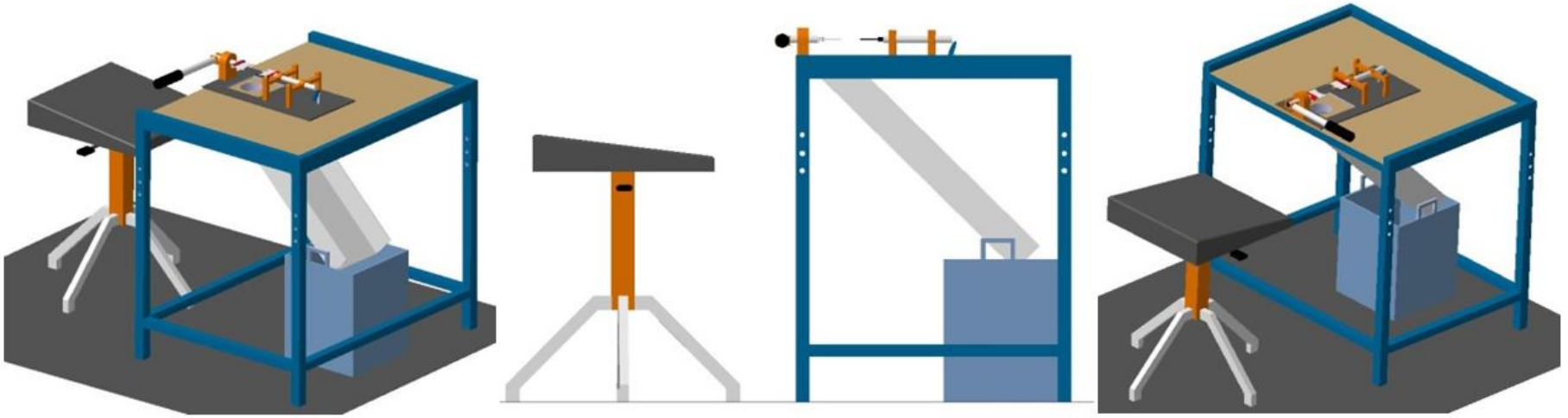

Figure 3.6 The ergonomic design alternative: Horizontal type.

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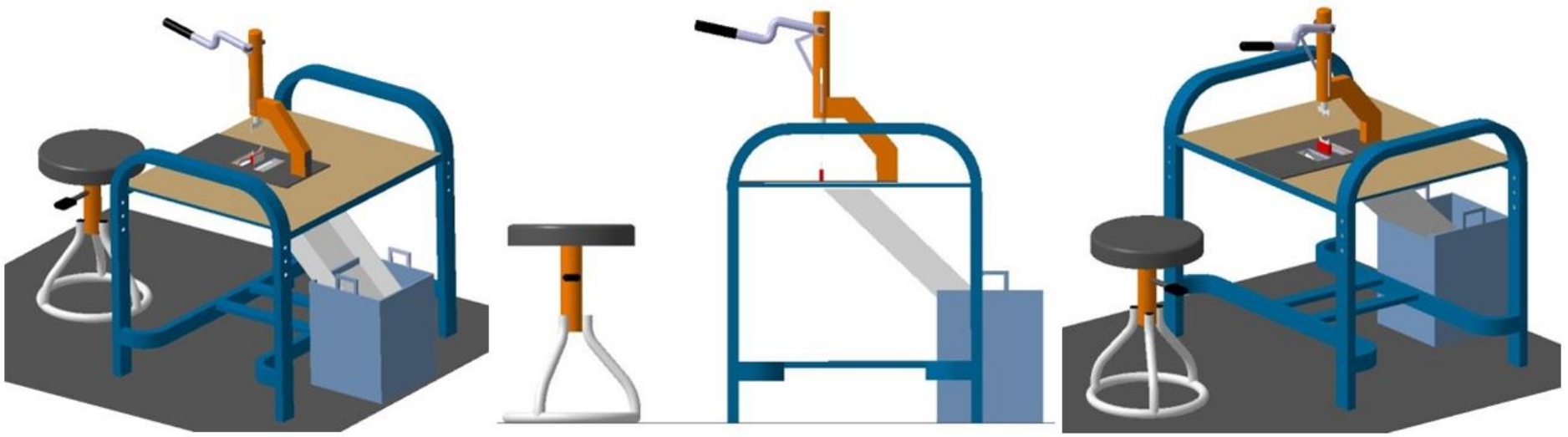

Figure 3.7 The ergonomic design alternative: Inclined type.

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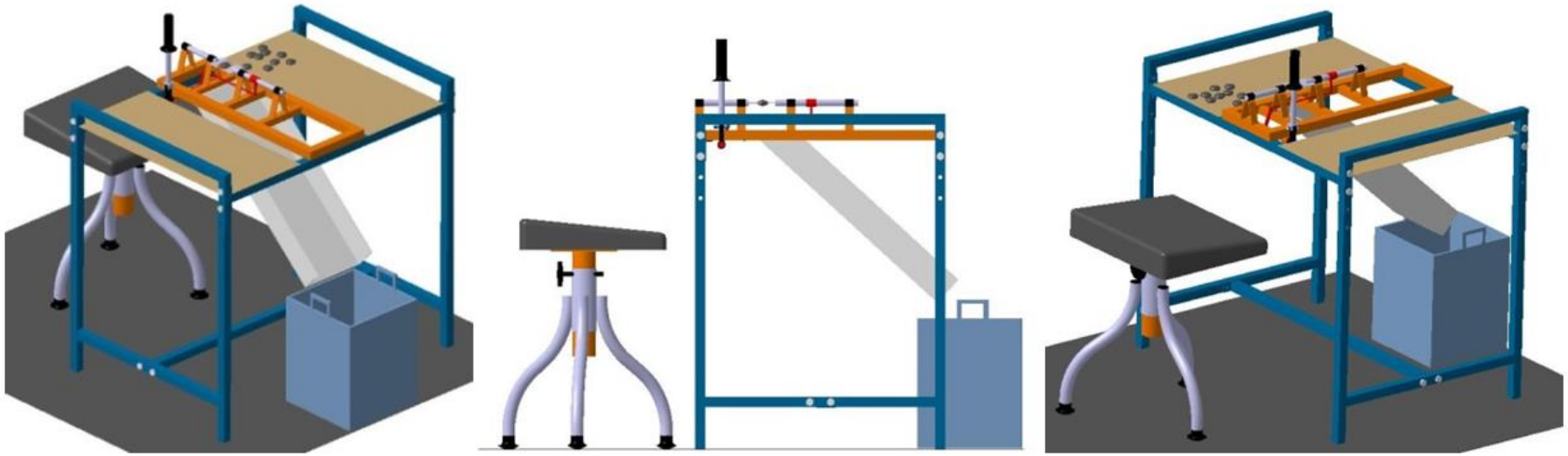

Figure 3.8 The ergonomic design alternative: Virtical type.

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3.7. Simulation-based evaluation of redesigned sheller

3.7.1. Creation of digital human model

In order to perform virtual simulation, three manikin models based on Indian anthropometric data, representing 5th percentile, 50th percentile, and 95th percentile, were developed. Table 3.5 shows the characteristics of manikin. The manikin models and new design of sheller were then interfaced in a 1:1 scale.

Table 3.5 The characteristics of manikin.

Manikin	Percentile	Stature (mm)	Weight (kg)	Sitting height (mm)	Waist circumference (mm)
Female (size: short)	5th	1429	35	698	614
Male (size: medium)	50th	1648	54	819	782
Male (size: very tall)	95th	1781	76	893	969

3.7.2. Posture analysis

Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett, 1993) method was used for assessing the working posture of cashew nut shelling workers in the human activity analysis workbench of CATIA DELMIA v6. RULA is a quick evaluation technique for assessing the ergonomic risk of upper extremities such as the neck, trunk, and upper limbs. Based on the working posture, load, and muscle use, RULA provides a combined score that ranges between 1 and 7 (Appendix IV). There is an advanced colour indication feature to display scores in DELMIA. Score 1 and 2: (Green colour) indicates posture is acceptable. Score 3 and 4: (Yellow) indicates further investigation is required, and changes may be needed. Score 5 and 6: (Orange) indicates investigation and changes required soon. Score 7: (Red) indicates investigation and changes are required immediately. Figure 3.9 illustrates the score range for each body segment and associated colour.

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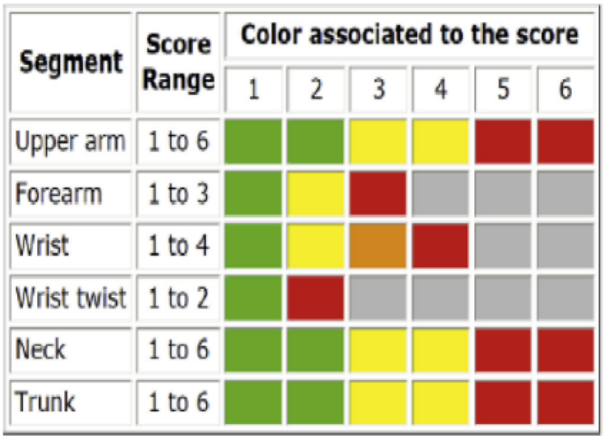

Figure 3.9 RULA score range and colour associated with score.

3.7.3. Visibility analysis

Visibility is the most important factor in shelling. DELMIA software provides a vision window that displays the scene through the eyes of manikin. The vision window is automatically updated when the manikin's head position is changed. To perform visibility analysis, the manikin vision is set to binocular view field having the boundary conditions such as view cone angle 25^0, and focus distance 300 mm.

3.7.4. Clearance analysis

Whilst seated on a stool, a sufficient gap between thighs and table working surface (bottom edge) allows free movement of legs. Therefore, thigh clearance analysis was performed for 5^{th} P, 50^{th} P, and 95^{th} P manikins.

3.7.5. Results of RULA

Figure 3.10 – 3.12 presents the RULA analysis. The RULA dialog box shows the details, including final score for the working posture and score for each body segment. These results of RULA revealed that there is a remarkable improvement in the working posture of the redesigned sheller. The RULA final score was 3, and the corresponding action level was 2 for 5^{th} P, 50^{th} P, and 95^{th} P manikins, respectively.

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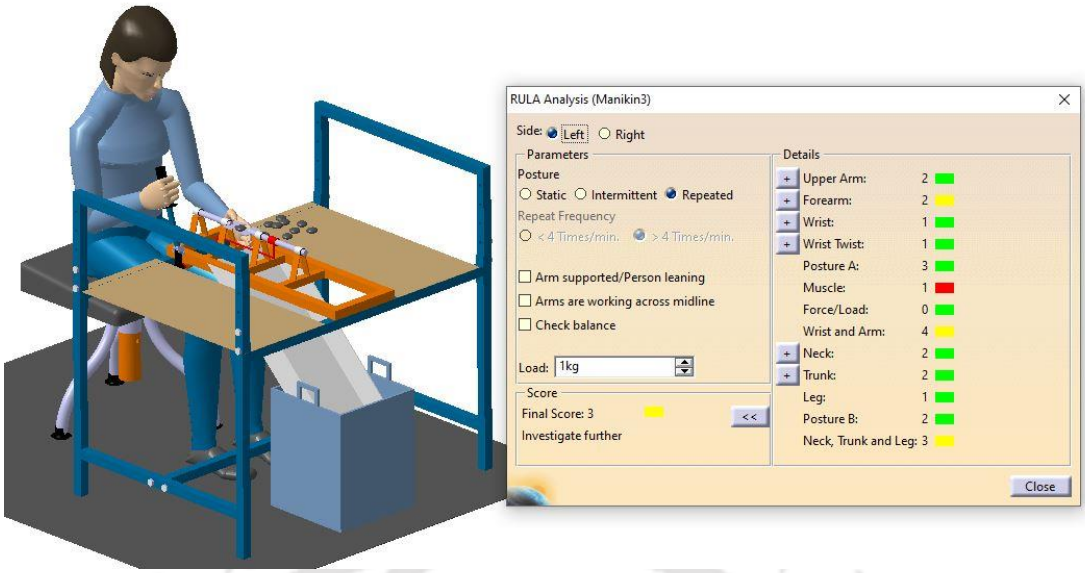

Figure 3.10 The RULA score for 5th percentile manikin in new cashew nut sheller.

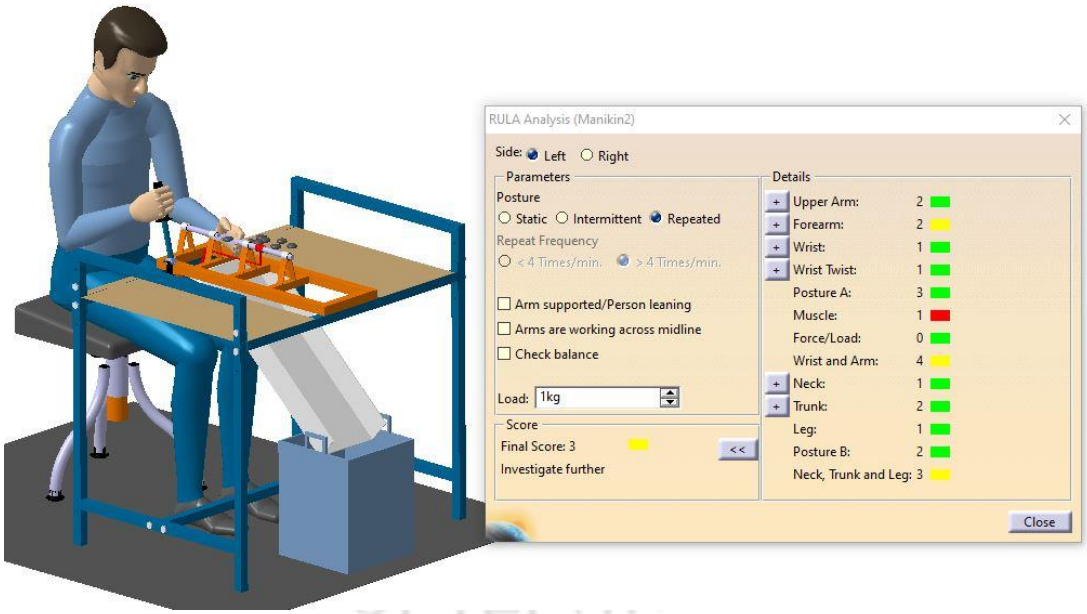

Figure 3.11 The RULA score for 50th percentile manikin in new cashew nut sheller.

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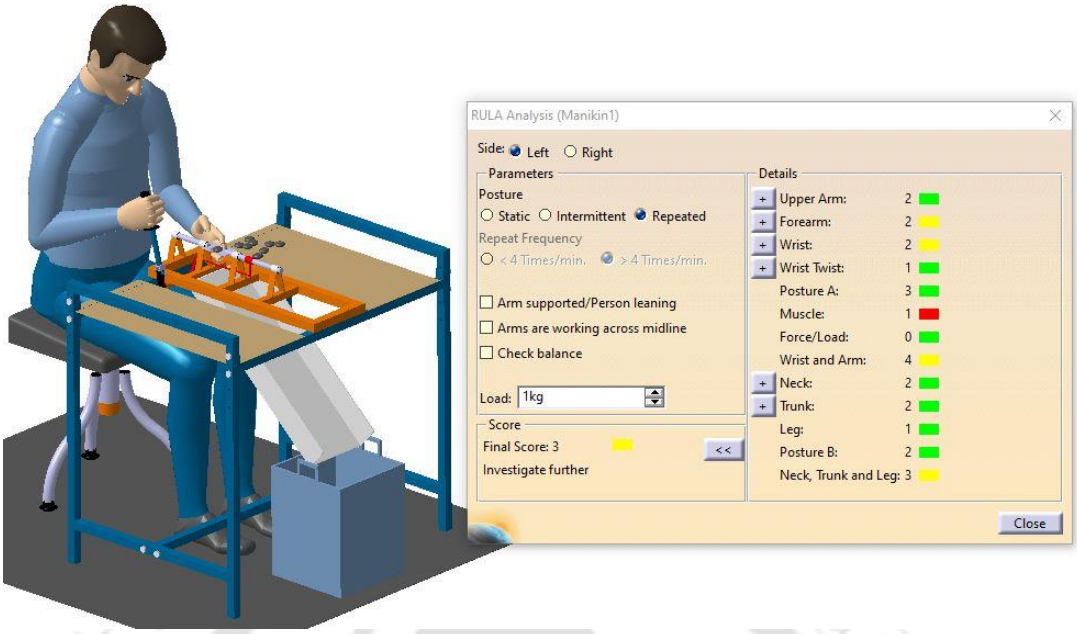

Figure 3.12 The RULA score for 95th percentile manikin in new cashew nut sheller.

3.7.6. Results of visibility analysis

Figure 3.13 – 3.15 shows the visibility analysis for 5th P, 50th P, and 95th P manikins in the new sheller. The results showed the visibility of shelling operation obtained for a head flexion of 13^0, 10^0, and 14^0 for 5th P, 50th P, and 95th P, respectively.

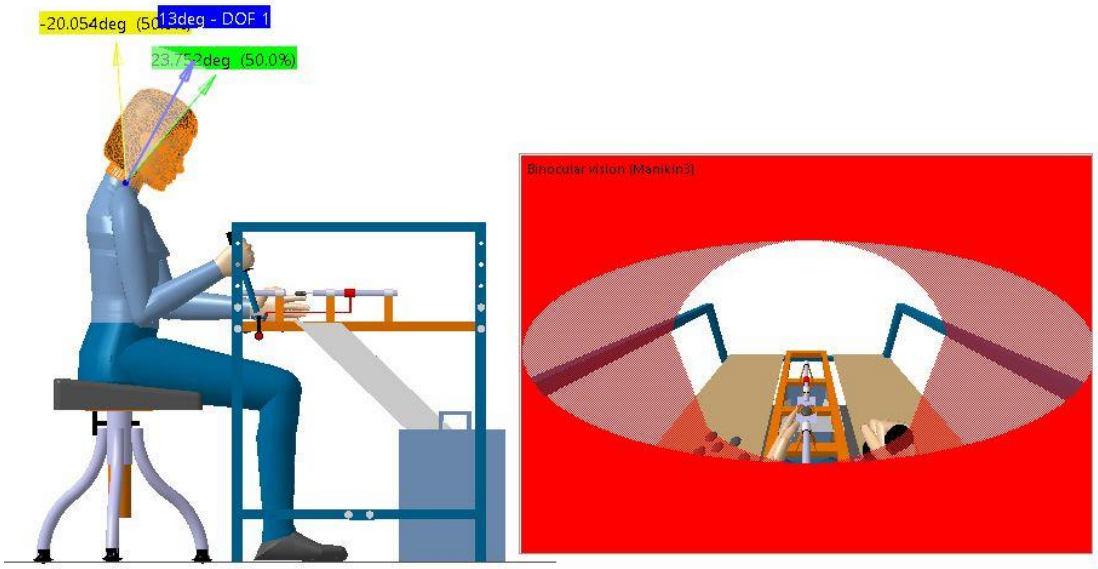

Figure 3.13 Visibility analysis for the 5th percentile manikin.

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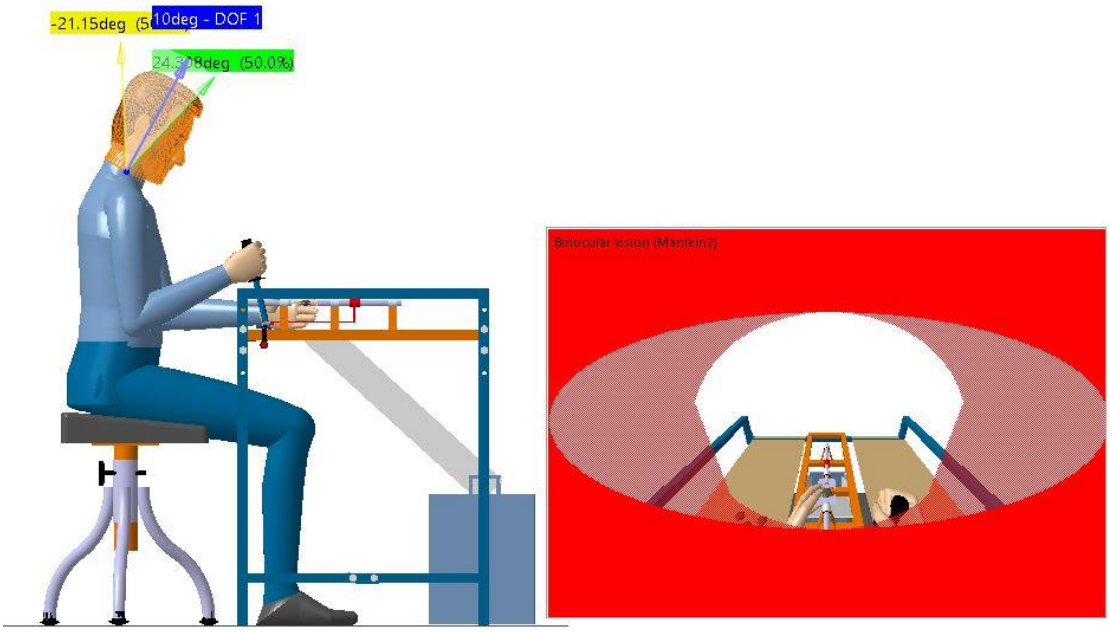

Figure 3.14 Visibility analysis for the 50th percentile manikin.

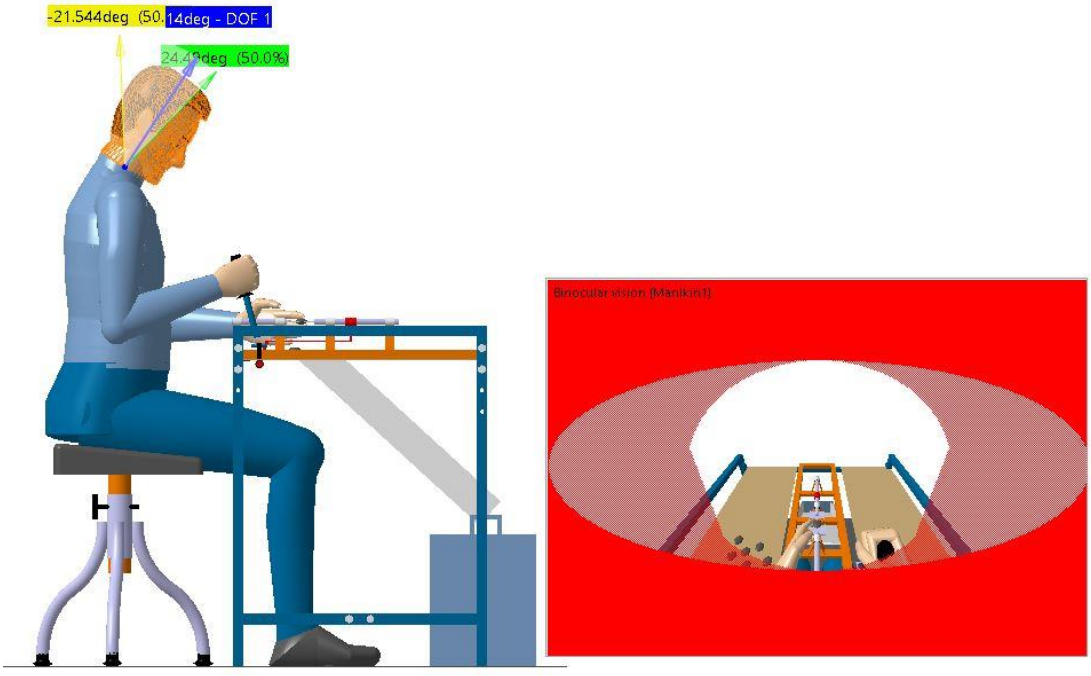

Figure 3.15 Visibility analysis for the 95th percentile manikin.

3.7.7. Results of clearance analysis

The results of thigh clearance analysis performed for three manikins in this study revealed the clearance values as 59 mm, 102 mm, and 101 mm for 5th P, 50th P, and 95th P, respectively. Figure 3.16 – 3.18 shows the thigh clearance analysis for the redesigned cashew nut sheller.

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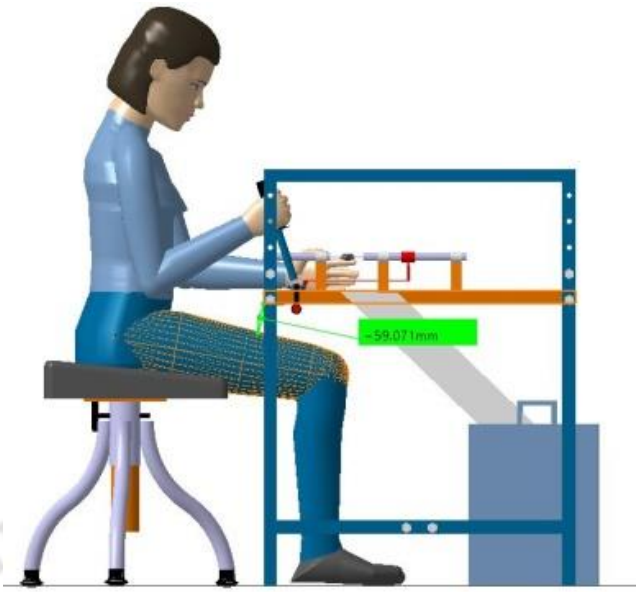

Figure 3.16 Thigh clearance analysis for the 5th percentile manikin.

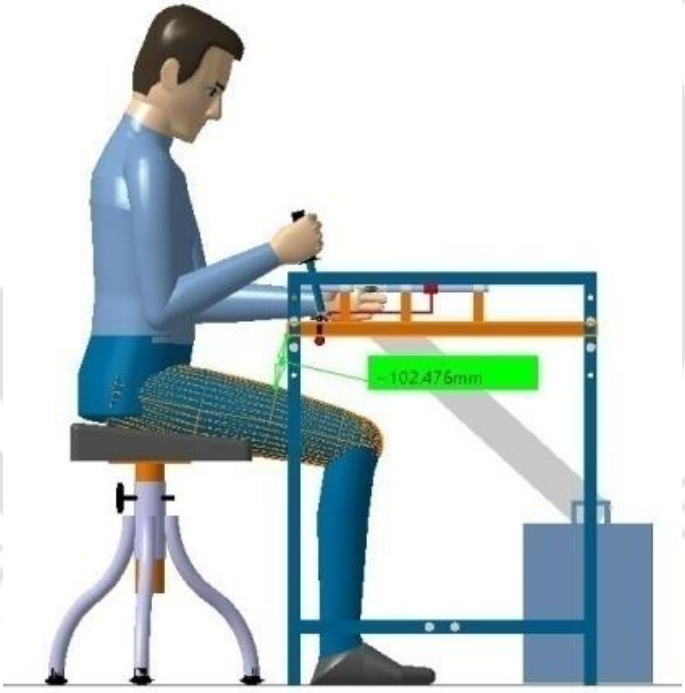

Figure 3.17 Thigh clearance analysis for the 50th percentile manikin.

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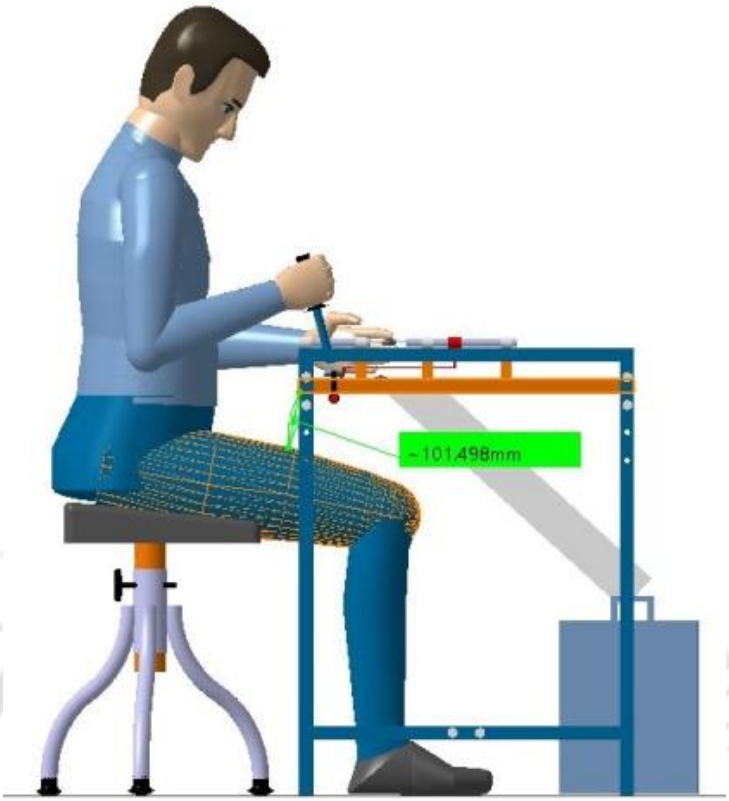

Figure 3.18 Thigh clearance analysis for the 95th percentile manikin.

3.8. Discussion

In this present study, the participatory approach involving a group of workers in focus group meetings was found to be useful to improve/modify the design of existing cashew nut sheller. The inputs given by the users were insightful in determining the design direction. The participatory approach for designing ergonomic tools/equipment has been previously reported in many studies (Earle-Richardson et al., 2005; Umar et al., 2019; Wu et al., 2020). In the present study, two participatory sessions were conducted. These sessions were helpful to bring the issues forward by the users themselves. Before beginning the interview sessions, all the users were made clear that the focus of the study was not about purchasing new equipment for them, and the focus was only about designing safe and comfortable shelling equipment with a collaborative effort from all the users. In the first session, the requirements of users were collected and carefully analyzed. The knowledge extracted from the first participatory session, including insights of users, on-site observations, and worker demonstrations, provided the platform for generating three different preliminary concepts. With the consensus of all the participants, the vertically oriented handle cashew nut sheller was finally selected.

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In terms of features/modifications offered, the exiting cashew nut sheller was designed to meet user satisfaction. The existing sheller was modified in shape, dimensions, and operation of the handle. The features and functional details of different components of redesigned cashew nut sheller are described below (Figure 3.19):

(1) **Hand lever:** A circular cross-sectional hand lever with a rubber cap was designed in the redesigned sheller. The rubber cap would provide slip resistance and good hand grip. Using hand lever, the necessary force required for cashew nut shelling can be applied manually.

(2) **V-shaped blades:** Blades have an important role in cashew nut shelling. Therefore, two V-shaped blades (one male; one female) were designed to fit the contour of cashew nut.

(3) **Sheller unit frame:** It provides housing for internal components such as the hand lever, blades, shaft, and the mechanism, a shelling unit in rectangular shape was designed.

(4) **Seat surface:** A seating surface with cushion and forward slope (10^0) was designed for a comfortable sitting position.

(5) **Height adjustment pin:** The seating arrangement designed in the proposed sheller has a height adjustment feature. The height adjustment pin provided at the bottom side of the seat would accommodate a wide range of people.

(6) **Shelling table frame:** The frame of shelling table would prevent shocks and vibration during the shelling operation. It provides structural rigidity to the sheller.

(7) **Dropping chute:** A rectangular-shaped dropping chute was constructed at the bottom side of the sheller unit. It would be useful to move the shelled cashew nuts to the lower level.

(8) **Container:** To collect shelled cashew nuts, a container was designed and placed at the exit of dropping chute.

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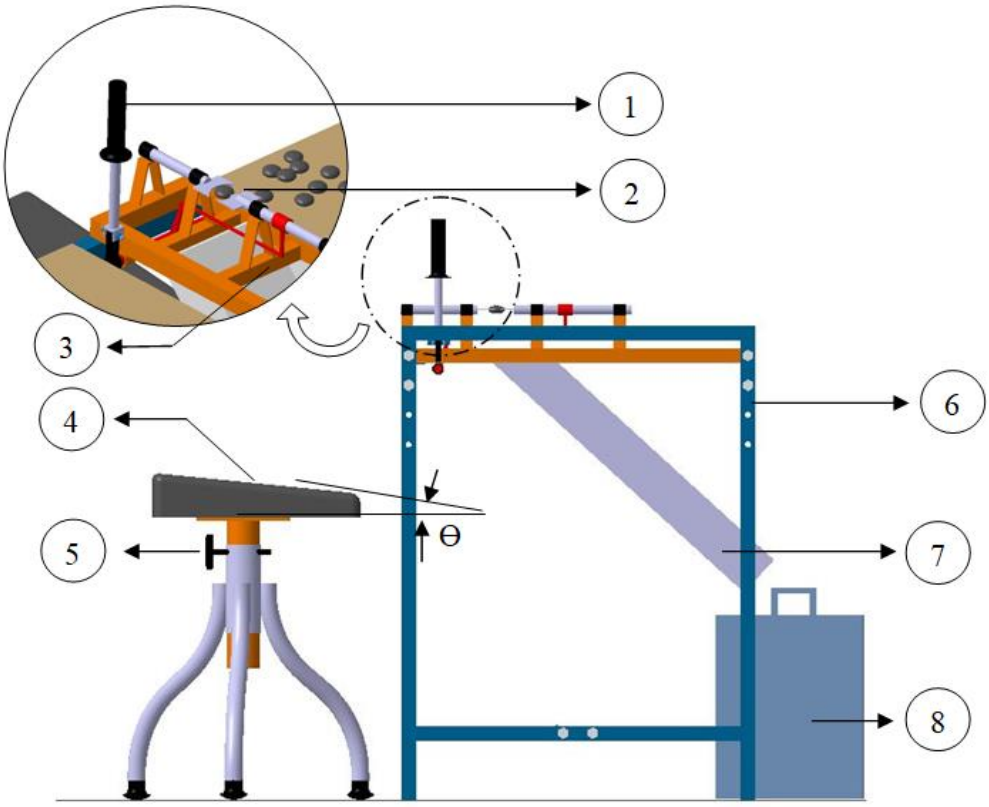

Figure 3.19 Design of new cashew nut sheller; 1: Hand lever; 2: Blades; 3: Sheller frame; 4: Seat, 5: Height adjustment pin; 6: Table frame (adjustable); 7: Chute; 8: Container.

The dimension of the shelling table is 850 X 600 X 950 (in mm), and the table height can be adjusted between 500 and 900 mm. When the table surface is at maximum height (i.e., 900 mm), the top of the handle lever can be accessed at 1100 mm from the ground. In the redesigned sheller, the elbow position of all the manikins (5^{th}, 50^{th}, and 95^{th}) was nearly at the same level of the table height. In the redesigned sheller, a new seating arrangement was introduced, which has not been permanently integrated with the shelling table. This feature would allow users to move the seat according to their comfort level. The seating surface height from the ground for 5^{th}, 50^{th}, and 95^{th} percentile manikins were 574 mm, 636 mm, and 648 mm, respectively. These seating heights were found to be within the range of allowed seat height adjustment (500 mm – 700 mm). These adjustment features provided in the redesigned sheller would eliminate ergonomic and anthropometric problems of the users. Figure 3.20 shows the adjustability parameters of the new sheller.

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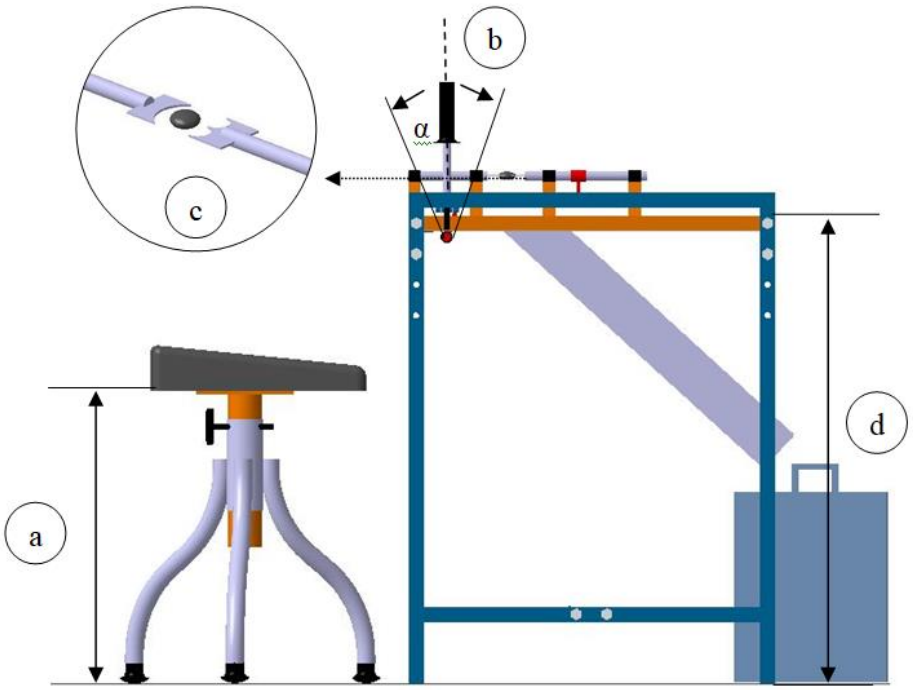

S. no.	Adjustable parameters	Range
a	Seat height adjustment	500 – 700 mm
b	Hand lever play (α)	0^0– 40^0
c	Gap between blades	0 – 60 mm
d	Table height adjustment	500 – 900 mm

Figure 3.20 The adjustable parameters of new cashew nut sheller.

The results of postural analysis using RULA also showed that posture of 5th, 50th, and 95th percentile manikins had a RULA grad score of 3. This score indicates that the postures with the redesigned sheller were safe and less harmful. The clearance analysis showed that there is enough gap between the thigh and the shelling table. Also, the results of visibility analysis were satisfactory as the head flexion was within the safe limit. With these findings, the next phase of the study focused on developing a physical prototype and testing it with real users.

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3.9. Chapter 3 summary

This chapter presented an ergonomic design and simulation-based evaluation of cashew nut sheller. Based on the feedback collected from the stakeholders, an appropriate sheller design was determined. A combination of steps, including identification of design requirements, idea formation, generation, and evaluation of alternatives, the simulation-based evaluation had resulted in the final design of the cashew nut sheller.

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Chapter – 4: Development and Evaluation of the New Cashew Nut Sheller

Chapter Abstract

The present chapter demonstrates development of the full-scale model of hand-operated cashew nut sheller and reports field test data that was conducted in order to ascertain its role in addressing the awkward working posture of shelling workers and high musculoskeletal load. The newly designed sheller consisted of three major parts: sheller unit, height-adjustable seat, and shelling table. This chapter reports that hand-operated sheller provides a comfortable physical posture at work and is useful to reduce the musculoskeletal load across different body parts of shelling workers.

4.1. Introduction

Use of work equipment, tools, and other mechanical means in industrial activities enhances productivity and physical capacities of workers. But excessive use of poorly designed tool affects workers' occupational health and are found to be a major reason for occurrence of WMSDs (Kumar et al., 2016; Ncube et al., 2019; Sanjog et al., 2016; Thetkathuek et al., 2018). Generally, work equipment can be categorized into two main categories, namely manually operated and automatic. While designing manually operated equipment, one must consider principles of ergonomics. Consideration of ergonomics while designing tools or work equipment has found to be effective in reducing WMSDs and in increasing user comfort, satisfaction, and productivity (Choobineh et al., 2004; McNeill & Westby, 1999). For example, Patel et al.(2017) developed a manually operated paddy thresher adaptable to agricultural needs of north-eastern region of India and recommended that improved design of agricultural equipment can reduce discomfort among agricultural workers. Another study by Singh et al. (2012) that designed a hand-operated maize dehusker-sheller using ergonomics reported that physiological workload has reduced over traditional method. McNeill & Westby (1999) redesigned and evaluated a manually operated cassava chipping machine and found that redesigned chipper reduced discomfort and drudgery among the workers. Umar et al. (2019) reported noticeable improvement in the working postures of technicians in manual material handling operation with ergonomic design of manually operated trolley-lifter. Kushwaha & Kane (2016) designed a manually operated crane cabin workstation and recommended that

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adopting an ergonomic based intervention in workplace greatly reduce mismatch between man and machine interaction. Sanjog et al. (2019) implemented a contextual design intervention from occupational ergonomics perspective and reported reduction in operator cycle time as compared to traditional operations. Jadhav et al. (2019) designed an ergonomic stitching workstation in footwear industry based on user requirements and ergonomic guidelines of workstation design. They found that the workstation design was effective in reducing postural workload. These studies highlighted that ergonomically designed work equipment is advantageous in terms of improving work and work methods, providing comfort to the user, reducing postural stress, and enhancing productivity.

By adopting a participatory approach to design and paying close attention to ergonomics aspects, a hand-operated cashew nut sheller was conceptualized and has been reported in detail in the previous chapter. The simulation-based evaluation of the sheller was found to be fairly satisfactory in terms of reducing musculoskeletal risk due to awkward postures. A sheller of such kind should be constructed in developing countries like India for small-scale processors and at village level application. The construction of a physical prototype, field testing, and feedback of users are essential to determine its long-term impact. In order to develop a physical prototype model, one needs to determine necessary dimensions of work equipment and anthropometric measurements of users. Researchers showed that a mismatch between anthropometric dimensions and equipment dimensions contributes to discomfort, biomechanical stress, and reduced productivity. On the other hand, the application of anthropometric data in design development is very much useful for a better fit between man and machine (Bhattacharjya & Kakoty, 2020). It also provides comfort to users and minimizes the risk of WMSDs. Bhattacharjya & Kakoty (2020) showed that the application of anthropometric data for designing pedal-operated Chaak in pottery industry and reported a higher level of comfort among workers. Zadry et al. (2017) designed an ergonomic spinal board based on anthropometric data of Indonesian people in order to improve safety and comfort while evacuating injured patients. So, anthropometry should be considered as an ideal factor during the design process for a good fit between human and the designed equipment.

Evaluation of working posture of workers during the interaction with work equipment and elements of work equipment is essential for reducing risks of

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biomechanical overload in workplace (Burton & WHO, 2010). Due to awkward working posture, workers' mental and biomechanical load may increase (Caffaro et al., 2018; Hallbeck et al., 2010) leading to WMSDs in different body regions (Mukhopadhyay & Ghosal, 2008; Patel et al., 2017). There are few international standards (EN 1005-4:2009, 2009; ISO 11226:2000, 2000; ISO 11228-3:2007, 2007) that have been developed to define risk assessment methods to evaluate postural stress referring to work activity, equipment characteristics, and human-machine interaction. These standards are aimed to protect workers' health and safety.

Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett, 1993) and Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000) are the two simple methods for assessing occupational postural risk. According to World Health Organisation (WHO) and International Ergonomics Association (IEA), both RULA and REBA are most cited among the selected tools for prevention of WMSDs (Enrico Occhipinti & Colombini, 2012). These methods are also referenced across international standard for occupational risk assessment (ISO 11228-3:2007, 2007). Indeed, previous studies also showed that observational methods are reported to be effective in biomechanical work-related load assessment. These are also advantageous in terms of being more versatile and less expensive compared to objective methods when time and resources are considered. While assessing specific work activity using RULA and REBA, these methods give a numerical index that quantifies workers' exposure to musculoskeletal risk and recommends the level of intervention required based on risk level. RULA method is applied to identify neck, back, and upper limb postural disorders in relation to muscular action and external loads applied on the body. The REBA method is suggested for identification of postural disorders of the whole body in relation to external loads applied on the body, muscular action, and the type of grip. Furthermore, these methods have been widely applied in industrial activities (Garosi, Mazloumi, Kalantari, Vahedi, & Shirzhiyan, 2019; Kumar et al., 2016; Kushwaha & Kane, 2016; Patel et al., 2017;Qureshi & Solomon, 2021; Sakthi Nagaraj et al., 2019; Umar et al., 2019) for quantification of biomechanical overload risk.

In developing countries like India, most of the industrial operations depend on manually operated equipment, and workers spend long hours interacting with them. Assessing postural aspects during human-machine interaction has been constantly

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under investigation. With regard to manual equipment, cashew nut sheller is the most widely used work equipment in cashew processing industry. The attention to this manual equipment is increasing because of high-level quality of yield (Ajav, 1996; Ojolo & Ogunsina, 2007) and incidence of WMSDs among workers. Given the importance of shelling equipment, the aim of the present study reported in this chapter was to construct a hand-operated sheller and to compare its postural risk with the conventional sheller.

4.2. Structure of cashew nut

Cashew nut is a greyish-brown kidney-shaped nut. A sectional view of cashew nut is shown in Figure 4.1. The cashew nut mainly features the shell (pericarp), testa, and kernel. The pericarp composes of three different protective layers, namely epicarp (the external segment), mesocarp (honey-comb structure that contains cashew nut shell liquid), and the endocarp. The central part of cashew nut contains cashew kernel. It is covered by a thin layer known as testa, which separates it from the endocarp.

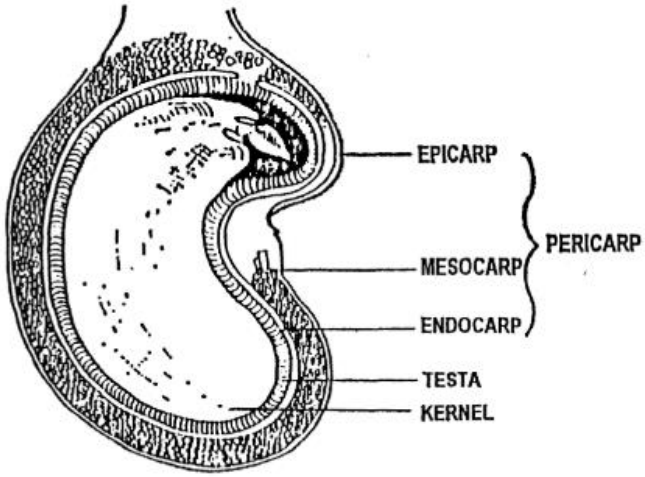

Figure 4.1 Schematic drawing of longitudinally sectioned cashew nut.
(Thivavarnvongs et al., 1995)

4.3. Physical dimensions of cashew nut

Physical dimensions of cashew nuts are often required for construction of shelling equipment, especially to design the blades and to determine the gap between them. Therefore, physical dimensions (i.e., length, width, and thickness) of raw cashew nut were measured during this study. Sixty raw cashew nuts were randomly selected

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during the field study and were measured using a digital Vernier calliper with a least count of 0.01 mm. Figure 4.2 and Table 4.1 presents the measurement of physical dimensions of raw cashew nuts.

Figure 4.2 Measuring physical dimensions of cashew nut using a digital Vernier caliper.

Table 4.1 The physical dimensions of cashew nut.

	Length (mm)	**Width (mm)**	**Thickness (mm)**
Mean (M)	40.3	31.4	18.9
Standard deviation (SD)	8.3	4.9	3.0
Minimum	24.4	21.9	14.5
Maximum	58.7	38.5	26.6

4.4. Basic considerations for the development of cashew nut sheller

The mechanics of the redesigned cashew nut sheller uses principles of compression and shearing forces. The following factors were considered for the redesigned sheller.

1) Shelling of the cashew nut must be completed in a single attempt.
2) The outer shell must be split into two halves without causing any damage to the cashew kernel.
3) Separation of shell needs to be carried out in the longitudinal direction to facilitate the rupture of cashew nut along the natural line of cleavage by compression force.
4) After compression, the shell halves must be pulled apart precisely along the developed line of rupture while applying twisting force.
5) The placement of cashew nut should be in dorso-ventral position, which effectively exposes natural line of cleavage for cracking.

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4.5. Development of hand-operated cashew nut sheller

The construction of the hand-operated cashew nut sheller was carried out using locally available engineering materials. The hand-operated sheller consists of three major components: the shelling unit, the non-integrated seat, and shelling table. The design and development of these components are described in the sections below.

4.5.1. Sheller unit design

An improved and user-friendly cashew nut sheller unit was designed and developed (Figure 4.3). The basic function of the sheller unit is to crack roasted cashew nuts. The sheller unit consists of a frame, rubber handle, hand lever, slider-crank mechanism, shafts (sliding and rotary), spring (tension), cross-pin, and blades. Figure 4.3 shows the design of the sheller unit.

1. ***Sheller unit frame*:** A simple and lightweight frame was designed. The dimension of the developed sheller unit is 600 mm X 200 mm X 25 mm. Mild steel was used for construction of the rectangular-shaped frame.
2. ***Rubber handle:*** Design of this element is one of the crucial elements in the sheller unit. During the entire working time, the shelling worker performs the shelling activity by manually operating the handle. Therefore, primary importance was given to handle design so as to provide maximum comfort and reduce fatigue, especially in hand/arm. According to Lewis & Narayan (1993), the primary factors that reduce fatigue in manual hand operations are handle orientation and handle shape. In the sheller unit, therefore, the handle was oriented about the y-axis (vertical direction). Das, Wimpee, & Das (2002) also described that the vertical orientation handle improves forearm posture and minimizes stress on the hand. This vertical orientation of handle was in good alignment with the forearm. Conversely, repetitive action of handle at flexed wrist posture can cause pain and inflammation of the wrist when used for long-term (Tichauer, 1966). Considering shape of the handle, it was suggested that the handle should be cylindrical, and the diameter of the handle must be determined based on hand anthropometry of the users for power grip and better performance (Eastman Kodak Co, 1986; Lewis & Narayan, 1993). Accordingly, the sheller handle shape was designed cylindrical, and handle diameter was chosen based on shelling workers' hand anthropometry (Section

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4.6 shows the application of anthropometric data). In addition, the material used for handle plays an important role. Therefore, the handle was made with soft rubber in order to provide hand comfort and reduce strains on the palm for long-term use. The rubber handle has a rough surface texture which provides slip resistance as well. The handle has a plain surface. No finger grooves were provided on the handle. This is because wide variations in the finger anthropometry of users can cause discomfort due to the development of compressive forces on the sidewalls of the fingers (Lewis & Narayan, 1993).

3. ***Hand lever:*** It is made out of mild steel (hollow pipe) and is inserted with rubber handle. This hand lever with a rubber handle is useful to apply enough mechanical pressure through hand while shelling. Hand lever is the direct power input medium in sheller unit.
4. ***Slider-crank mechanism:*** It is an important part of sheller unit which is connected to the hand lever. The basic function of the slider-crank mechanism is to transform the manual force applied on the handle into pressing force. The necessary components of the slider-crank mechanism are the crank lever, connecting rod, spring (compression), and adjustment screw. The crank lever has two ends. One end of the crank lever is connected with the hand lever, whereas the crank lever's second end is drilled with three holes at equal distance and joined (pin-joint) with a connecting rod to the first end. The pin-joint of crank and connecting rod is crucial in the operation of mechanism. The connecting rod can be pin joined with any one of these holes. This feature enables the adjustment of stroke length.

   The connecting rod's second end, which is connected with a sliding shaft, is designed with compression spring and adjustment nut. The compression spring provides better shock resistance when an excessive force is applied for pressing the cashew nuts. The excessive force is absorbed by the spring. Further, this spring would also prevent hand exposure to vibrations; hence the risk of wrist disorders could be reduced. As mentioned earlier, the handle design was given foremost importance. The aim was to design a handle that can be operated with optimal angular movement as higher the angular movement of handle would increase the shoulder flexion of user. Therefore, the role of adjustment nut is plays a crucial part in determining shoulder flexion.

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5. ***Cross-pin:*** It is one of the important components of the sheller unit, assisting in producing the twisting force. This pin is inserted orthogonally to the shaft (rotary). Using hand lever, a transverse force is applied at one end of the cross-pin, which in turn rotates the shaft in the applied force direction.
6. ***Return spring (tension)***: It is mounted at the rear end of the rotary shaft that brings the shaft to its original position after releasing the hand lever.
7. ***Blades:*** These were designed in V-shape (one male and one female) and made up of tempered steel alloy. The blades were simply bolted to the ends of rotary shaft and slider shaft, respectively. The gap between the blades was designed to be 60 mm (40 mm gap + 20 mm clearance) based on the physical properties of cashew nut (Table 4.1).

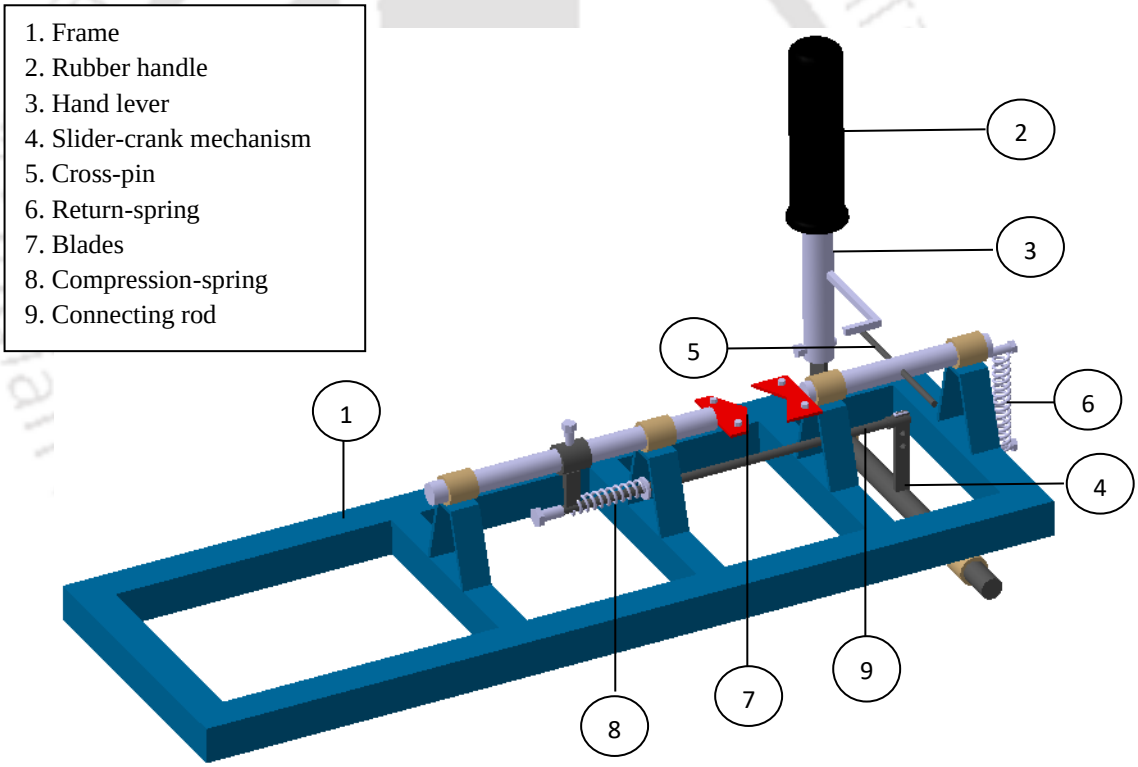

Figure 4.3 Three-dimensional view of sheller unit.

4.5.2. Seat design

In the hand-operated cashew nut sheller, seat is the main and essential component that provides a comfortable sitting position. The components of seat include a seating surface with a double-ply synthetic cover and cushion, telescopic seat base, height adjustment pin, and three-leg stand. The entire structure of the seat is made up of

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Galvanised Iron. Figure 4.4 shows the design of seat.

1. ***Seat:*** The seating surface is rectangular without back rest. The seat front edge has a curved surface, and a forward-slopping of 10^0 was also provided as some researchers had suggested the same (Choobineh, Hosseini, Lahmi, Khani Jazani, & Shahnavaz, 2007; Labbafinejad et al., 2019). This feature is useful in reducing stress on the legs and lumbar region.

2. ***Cushion:*** Sitting on a hard surface for a longer period of time may cause discomfort due to contact pressure. To reduce this contact pressure, a cushion of 50 mm thickness was provided for the seat.

3. ***Telescopic structure:*** The telescopic structure of seat is useful to easily move the seat up or down. There is also a provision for height adjustment in the telescopic structure.

4. ***Height adjustment pin:*** Using height adjustment pin, the seat base can be locked at a required height. This height adjustment feature of the seat would accommodate wide variability of users.

5. ***Three leg stand:*** Through physical observation, it was found that flooring of most of the mills was mostly uneven. Therefore, the stool stand has been designed with a three-leg structure. This structure provides stability even at uneven surfaces and is easy to move.

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1. Seating surface
2. Cushion
3. Telescopic structure
4. Height adjustment pin
5. Three leg stand

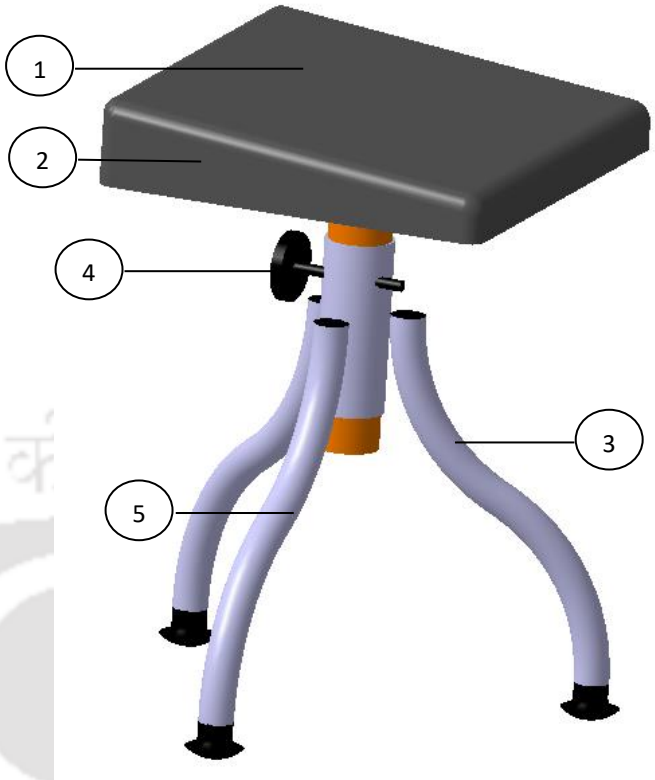

Figure 4.4 Three-dimensional view of the seat.

4.5.3. Table design

Shelling activity is mostly performed in the day time due to poor lighting conditions inside the mill. Therefore, shelling workers mostly perform shelling activity outside the factory. Most commonly, they choose open places (under the tree shadow). In this process, shelling workers commonly move the existing sheller outside and keep it inside once their work is complete. This whole process involves carrying and requirement of additional manpower for installation. Based on these observations, the new sheller table is designed with a simple, lightweight, and adjustable structure. Mild steel is used for the construction of the sheller table frame. The dimension of the table is 850 mm X 600 mm X 950 mm. It is lightweight and provides housing for the sheller unit. Even one person is sufficient to carry the entire table with ease. Enough leg room was provided under the table for free movement of legs. Further, a footrest is also designed and incorporated to minimize the tension in the legs and back. The cross bars (front edge and back edge) of the table are made height adjustable. The collector and chute are additional components that have been provided in the shelling table. Figure 4.5 shows the design of the sheller table.

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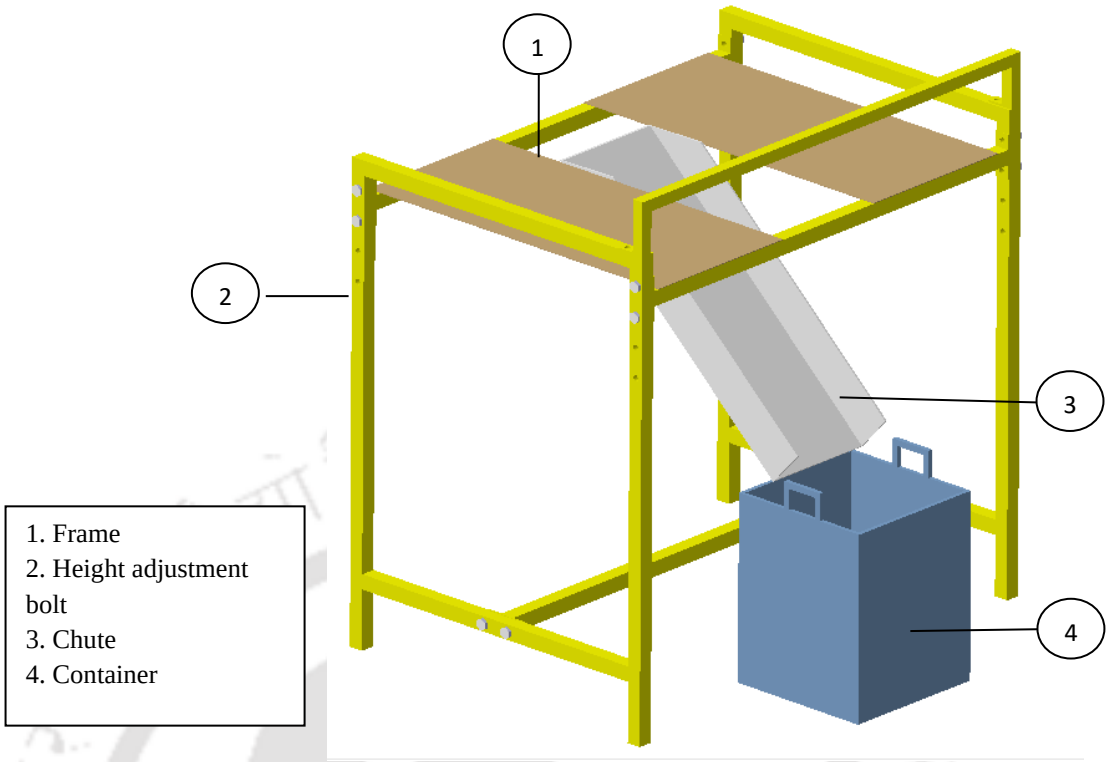

Figure 4.5 Three-dimensional view of sheller table.

4.5.4. Final design

Based on the final format of the simulation and the detailed drawings, a prototype of the hand-operated cashew nut sheller was constructed. Figure 4.6 presents the different schematic views of the hand-operated cashew nut sheller. The overall dimensions of developed sheller is 850 mm X 1000 mm X 1100 mm. This prototype sheller was constructed using locally available engineering materials. The main materials used for developing the new sheller include mild steel, galvanized iron, wood, and rubber. Appendix V shows the materials used and specifications of the individual items. Majority of the components used in the development of the hand-operated were sourced and fabricated at a local workshop. The basic engineering manufacturing operations such as cutting, grinding, drilling, welding, bending, turning, and boring were carried out (Appendix VI). In the end, all the individual machine components were joined to form a single unit. Figure 4.7 presents a physical model of the hand-operated sheller. In the present work, this final prototype form of hand-operated cashew nut sheller was used for the ergonomic assessment and performance evaluation. Figure 4.8 shows the 2D drawings (a) side view; (b) trimetric view, respectively.

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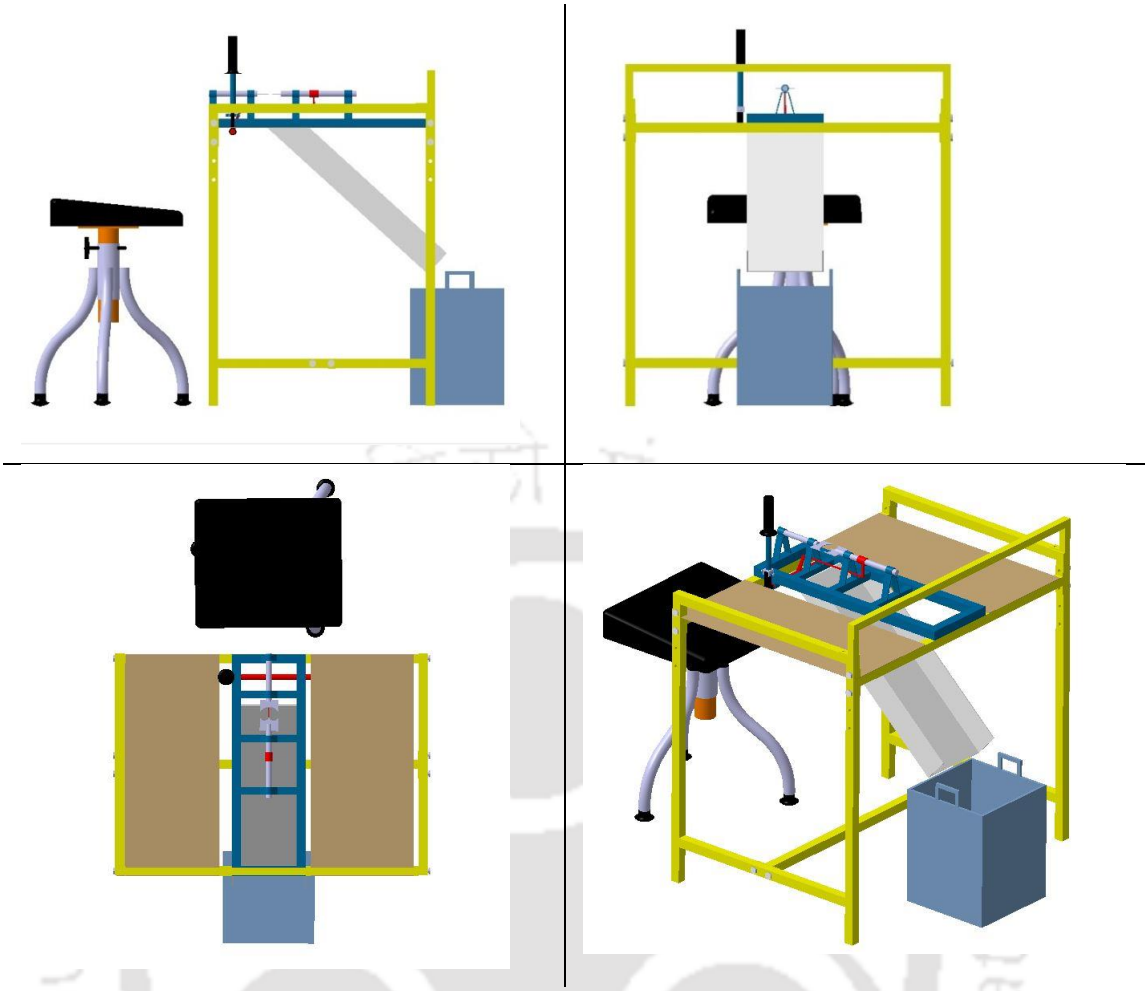

Figure 4.6 Schematic views of hand-operated sheller.

Figure 4.7 The physical prototype of hand-operated sheller.

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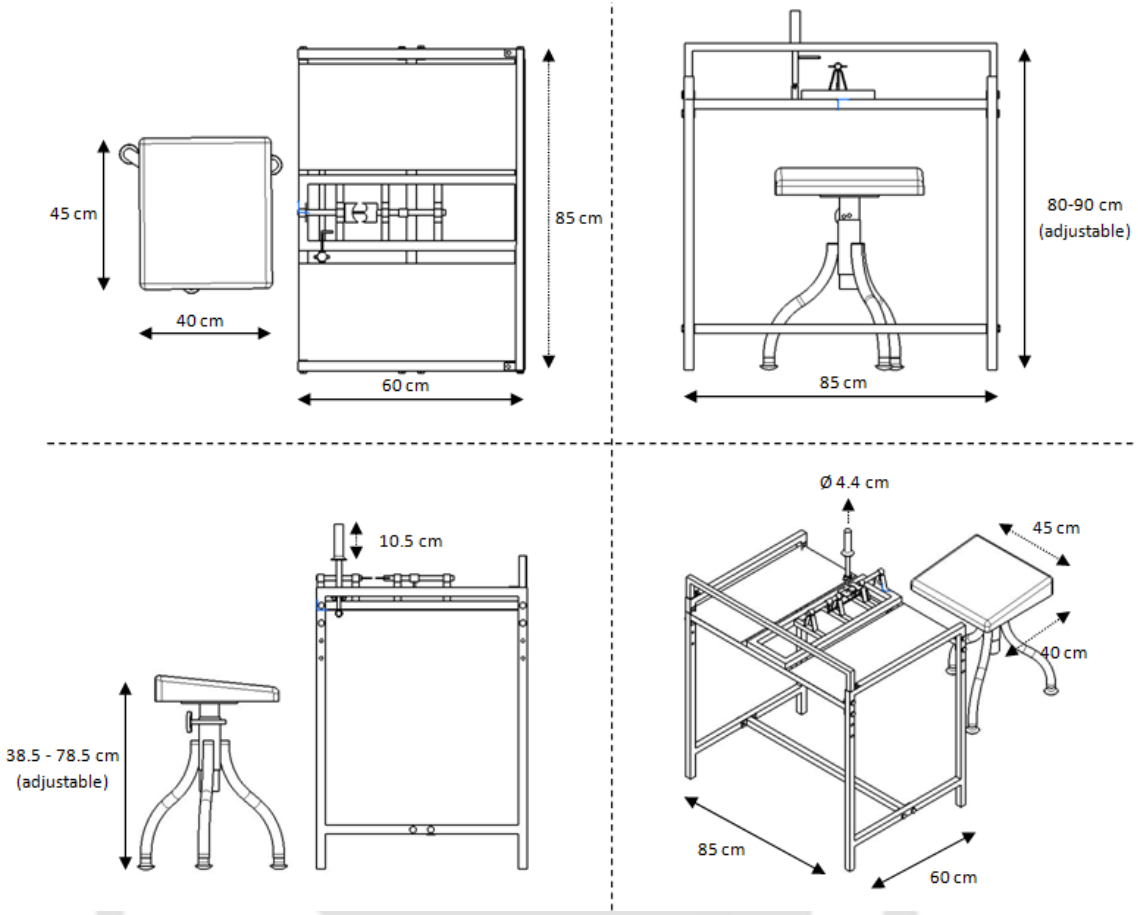

Figure 4.8 Two-dimensional drawing of hand-operated sheller.

4.5.5. Working principle of hand-operated cashew nut sheller

The slider-crank mechanism has two degrees of freedom. The mechanism of the sheller unit is powered manually by hand. The application of manual power on the mechanism generates two different forces: the linear (compressive) and rotation (twisting) forces. The position and velocity of the slider shaft directly depend on the position of the handle and hand action by the worker, respectively. Figure 4.9 shows the sequence of steps involved in cashew nut shelling during the shelling operation. The cashew nut is placed in between the blades in the longitudinal direction. The cashew nut is compressed between the blades. The twisting movement of the blade generates a shearing force, and as such, the shell halves are pulled apart.

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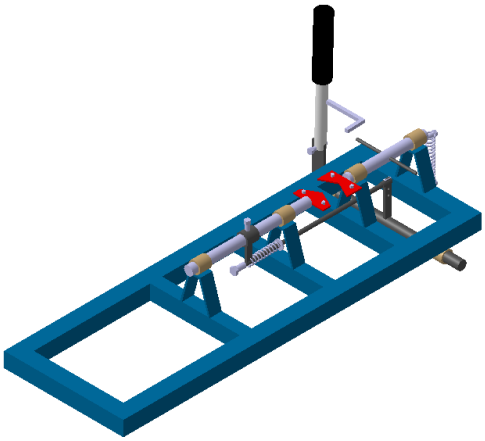
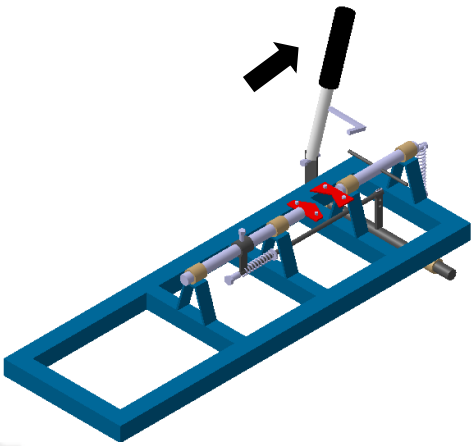
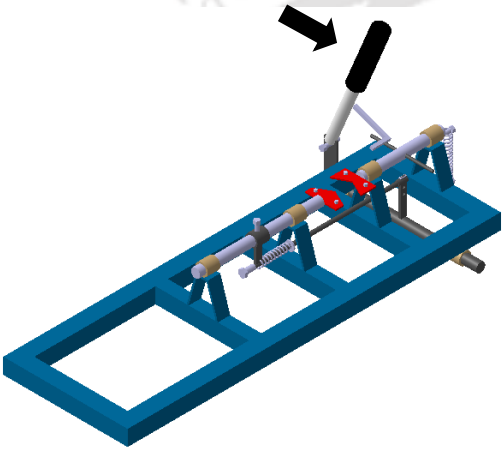


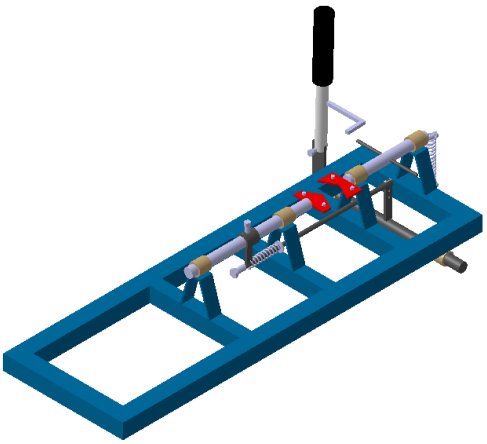
(1) Place the cashew nut into blades



(2) Pull the hand lever in backward direction



(3) Tilt the hand lever towards cross-pin



(4) Return the hand lever to its original position

Figure 4.9 Sequence of steps involved in the operation of hand-operated sheller.

4.6. Application of anthropometric data

Anthropometric data of shelling workers is prerequisite for the development of ergonomic hand-operated sheller. Therefore, eleven relevant anthropometric measurements as described by Pheasant (1990) were collected from Vetapalem Mondal, Andhra Pradesh, India. A total of thirty shelling workers (18 males and 12 females) participated in this stage of the study. Their average age and work experience were 33.7 ± 7.9 years and 7.7 ± 3.7 years, respectively. Figure 4.10 shows the measurement of anthropometric dimensions in the field, and Table 4.2 presents the anthropometric data used. As mentioned earlier, application of anthropometric data for determining the physical dimensions of equipment is discussed in the following

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sections. In the present study, the 5^{th}, 50^{th}, and 95^{th} percentile values of relevant body dimensions are considered while developing the sheller prototype.

Figure 4.10 Anthropometric data measurement in the field.

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Table 4.2 The anthropometric measurements of study population in millimeters (n = 30).

Parameter	Women (n = 12)					Men (n = 18)					Minimum	Maximum
	Percentile			M	SD	Percentile			M	SD		
	5th	50th	95th			5th	50th	95th				
Stature	1545	1571	1624	1575	28	1651	1675	1723	1677	23	1544	1724
Acromion height	1245	1258	1285	1264	15	1325	1355	1406	1361	27	1244	1409
Waist height	945	958	968	957	9	967	983	1003	983	12	944	1005
Popliteal height	385	394	410	395	10	386	416	439	412	19	384	440
Hip breadth	337	348	383	354	17	326	337	351	338	13	325	390
Buttock-popliteal length	380	416	436	408	23	425	452	486	452	19	380	486
Acromion radiale length	224	236	246	235	8	246	266	286	265	14	223	289
Radiale-stylion length	263	277	294	277	12	282	297	318	299	14	262	319
Hand length	174	176	177	176	1	176	178	180	178	2	174	180
Hand Breadth	72	73	75	73	1	75	76	79	77	2	72	80
Grip diameter	43	44	45	44	1	44	45	46	45	1	43	47

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4.6.1. Handle length

Handle length was determined based on handbreadth (Lewis & Narayan, 1993; Zadry et al., 2017) (Table 4.2). The handbreadth values of 5^{th} percentile males, 50^{th} percentile males, and 50^{th} percentile females were added. This sum was then divided by 3, which equals to 74.66 ~ 75 mm. The obtained total was then added with a clearance of 15 mm on either side of the handbreadth. Thus, the handle length came around to be 105 mm. The clearance provided on the handle length facilitated the user to position their hand with ease.

4.6.2. Handle diameter

According to Motamedzade et al. (2007), the diameter of handle was determined using grip diameter (inner) (Table 4.2). The grip diameter values of 5^{th} percentile males, 50^{th} percentile males, and 50^{th} percentile females were added. The obtained sum is 133 mm, which is divided by 3. Hence, the diameter of the handle camearound to be 44.3 mm.

4.6.3. Seat width

According to Mehta, Gite, Pharade, Majumder, & Pandey (2008), the seat width is determined based on hip breadth of a female (Table 4.2). The 95^{th} percentile of female hip breadth is equal to 383 mm, which is added with a clearance of 50 mm. Therefore, the seat width is equal to 433 mm ~ 450 mm.

4.6.4. Seat length

The seat length is determined based on the buttock-popliteal length of female population according to Mehta et al. (2008) (Table 4.2). The length of seat is determined based on mean buttock-popliteal length of female. Because the depth of seat is designed in such a way that it should provide necessary support for the buttock and should not tough the lower legs of worker. Therefore, the mean buttock-popliteal length of females is 408 mm ~ 400 mm, which is the same for seat length.

4.6.5. Seat forward-inclination

As recommended by Choobineh et al. (2007), forward-slopping of approximately 10^0 was provided to the seat, this would provide comfort for the back and knees while working in a sitting position.

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4.6.6. Seat height

Height of the seat can be adjustable between 385 mm and 785 mm. Four height adjustment holes 100 mm apart were provided for adjusting the seat height. The lower limit of seat height (i.e., 385 mm) was determined based on the 5th Percentile female popliteal height according to Mehta et al. (2008) (Table 4.2).

4.7. Field testing

4.7.1. Posture assessment

A filed test to assess the applicability of the hand-operated sheller and its working posture improvement was conducted in comparison with existing sheller. The simulations of cashew nut shelling activity involving twelve shelling workers (six males and six females) were conducted. Participants' average age, height, and weight were 33.5 ± 4.8 years, 1612 ± 53mm, and 58.3 ± 7.1 kg, respectively. All the participants are right-handed. They were healthy and did not report any MSDs or injuries. Photography and video recordings techniques were used to record and analyze the working posture of participants while shelling. Through recorded videos and direct observation, three most common tasks, namely picking, placing, and shelling tasks, were identified in shelling operation and were selected for further assessment. The working posture assessment using the observational techniques,the rapid upper limb assessment (RULA) (McAtamney & Nigel Corlett, 1993) and the rapid entire body assessment (REBA) (Hignett & McAtamney, 2000) techniques, was conducted in order to assess the workers' exposure to ergonomic risk while performing the shelling activity. Both RULA and REBA are postural assessment methods that evaluate the musculoskeletal load on the workers' body when they are exposed to risk factors such as awkward working posture, forceful exertions, and muscle work. The special scoring system generates different intervention actions that were required to reduce risk associated with the working posture. Two different assessors having knowledge about RULA and REBA methods performed the assessments independently. Figure 4.11 presents the images of the working condition with existing sheller and newly redesigned sheller.

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Task	Using existing sheller	Using new sheller
1. Pick: picking the cashew nut on the shelling table		
2. Place: placing the cashew nut in-between the blades		
3. Shell: shelling the cashew nut using hand lever.		

Figure 4.11 Cashew nut shelling using existing sheller and new sheller.

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4.7.2. Comparison of tasks in shellers

A simple task analysis was carried out to compare the number of steps performed by the shelling workers in both existing and the newly designed cashew nut shellers.

In the existing sheller, first, the worker uses the left hand to grab the cashew nut and place the same cashew nut in between the blades. At the same time, the right leg is raised to a certain height from the ground and placed on the foot pedal. The foot pedal is pressed downwards; thus, the cashew nut is pressed by the blades. After pressing the cashew nut, the left hand of worker is retracted. By keeping the pressure on the foot pedal, hand lever is pulled upwards with a right hand.

In the new sheller, cashew nut is grabbed and placed in between the blades using left hand. Handle is grabbed using right hand and pulled backward (towards body) to press the cashew nut between blades. Left hand is retrieved. Subsequently, handle is tilted towards the shaft by keeping the same pressure and return to actual position by hitting the cross-pin at the middle.

4.7.3. Results of posture analysis

RULA and REBA methods were used to assess the working posture while workers perform the shelling activity. As mentioned earlier, the most common and repetitive postures in shelling operation (i.e., pick, place, and shell) were considered and assessed by two individual assessors. The averaged RULA and REBA final scores for the existing and new sheller are tabulated in Tables 4.3 - 4.6. In the existing method, the operator is required to perform the shelling task in a standing position, whereas the operator sits while operating the redesigned hand-operated sheller.

Both RULA and REBA analyses indicated that after the use of a hand-operated sheller there was evidence of improvement in the final scores. The RULA scores reduced from 6-7 to 4-5 respectively across all the three selected tasks. Specifically, picking and shelling were at high and very high-risk levels (RULA = 6-7) in existing sheller, whereas with the use of the new hand-operated sheller RULA reduced to medium risk level (RULA = 4) for the same tasks. Similarly, the REBA scores reduced from 8 – 12 to 3 – 4 with the new hand-operated sheller. The REBA score of greater than 11 for existing sheller indicated a very high-risk level. The same REBA rating level reduced to low and medium risk level (REBA = 3-4) with the new hand-

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operated sheller.

Table 4.3 The RULA scores for existing sheller.

Participants	RULA grand scores		
	Tasks		
	1. Picking the cashew nut	**2. Placing the cashew nut in between blades**	**3. Shelling the cashew nut**
1 (F)	7	7	7
2 (F)	7	6	7
3 (F)	7	6	7
4 (M)	6	7	7
5 (M)	6	6	7
6 (M)	7	6	7

RULA final score of 1 – 2 = low risk, no action required; 3 – 4 = medium risk, investigate further; 5 - 6 = high risk, investigate further and change soon; 7 = very high risk, investigate and change immediately. RULA: Rapid Upper Limb Assessment.

Table 4.4 The RULA scores for new sheller.

Participants	RULA grand scores		
	Tasks		
	1. Picking the cashew nut	**2. Placing the cashew nut in between blades**	**3. Shelling the cashew nut**
1 (F)	4	5	4
2 (F)	4	5	4
3 (F)	4	5	4
4 (M)	4	5	4
5 (M)	4	5	4
6 (M)	4	5	4

RULA final score of 1 – 2 = low risk, no action required; 3 – 4 = medium risk, investigate further; 5 - 6 = high risk, investigate further and change soon; 7 = very high risk, investigate and change immediately. RULA: Rapid Upper Limb Assessment.

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Table 4.5 The REBA scores for existing sheller.

Participants	REBA grand scores		
	Tasks		
	1. Picking the cashew nut	2. Placing the cashew nut in between blades	3. Shelling the cashew nut
1 (F)	9	9	11
2 (F)	9	8	12
3 (F)	8	8	12
4 (M)	8	9	11
5 (M)	8	8	12
6 (M)	9	8	11

REBA final score of 1 = negligible risk, no action required; 2 - 3 = low risk, change may be needed; 4 - 7 = medium risk, further investigation and change soon; 8 - 10 = high risk, investigate and implement change; 11 – 15 = very high risk, implement change immediately. REBA: Rapid Entire Body Assessment.

Table 4.6 The REBA scores for new sheller.

Participants	REBA grand scores		
	Tasks		
	1. Picking the cashew nut	2. Placing the cashew nut in between blades	3. Shelling the cashew nut
1 (F)	4	4	4
2 (F)	4	4	3
3 (F)	4	3	3
4 (M)	4	4	4
5 (M)	4	4	4
6 (M)	4	4	4

REBA final score of 1 = negligible risk, no action required; 2 - 3 = low risk, change may be needed; 4 - 7 = medium risk, further investigation and change soon; 8 - 10 = high risk, investigate and implement change; 11 – 15 = very high risk, implement change immediately. REBA: Rapid Entire Body Assessment.

4.7.4. Results of task analysis

Table 4.7 shows the differences in sub-tasks performed in both existing and hand-operated shellers. The number of tasks performed in a hand-operated cashew nut sheller was marginally lesser than the conventional sheller.

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Table 4.7 The subtasks in the existing and hand-operated cashew nut sheller.

Sub-tasks in pedal-operated cashew nut sheller	Sub-tasks in hand-operated cashew nut sheller
Grabbing the cashew nut using the left hand	Grabbing the cashew nut using the left hand
Placing the cashew nut in between shelling blades using the left hand	Placing the cashew nut in between shelling blades using the left hand
Right leg is placed on the foot-pedal	-
Grabbing the handle with the right hand	Grabbing the handle with the right hand
Foot-pedal pressed downwards	Pull the handle backward (towards body)
Left hand is taken away from the blades	Left hand is taken away from the blades
Pulling the handle upwards	Hitting the cross pin on the shaft in return
Returning the handle to the actual position	Returning the handle to the actual position
Returning the foot-pedal to the actual position	-

4.8. Discussion

Despite the potential of cashew processing industry in India, the development of equipment from an ergonomic perspective has been neglected. Cashew nut shelling activity is a traditional activity in all small and medium-scale cashew processing mills. In this traditional activity, workers require to perform routine actions for long durations specifically in an awkward standing posture using a hand-cum-pedal operated sheller. Due to this un-ergonomic working condition involving poor working postures, they get exposed to the risk of WMSDs. In this chapter, therefore, a simple and improved ergonomic hand-operated cashew nut sheller was developed and evaluated for better postural status of shelling workers.

Figure 4.11 presents the visual comparison of the working posture of the shelling workers using existing sheller and the newly developed sheller. Overall, it can be observed that the hand-operated sheller was able to reduce the awkward working posture and continuous physical contact with the foot pedal. Using hand-operated sheller with a seat on, shelling workers no longer need to stand and bend their trunks during the shelling activity. The dramatic change in working posture of shelling workers in hand-operated sheller can be attributed to the height-adjustable seat and the ergonomic handle design. Utmost importance was given to comfortable (erect) sitting position in shelling activity in order to reduce the lower back problems. With a height-adjustable seat and cushion, the workers adopted comfortable erect posture and had an optimum vision at minimal head flexion. Another possible explanation can be the

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elimination of foot-pedaling in the newly developed sheller, which contributed greatly to minimize awkward leg posture as compared to the existing sheller. Further, the vertically oriented handle design has remarkably improved forearm posture while shelling.

The results of postural analysis also showed that there is evidence of improvement in working posture after the intervention. Working on the hand-operated sheller caused less deviation of body segments from neutral position. Body postures such as the neck, trunk, legs, and upper arm postures were improved noticeably. However, RULA score for placing the cashew nut using the hand-operated sheller was 5, which indicates further investigation and change. Considering the potential risk, further investigation is required to improve the posture, especially wrist posture, while placing the cashew nut. Introducing feeding attachment for placing the cashew nut may be considered in the future.

Regarding task analysis, the sub-tasks performed with the hand-operated sheller were less as compared to the existing sheller. The total number of steps performed in the existing sheller was 9, whereas it was 7 in the hand-operated sheller (Table 4.7). This reduction in the number of steps in a typical work cycle of cashew nut shelling activity using hand-operated cashew nut sheller is beneficial for shelling workers because the number of repetitions of work cycles and cycle time will definitely be reduced in the long-term. Appendix VII depicts the actual use cases of completing shelling activity using hand-operated cashew nut sheller in comparison with existing cashew nut sheller.

Despite the fact that hand-operated sheller could improve the cashew nut shelling task in terms of working posture; what is more that the performance evaluation of hand-operated sheller showed a shelling efficiency of 100%.The time required to cut one cashew nut using existing sheller was only 3-4 sec, whereas with the new hand-operated sheller was it was found to be 5-8 sec. The shelling rate of hand-operated sheller was a little longer than the existing sheller. Although the shelling efficiency and shelling rate were not the objective of the study; however, it must be noted that such trade-offs are often considered in the selection and application of any equipment like the hand-operated sheller in the market. It may be worth noting that the training sessions can improve the shelling rate in future. According to

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Oulasvirta, Wahlström, & Anders Ericsson (2011), lack of device-specific experience accounts for poorer performance of novices.

Overall, the developed hand-operated cashew nut sheller was well received and liked by all the participants. During an informal meeting with the participants, most of them felt that the hand-operated sheller improved their working posture. They also felt that the use of a vertical handle was comfortable while shelling. The height-adjustable seat with cushioning was liked by all of the participants.

4.9. Chapter 4 summary

This chapter reported the development of a fully-functional prototype using appropriate anthropometric data. This anthropometric data helped to determine dimensions of machine elements such as handle design, seat, and sheller table. Field testing of the developed prototype showed that there is evidence of improvement in the RULA and REBA scores, which indicated that the new hand-operated sheller is useful for reducing musculoskeletal load and improving the working conditions of the shelling workers.

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Chapter – 5: Summary and Conclusions

Chapter Abstract

This chapter presents the summary and conclusions of the present research work. Results and observations obtained from "Chapter – 2" to "Chapter – 4" have been briefly presented here. It is also described how the aim and objectives were accomplished. Finally, the key contributions, limitations, and suggestions for future work have been highlighted in this chapter.

5.1. Summary

Cashew nut processing industry mainly converts raw cashew nuts into edible cashew kernels. A series of operations are carried out during the cashew processing to transform raw nut into the processed kernel. Mostly all the activities are manual in nature and are performed in health-threatening working conditions. Among all the cashew processing activities, cashew nut shelling is the most important operation where the main purpose is to extract the whole kernel without any breakage by splitting the tough outer shell of the roasted cashew nut. The majority of the Indian cashew nut processing mills use the steam roasting method followed by manual shelling operation using hand-cum-pedal operated devices to extract the nuts. This device has several shortcomings from an ergonomic point of view. While operating this conventional sheller shelling workers adopt complex work postures. The current method of shelling is also tedious and time-consuming. So, this discomforted working condition exposes shelling workers to many risk factors from an ergonomics point of view. Therefore, this piece of research work focused on analyzing the current working conditions scenario in Indian small and medium-scale cashew nut processing and modification of existing cashew nut sheller by incorporating stakeholders' views and ergonomic design principles. This entire research work was broadly divided into three phases. A brief summary and salient findings of each phase were described point-wise in the below section, respectively.

5.2. Salient findings from present research work

The salient findings from the present research work are presented under three separate phases as:

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- **Phase I: A cross-sectional study to evaluate the existing working conditions in Indian small and medium-scale cashew nut processing mills**

This first phase of the thesis reported the findings of a cross-sectional study that was conducted across four different states (Andhra Pradesh, Orissa, Assam, and Meghalaya) of India. Since not much work had been reported in the area of occupational health of cashew workers, an effort was made to demonstrate the occupational health of cashew workers in Indian small and medium-scale cashew nut processing mills. During the survey, the working conditions in small and medium-scale cashew nut processing mills were closely observed and work activities across different work sections, namely boiling, shelling, peeling, and grading, were observed, and insights were recorded. Demographic and work-related characteristics were collected through a questionnaire. Information related to the prevalence of musculoskeletal disorders was collected using Nordic Musculoskeletal Questionnaire (NMQ). Digital photography and video recording techniques were used to document the work activities in the factories. The work activities involve both upper and lower body parts. Therefore, Rapid Entire Body Assessment (REBA) technique was used for postural assessment. The relationship between WMSDs and demographic and work-related risk factors was analyzed using logistic regression analysis. The following are the main conclusions that were drawn from the first phase of the investigation.

i. The cross-sectional study was conducted on 290 cashew workers, and the sample included 73.4 % females and 26.6 % males from four different work activities. The activities and sample percentage are: boiling (11.4 %), shelling (51.8 %), peeling (22.0%), and grading (14.8 %).
ii. Participants were aged between 19 and 65 years (Mean = 35.0; SD = 9.1), and around 79 % participants were married. Their work experience ranged between 1 and 30 years (Mean = 8.5; SD = 5.8), and their mean daily working time was 9.6 hours per day.
iii. Musculoskeletal disorder analysis revealed that the prevalence of WMSDs was high among cashew workers in Indian small and medium-scale cashew nut processing mills. Around 70.3 % of the cashew workers had experienced discomfort in at least one body region during the past 12 months. Among them, females reported high prevalence of WMSDs than males.

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iv. Shoulders, lower back, hands/wrists, and knees were found to be the most commonly affected body regions, and their prevalence rates were 52.4 %, 51.4 %, 43.4 %, and 35.9 %, respectively.

v. With regard to the prevalence of WMSDs among workers in examined work activities, shelling activity workers were found to report higher prevalence compared to other activities.

vi. Analysis of working postures of cashew workers using the REBA showed that most of the workers' postures were at high and very high risk and required immediate investigation and change.

vii. Analyses of logistic regression revealed that work-related factors including work experience, job stress, daily working time, work fatigue, and demographic factors (age, gender, educational level, marital status, and type of work activity) were significantly associated with WMSDs.

viii. Logistic regression also showed that the type of work activity, particularly shelling, had a significant relationship with WMSDs. The shelling activity workers were found to be 5.34 (odds ratio) (95 % CI: 2.12 – 13.44) times more likely to develop knee disorders than boiling workers.

ix. Overall, the field assessment of problems in Indian small and medium-scale cashew nut processing mills revealed the complicacy of cashew nut shelling activity where the majority of shelling workers suffered from prevalence of musculoskeletal disorders and adopted postures that were risky while using existing shelling equipment.

- **Phase II: Ergonomic design and simulation-based evaluation of a cashew nut sheller**

In the second phase of the study, cashew nut shelling activity was selected for further investigation. The workers in shelling operation used conventional hand-cum-pedal operated sheller. The design of the existing sheller is mainly attributed to causing musculoskeletal disorders among sheller workers. In order to identify the ergonomic and design issues related to existing cashew nut sheller, direct observations and focus group meetings involving the stakeholders were conducted in four selected small and medium-scale cashew nut processing mills in Andhra Pradesh, India. Through the meetings, initial user requirements related to redesign of existing cashew nut sheller were collected. Using grouping/combining/eliminating technique, the initially

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collected user requirements were screened and finalized. With an intention to provide customer satisfaction and a more acceptable solution, a methodological design tool, Quality Function Deployment (QFD) approach, was used. Preliminary concept sketches were generated and screened based on the initial information and previous interactions with the stakeholders. Following the participative design process, a simple, improved, and desired cashew nut sheller design (CAD model using CATIA V5 software) was conceptualized. To check the compatibility of redesigned sheller, virtual simulation using the digital human modeling technique was performed. Three digital human models representing 5^{th} percentile, 50^{th} percentile, and 95^{th} percentile were developed based on Indian anthropometric database. Rapid Upper Limb Assessment (RULA) tool was used to assess the working posture in redesigned sheller. Vision analysis and thigh clearance analysis were also conducted to check the effectiveness of the new design. The following are the main conclusions that were drawn from the second phase of investigation.

i. Even though various semi-automated and automated shelling equipment were developed and patented by different researchers from India and other countries, the commercial use of such equipment is scant in India. Some of the reasons which contributed to this were found to be: limited capital investments, lack of effective operational knowledge and technical support, seasonal nature of production, lack of electricity, and recovery of whole kernels.

ii. In this context, the focus group meetings with thirteen stakeholders has resulted a total of 45 initial requirements for redesigning existing cashew nut sheller. The screening of these initial requirements using grouping/combining/eliminating gave fifteen final user requirements.

iii. A questionnaire survey including the finalized user requirements was conducted on thirty randomly selected participants. The computed Cronbach's alpha was 0.75, which indicated acceptable reliability of survey questionnaire.

iv. Based on the user requirements and interaction with stakeholders, three preliminary design concepts of redesigned existing cashew nut sheller were generated in the present study. A final concept, the vertical hand-operated cashew nut sheller with seat, was finalized by the users. Some important design features of redesigned cashew nut sheller are (1) Hand lever (2) V-

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shaped blades (3) Sheller unit frame (4) Seat surface (5) Height adjustment pin (6) Shelling table frame (7) Dropping chute (8) Container.

v. Simulation-based evaluation of redesigned cashew nut sheller was performed using digital manikins (5^{th} P- short (female), 50^{th} P- medium (male), and 95^{th} P- large (male)) to check its effectiveness.

vi. The results of the simulation-based evaluation revealed that the redesigned cashew nut shelling equipment is effective in reducing the risk of harmful postures.

vii. The vision analysis and thigh clearance analysis were also satisfactory. The head flexion has improved, and there is enough gap (thigh clearance) between the manikin and the redesigned sheller.

- **Phase III: Development and evaluation of a new cashew nut sheller**

The third phase of the thesis reports the construction and evaluation of the newly developed sheller. Using appropriate anthropometric data of thirty shelling workers from the field, an ergonomically improved cashew nut sheller was developed. Digital photography and video recording techniques were used to field test the redesigned sheller. Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) methods were used to evaluate the new sheller and a comparison test was conducted with the existing one. The number of steps to complete shelling using existing and redesigned sheller was compared.The following are the main conclusions that were drawn from last phase of present investigation.

i. The construction of a hand-operated sheller was carried out by the application of anthropometric data of thirty random participants from the local population. The specifications of important machine elements are: handle length = 105 mm; handle diameter = 44 mm; seat width = 450 mm; seat length = 400 mm; table area = 850 mm X 600 mm.

ii. The method of shelling has been changed in the new sheller. In the existing sheller, both hand and leg were used for completing the shelling of the roasted cashew nut, whereas use of hands can accomplish the shelling operation in the new sheller.

iii. Filed testing results showed that the grand scores for both RULA and REBA had improved and indicated working postures in the redesigned cashew nut sheller were safe.

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iv. The number of steps performed in a hand-operated cashew nut sheller was lesser than the conventional sheller.

Considering ergonomic design and evaluation, it can be concluded that the hand-operated cashew nut sheller developed based on ergonomic principles and anthropometric data is useful in improving the working conditions of the shelling activity across small and medium-scale cashew nut processing mills in India.

5.3. Achievement of research aim

The overall aim of the present research investigation was to design and evaluate an ergonomic intervention that minimizes risk of musculoskeletal disorders in Indian small and medium-scale mills. Initially, a cross-sectional study was carried out that provided required information about the current working conditions with respect to working posture, the prevalence of musculoskeletal disorders, and related risk factors among cashew workers. Subsequently, designing and evaluating an ergonomic intervention as a solution to minimize the risk of musculoskeletal disorders in Indian small and medium-scale cashew nut processing mills was carried out in shelling activity. The knowledge produced during this research work indicated that the development of hand-operated cashew nut sheller by the participation of workers and incorporating ergonomics into design process has contributed to improving the working conditions, especially working posture, in Indian small and medium-scale cashew nut processing mills. Improvement in adopted working postures is expected to reduce risk of musculoskeletal disorders among workers. The following section presents the salient findings from the present research.

5.4. Fulfillment of the objectives

Obj. 1 *To investigate the current working conditions in small and medium-scale cashew nut processing mills in terms of: (a) investigation of the prevalence of WMSDs among cashew nut processing workers, (b) risk assessment of awkward working posture among cashew nut processing workers, and (c) examination of the relationship between WMSDs, and demographic and work-related risk factors.*

Obj. 2 *To identify specific activity that gives high potential for the improvements of the existing method and to reduce musculoskeletal disorders in small and medium-scale cashew nut processing mills.*

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A cross-sectional study was conducted on 290 cashew workers across four states in eastern region of India. The study results demonstrated that these cashew workers across four activities (boiling, shelling, peeling, and grading) in the mills had high level of WMSDs in different body regions as well as high level of ergonomic risk for the adopted postures. It also established a significant ($p < 0.05$) association between WMSDs and potential risk factors (demographic and work-related). Overall, this study provided a detailed view of current working conditions scenario in Indian small and medium-scale cashew nut processing mills. Specifically, this study highlighted the need for more research in specific activities. Existing cashew nut shelling practices could be an interesting area for research and can give the high potential for improving the working conditions, especially working postures, and reduce musculoskeletal load in Indian small and medium-scale cashew nut processing mills. So this piece of research chose shelling activity for further research. **Thus, objective 1 and objective 2 were fulfilled.** It is described in Chapter – 2 of this thesis.

Obj. 3 *To devise possible ergonomic intervention using participatory design approach for minimising musculoskeletal problems taking into consideration: (a) Identification of ergonomic design needs.(b) Generation and evaluation of design alternatives. (c) Pre-testing of the proposed intervention using digital human modeling.*

A group of stakeholders from Vetapalem cashew nut cluster were interviewed during participatory sessions. The ergonomic issues and needs related to the redesign of existing sheller were collected. Alternative design concepts were generated and were screened by the participants. The results of simulation-based evaluation using digital human modelling showed that the redesigned sheller could provide safe and less-risky working postures during shelling. **Thus, the objective 3 was fulfilled.** It is described in Chapter – 3 of this thesis.

Obj. 4 *To introduce a novel shelling method/style for shelling activity.*

Obj. 5 *To evaluate the developed intervention in comparison to existing one using field testing.*

Following an extensive review of existing sheller designs (Chapter – 3; Section 3.3) and referring to similar tasks, a novel shelling method for cashew nut shelling was developed. Only one hand is used to operate the newly developed sheller, whereas

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both hand and leg are required in the existing one. The evaluation of newly developed sheller in comparison to existing sheller was conducted through field testing. The results of evaluation showed the reduction of ergonomic risk level (i.e., low scores of both RULA and REBA) for new sheller. **Thus, objective 4 and objective 5 were fulfilled.** It is elaborated in Chapter – 4 of this thesis.

5.5. Contributions of the present research work

The following are the contributions from this research investigation:

i. The first phase of the study probed into current working conditions in small and medium-scale cashew nut processing mills in (eastern) India. Workers' demographic details, job characteristics, awkward working postures, the prevalence of MSDs, and associated risk factors were reported in this thesis, which would otherwise be less known to cashew workers and management. The information presented in this study (Chapter II) is a significant contribution to the existing knowledge base of ergonomic investigations in small and medium-scale industrial sector in Indian scenario. As a matter of fact, this can become an important source of information for new and existing workers in small and medium-scale cashew nut processing mills to have knowledge about the risk factors.

ii. Another valuable contribution of the present work is that the comprehensive participation of workers in developing a novel hand-operated cashew nut sheller design was achieved. Developing a solution within the interest of researchers may become harder rather than collaborating with users and incorporating their viewpoints to build one. Thus, effective discussions were conducted during the focus group sessions; the workers shared their valuable viewpoints and significant interest to modify the existing sheller design. By carefully analyzing the user requirements, design alternatives for the existing sheller were conceived, and finally, the design of a hand-operated sheller was finalized by the users.

iii. Before developing a physical model, the hand-operated sheller design was evaluated by using a digital human modeling approach. Perhaps, to the best of our knowledge, this is the first of its kind in Indian context to adopt virtual

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simulation using digital human modeling technology for ergonomic design and evaluation of work equipment in cashew sector.

iv. During the course of this study, a novel cashew nut shelling method for manual shelling activity was developed. It was demonstrated that the new sheller could be operated with a single hand instead of hand and foot-pedaling, which was required in the existing sheller. This is an important contribution from this study.

v. Following a virtual ergonomic simulation, a full-scale model of hand-operated sheller was developed by the application of anthropometric data and was filed tested with users. The development of a hand-operated sheller that is useful for reducing the risk of musculoskeletal load during the shelling task is the significant outcome of the present study.

5.6. Limitations and suggestions for future work

i. Since the study was a questionnaire-based cross-sectional study, the possibility of recall bias (where workers could remember recent pains better than older and less serious pains) could not be ruled out. A physical examination is required to strengthen/verify the self-reported pains/disorders by the workers. In addition, the causation could not be established due to the cross-sectional study design in the study. Therefore, we highly recommend longitudinal studies in future research to thoroughly understand the WMSDs in this occupational group.

ii. Data were collected from the cashew nut processing mills across the eastern region of India, and the survey results related to the mills in western region may differ. So, future studies could be further extended considering cashew nut processing mills of the western region as well.

iii. While working on the hand-operated sheller improved body postures (neck, trunk, and legs), but the forearm posture while placing the cashew nut did not improve much. Further investigation is required for the improvement of forearm posture while placing the cashew nut. A feeding attachment/hooper coupled with the hand-operated cashew nut sheller may be considered in future research.

iv. Although the use of photographs to calculate RULA and REBA scores gives a snapshot of the articular angles used by workers in order to assess discomfort

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and joint stressors, these may not necessarily represent accurate physical postural stress. Thus further research using instrument-based ergonomic assessment methodologies (e.g., motion capture systems or tri-axial electronic goniometers) are highly recommended to quantitatively measure musculoskeletal loading.

v. In present work, no attempt was made to determine the effects of hand-operated sheller on performance of workers. Therefore, we highly recommend training workers and further field trials to test the efficiency of hand-operated sheller under real production conditions.

5.7. Chapter 5 summary

This chapter presented the summary of the present research and conclusions of this research work. It described how the study aim and objectives were accomplished. Salient findings from present research work were also presented, indicating the results that have contributed to those conclusions. This summary and conclusion chapter then presented contributions and limitations of present work and also indicated direction for future research.

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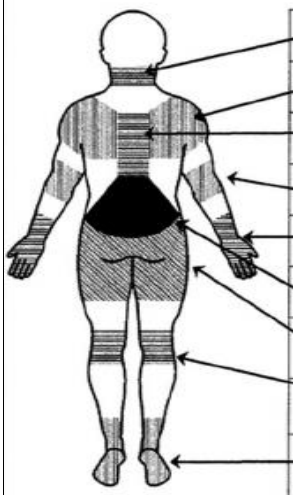
6 Appendices

Appendix I Questionnaire used for data collection.

Part-1	
Gender: Male/ Female	Age (in years):
Height (in cm):	Weight (in Kg):
Material status: Single/Married	Educational level:
Smoking: Yes/No	Native state:
Work Section:	
Part-2	
Work experience (in years):	Working hours per day:
Working very fast: Yes/No	Personal satisfaction in work: Low/Moderate/High
Job stress: Low/Moderate/High	Work fatigue : Low/Moderate/High
Current occupational health status: Good/Moderate/Bad	
Part-3	
Standardised Nordic questionnaire for the analysis of musculoskeletal symptoms (Kuorinka et al., 1987).	



	Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:	During the last 12 months have you been prevented from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble in:	During the last 12 months have you seen a physician for this condition:	During the last 7 days have you had trouble in:
NECK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
SHOULDERS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
UPPER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ELBOWS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
WRISTS/ HANDS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
LOWER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
HIPS/ THIGHS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
KNEES	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ANKLES/ FEET	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes

If you experiecned any pain during past 12 months, please pick a number on the scale.

1 Very mild pain	2	3	4	5 Very high pain

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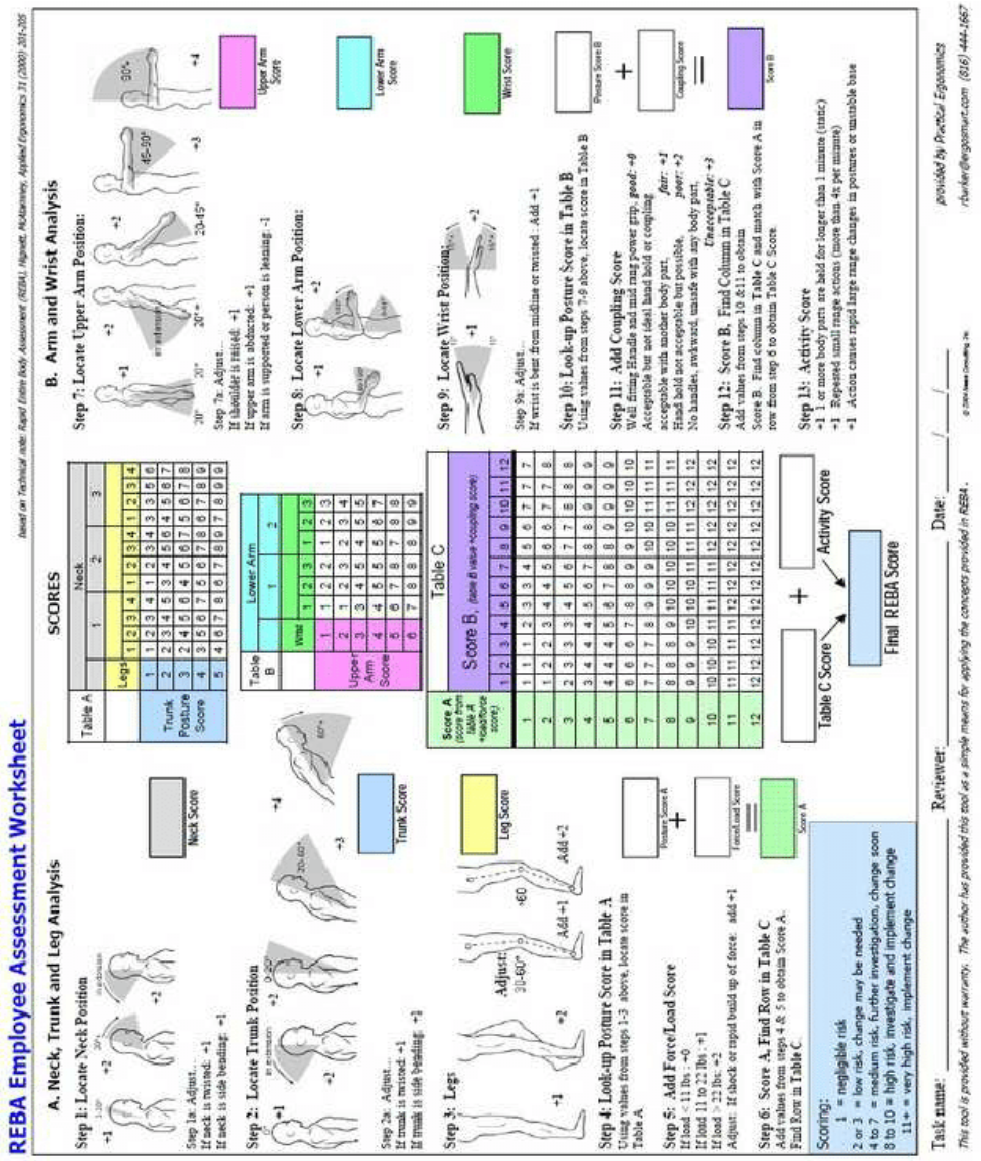
Appendix II Rapid Entire Body Assessment (REBA).



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Appendix III Questionnaire survey for the user requirements.

Questionnaire						
Age:				Gender:		
Please rate the importance of each user requirement for the redesign of existing sheller. Pick a number from the scale to give your opinion.						
Rating Scale						
Extremely unimportant	1	2	3	4	5	***Extremely important***
1.	Good shelling					Scale:
2.	Comfort					
3.	Cleanable					
4.	Durable					
5.	Appearance					
6.	Portable					
7.	Stable					
8.	Maintenance					
9.	Easy to use					
10.	Save space					
11.	Storage and collection					
12.	Affordable price					
13.	Sit					
14.	Recyclable					
15.	Handle anti-slip					

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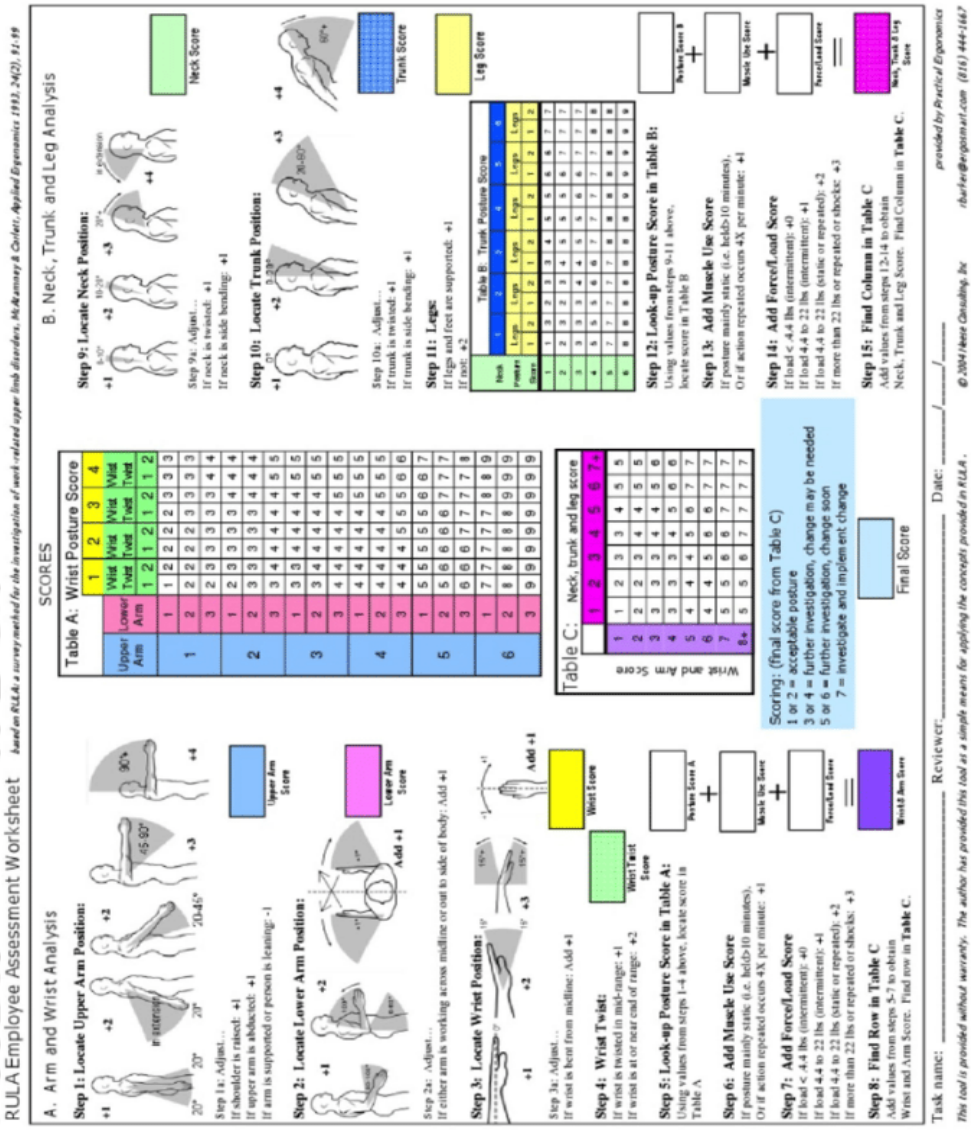
Appendix IV Rapid Upper Limb Assessment (RULA).



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Appendix V Name and specifications of the items used for fabrications of hand-operated cashew nut sheller.

S.No	Name of the item	Specifications	Quantity
1.	MS square tube	25 mm X 25 mm X 18 feet	3 nos
2.	MS square tube	19 mm X 19 mm X 500 mm	1 nos
3.	MS flat	40 mm X 500 mm X 5 mm	1 nos
4.	SS round rod	16 mm X 800 mm	1nos
5.	Rubber caps	25 mm X 25 mm (black)	14 nos
6.	Rubber caps	19 mm diameter (black)	3 nos
7.	Rubber caps	12 mm diameter (white)	3 nos
8.	MDF board	1000 mm X 1000 mm X 15 mm (medium density)	1 nos
9.	MDF board	400 mm X 600 mm X 10 mm (medium density)	1 nos
10.	GI pipe	400 mm (length) X 60 mm (diameter)	1 nos
11.	GI pipe	400 mm (length) X 50 mm (diameter)	1 nos
12.	GI pipe	1500 mm (length) X 19 mm (diameter)	1 nos
13.	MS square plate	200 mm X 200 mm X 8 mm	1 nos
14.	MS rod	500 mm (length) X 12 mm (diameter)	1 nos
15.	SS bush	25 mm (length) X 40 mm (diameter)	8 nos
16.	Seat cushion cover	1000 mm X 1000 mm (black)	1 nos
17.	Seat cushion	450 mm X 400 mm X 50 mm (foam)	1 nos
18.	Paint (yellow)	0.5 litre	1 nos
19.	Paint (sky blue)	0.5 litre	1 nos
20.	Bolt and nut	3/16” X 4”	24 nos
21.	Bolt and nut	1/2“ X 5”	4 nos
22.	Rubber handle	105 mm (length) X 19 mm (inner diameter)	1 nos
23.	Fevicol (adhesive)	500 gram	1 nos
24.	Cotton waste	1 kg	1 nos
25.	Paint thinner	1 litre	1 nos
26.	Paint brush	25 mm	4 nos
27.	Paint (red-oxide)	0.5 litre	1 nos
28.	Paint (white)	0.5 litre	1 nos

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Appendix VI Fabrication and specific mechanical operations.

Cutting

Grinding

Drilling

Welding

Turning

Assembling

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Appendix VII The actual use cases of completing shelling activity using hand-operated cashew nut sheller and existing cashew nut sheller.

Pedal-operated cashew nut sheller	Hand-operated cashew nut sheller
Grabbing the cashew nut manually	Grabbing the cashew nut manually
Placing the cashew nut in between sheller blades	Placing the cashew nut in between sheller blades
Placing one leg on the foot pedal (single leg standing)	Legs on foot rest (both legs in free position)
Grabbing the hand lever	Grabbing the hand lever

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Appendix VII The actual use cases of completing shelling activity using hand-operated cashew nut sheller and existing cashew nut sheller (continued).

Pedal-operated cashew nut sheller	Hand-operated cashew nut sheller
Pressing foot-pedal downwards penetrates the blade into cashew nut	Pulling the handle backwards penetrates the blade into cashew nut
Pulling the handle upwards breaks cashew nut into two halves	Hitting cross pin rotates the shaft and breaks the cashew nut into two halves
Sample of shelled nuts after shelling	Sample of shelled nuts after shelling

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Appendix VIII List of publications.

Journal Papers

1. **Mallampalli, K. C.**, Dhar, D., & Pal, S. (2021). Work posture and risk factors associated with work-related musculoskeletal disorders among cashew workers in Eastern India. *International Journal of Human Factors and Ergonomics*, *8*(1), 44-63.
2. **Mallampalli, K. C.**, Dhar, D., & Pal, S. (2022). Ergonomic design and simulation-based evaluation of a new cashew nut sheller. *Journal of Industrial and Production Engineering*, 1-15.
3. **Mallampalli, K. C.**, Dhar, D., & Pal, S. Development and ergonomic evaluation of a hand-operated cashew nut sheller. *International journal of Industrial Ergonomics. (Submitted)*

Conference proceedings

1. **Mallampalli, K. C.**, Dhar, D., & Pal, S. (2020, July). Prevalence and risk factors associated with musculoskeletal disorders among cashew-nut shelling workers in India. In *International conference on Applied Human Factors and Ergonomics* (pp. 79-86). Springer, Cham.
2. **Mallampalli, K. C.**, Dhar, D., & Pal, S. (2020, December). Prevalence of Musculoskeletal Disorders Among Female Cashew Nut Shelling Workers. In *Joint Conference of the Asian Council on Ergonomics and Design and the Southeast Asian Network of Ergonomics Societies* (pp. 281-291). Springer, Cham.
3. **Mallampalli, K. C.**, Dhar, D., & Pal, S. (2021, January). A Comparative Study of Design Methodologies to Integrate Ergonomics Requirements into Design. In *International Conference on Research into Design* (pp. 291-301). Springer, Singapore.
4. **Mallampalli, K. C.**, Dhar, D., & Pal, S. Design and Ergonomic Evaluation of a New Cashew Nut Shelling Workstation. In *Progressive Research in Industrial & Mechanical Engineering (PRIME – 2021)*. Lecture Notes in Mechanical Engineering. Springer.*(Forthcoming)*

Patent

1. A novel hand-operated cashew nut sheller. *(in preparation)*

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