

Exploring Innovative Design Solutions for Pineapple Harvesting in the Context of Northeast India

A thesis submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

Submitted by

Hijam Jiten Singh

186105004

Under the supervision of

Prof. Sougata Karmakar



Department of Design

Indian Institute of Technology Guwahati

Guwahati, Assam, India

DECLARATION

I hereby declare that the thesis entitled “Exploring Innovative Design Solutions for Pineapple Harvesting in the Context of North East India” being submitted in the partial fulfillment for the award of the degree of **Doctor of Philosophy**, is an authentic work of my research work carried out in the Department of Design, Indian Institute of Technology, Guwahati under the supervision of Prof. Sougata Karmakar, Professor and Head, Department of Design, Indian Institute of Technology Guwahati. The thesis has not been submitted by me earlier for any other degree or diploma.

Date: 13th June 2024

Place: IIT Guwahati, Assam

Hijam Jiten Singh

Registration No: 186105004

Department of Design

Indian Institute of Technology Guwahati

Prof. Sougata Karmakar

Professor, Department of Design,

Indian Institute of Technology Guwahati

Assam- 781039



CERTIFICATE

This is to certify that the thesis entitled, “**Exploring Innovative Design Solutions for Pineapple Harvesting in the Context of North East India**” submitted herein, in partial fulfillment of the requirements for the award of the degree of **Doctor of Philosophy** is a record of *bonafide* research work carried out by **Mr. Hijam Jiten Singh (Registration No. 186105004)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

He has undergone the specified courses and fulfilled all the requirements as mentioned in the rules and regulations for submitting the thesis for the Ph.D. degree of the Indian Institute of Technology Guwahati.

It is further certified that all the assistance and help availed during the course of investigation as well as all sources of information have been duly acknowledged by him.

Date: 13th June 2024

Place: Guwahati, Assam

Prof. Sougata Karmakar

Supervisor

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Date: 13th June 2024

Place: IIT Guwahati, Assam

Hijam Jiten Singh

EXECUTIVE SUMMARY

Pineapple (*Ananas comosus*) holds a significant position as the third most crucial tropical fruit globally, following banana and citrus. Originating from South America, it has become a major commercial fruit crop cultivated worldwide. In India, it ranks second in pineapple cultivation area (0.11 million hectares) and seventh in terms of production (1.80 million tonnes). Despite its importance, India faces challenges with low productivity (16.81 tonnes per hectare) compared to global leaders like Indonesia (127.29 tonnes per hectare).

The northeast region of India, consisting of eight states, contributes significantly to the country's pineapple production. The states of Assam, Manipur, Meghalaya, Tripura, and Nagaland are among the top pineapple cultivators, with production more than half of the total production of the country and being cultivated organically by default. Agriculture is a crucial income source for the majority of the population in this agrarian society. The cultivation practices in northeast India involve traditional methods, primarily on hill slopes and foothills under rain-fed conditions. Pineapple varieties like *Queen* and *Kew* dominate, and the region faces challenges related to low productivity and traditional cultivation practices. Efforts, including government initiatives like the Horticulture Technology Mission, have aimed to improve cultivation practices and increase productivity.

Harvesting, a labour-intensive task, is primarily done manually using traditional tools. Despite attempts to mechanize harvesting in other major pineapple-producing countries, the difficult hilly terrain and traditional practices make large machinery impractical in India and northeast India in particular. Manual harvesting, while preserving the fruit and crown, poses challenges such as labour intensiveness, time consumption, and ergonomic hazards leading to health issues among farmers.

The existing literature identifies research gaps related to the harvesting systems, musculoskeletal symptoms, working conditions, and ergonomic interventions specific to pineapple harvesting in the region. While major pineapple-producing countries have explored mechanization, the unique challenges of northeast India require tailored solutions, possibly involving ergonomically designed tools to address the prevalent issues and improve harvesting efficiency. In northeast India, the

pineapple crop plays an important role in the region's agriculture and economy. However, addressing the challenges in cultivation practices and manual harvesting methods through targeted research and interventions is vital to enhance productivity, reduce drudgery, and improve the overall well-being of pineapple farmers in the region.

Keeping the above discussion in mind, this research study focuses on the challenges faced by pineapple farmers in northeast India, particularly in terms of working conditions, the prevalence of musculoskeletal disorders (MSDs), the manual harvesting process, and associated ergonomics risk factors. Based on the above research gaps and initial interactions with the farmers, a set of research questions was raised, as listed below.

- RQ 1: Who are the pineapple farmers and what are their working conditions?
- RQ 2: What are the problems associated with pineapple harvesting tasks in northeast India?
- RQ 3: What would be the best feasible solutions for ease and safe pineapple harvesting specifically for pineapple farmers in northeast India?
- RQ 4: What would be the strategy of design solutions from an ergonomics perspective for pineapple harvesting adoptable for the needs among pineapple farmers in northeast India?

Hence, the proposed research work aims to investigate the socio-demography of pineapple farmers, and problems associated with pineapple harvesting tasks and to come up with innovative design solutions adoptable for the needs of pineapple farmers in northeast India. To achieve the aim of this proposed research work, the following objectives have been laid down:

- Objective 1: To assess the socio-demography of pineapple farmers, working conditions, and problems associated with pineapple harvesting tasks in northeast India
- Objective 2: To explore innovation design solutions for ease and safe pineapple harvesting in the context of northeast India
- Objective 3: To develop and evaluate the performance of the prototype pineapple harvester from an ergonomic perspective
- Objective 4: To study the effect of newly developed harvester on productivity, efficiency and manual labour

The hypothesis that was formulated at the beginning of this research work has been tested by achieving several aforementioned objectives.

H1: The equipment which facilitates easy holding of pineapple fruit and allowing cutting from a certain location to avoid awkward working posture and injury from leave tips and spines would significantly reduce drudgery thereby improving productivity and efficiency of pineapple harvesting.

The study provides insights into the cultivation practices and physical characteristics of pineapple plants and pineapple fruit. A thorough analysis of the socio-demographic traits, working conditions, and related issues with integrating cutting-edge equipment and methods for pineapple farming and harvesting, however, was lacking. Therefore, a great deal of work in this field has been investigated in the present study. The study revealed that the working hours of pineapple farmers in the region were relatively less compared to other pineapple-producing countries. However, the prevalence of perceived high workload and MSDs among farmers was significant. The pineapple farms were located in remote areas with no direct access to electrical power, posing challenges to the adoption of motorized harvesting equipment. The study emphasized the need for context-specific tools and equipment considering the available farm power in the region. The prevalence of MSDs among pineapple farmers was higher than reported in other agricultural studies, with the lower back being the most affected body part. Demographic factors such as age, education level, and farming experience were significantly associated with MSDs prevalence, highlighting the importance of education and training for farmers.

Ergonomic stressors such as bending, twisting, repetitive work, and carrying heavy loads contributed to MSDs. The study also suggested that innovative interventions, including engineering changes and behavioural modifications, could help reduce ergonomic risks. The intricate dynamics between human practices and the challenges posed by the natural defences of pineapple plants were also explored during the study. Protective gear, such as hand gloves, footwear, special guards made of thick cloths for forearms, etc. were adopted by the farmers to mitigate risks during manual harvesting practices. In addition to the identification of ergonomic stressors, the study also addressed the issues in pineapple harvesting tasks through a systematic research approach. This thesis

included extensive work in this area, carefully examining the frequency of issues linked to occupational health, including musculoskeletal illnesses as well as evaluating ergonomic risk factors.

The present research explored the feasibility of developing a pineapple harvesting device, considering crop, user, and machine parameters. A full-scale prototype of pineapple harvesting devices was developed, incorporating features such as a fruit grabber and cutting blade. Field trials and evaluations were conducted at farmers' farms to assess the performance, usability, and acceptability of the targeted users. Field trials and farmer feedback highlighted the need for modifications to enhance usability, emphasizing the importance of user-centric design. The study revealed that the developed pineapple harvester has the potential to improve various aspects of the harvesting process, including physiological parameters, ergonomic impact, productivity, and usability. It was proved that the newly developed pineapple device helped to avoid awkward working postures and injury from leave tips and spines and reduced drudgery significantly thereby improving the productivity and efficiency of the pineapple harvesting process. Therefore, it could be argued that the research hypothesis H1 has been accepted.

The present study also highlights a systematic research methodology that begins with a review of the literature and a field survey to determine the research need and problem statement. Research approaches, both qualitative and quantitative, were implemented based on the needs of data gathering. This research effort has shown how to use a pre-tested schedule and SNQ questionnaire for data collection and to determine the need for proper ergonomic intervention followed by direct observations (photography and videography) to identify ergonomic stressors during field study. The REBA technique for postural load evaluation, mapping of body parts discomfort, quantification of energy requirement, and oxygen consumption rate based on heart rate were also included in this study. The System Usability Scale (SUS) was also used as a reliable tool for measuring usability. The SUS was applied during pineapple harvesting activities by both existing traditional method and newly developed pineapple harvester to demonstrate the effectiveness of the newly developed pineapple harvesting device in comparison to the traditional method. The complete methodology of problem identification to provide an adoptable and sustainable solution as described in the present research would help the designer/engineers to adopt a similar strategy as a standardized approach that was outlined and used in this study as a guide for their research.

From a societal perspective, this study has focused on addressing practical challenges and ergonomic concerns related to the task of harvesting pineapples in northeast India. This region is characterized by hilly terrains where small and marginal farmers cultivate pineapples for their livelihoods. Unfortunately, pineapple farmers in the northeast are constrained by outdated harvesting tools due to limited fabrication resources, insufficient research initiatives, and geographical barriers. Given this context, there is a pressing need to create innovative tools tailored to the safety requirements of northeast India. A novel harvesting device resulting from this study ensures the well-being of farmers and mitigates ergonomic challenges. Through enhanced consideration of design parameters, this intervention led to a marked improvement in working postures and a reduction in ergonomic risks. It is anticipated that the large-scale production and deployment of such devices for pineapple harvesting will have a profound positive impact on the lives of disadvantaged pineapple farmers in northeast India. The availability of fully developed, locally manufactured industrial products of this nature will likely garner significant acceptance within northeast India, ultimately benefiting the targeted community in a substantial way.

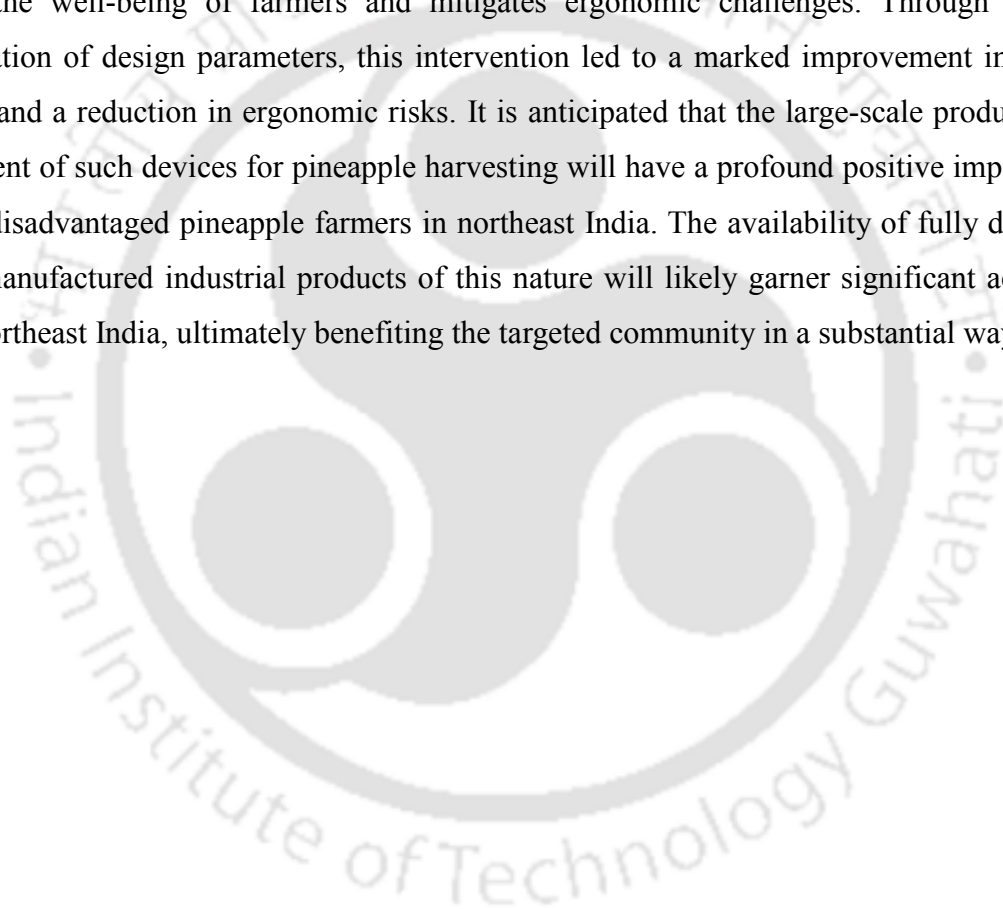


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1 Introduction

1.1 An Overview

Pineapple, scientifically known as *Ananas comosus*, holds the distinction of being the third most significant tropical fruit globally, following banana and citrus (Rohrbach *et al.*, 2003). It originated in South America and with subsequent global dissemination (Singh *et al.*, 2016; Saloni *et al.*, 2017). It has been grown as a significant fruit crop for commercial purposes. The top 10 nations in the world for pineapple production are Philippines, China, Costa Rica, Brazil, Indonesia, China (Mainland), India, Thailand, Nigeria, and Mexico (Anon, 2023). With productivity as low as 16.81 tonnes per hectare compared to as high as 127.29 tonnes per hectare in Indonesia, India ranks 7th in the world for pineapple production (1.80 million tonnes) and 2nd behind Nigeria in terms of the area covered by pineapple farming (about 0.11 million hectares). The area under plantation and production of pineapple is growing in India as indicated by the time series line chart shown in Figure 1.1. The list of the top pineapple-growing states in India along with their respective contributions in terms of production and cultivated area is given in Figures 1.2 and 1.3. The leading states in the nation in terms of area under pineapple cultivation are Assam (16%), Manipur (12%), Meghalaya (12%), West Bengal (11%), Kerala (10%), Tripura (9%), Nagaland (8%), Mizoram (5%), Andhra Pradesh (4%), Bihar (4%) etc. (Anon, 2023). According to Paul *et al.* (2016), practically all the states in northeast India cultivate pineapple commercially, accounting for more than half of the nation's total production. Additionally, it was stated that six states in the area often ranked among the top 10 pineapple-producing belts in the nation and that practically all of these are cultivated organically by default.

Eight states - Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim - make up northeastern India. In essence, this region of the nation is an agrarian community. The tribal community comprises around 80% of the population, except for Assam and Sikkim. This region's climate, terrain, and organic matter-rich soil create favourable conditions for a variety of agricultural endeavours and related industries. For this reason, farming is thought to be the majority of people's primary source of income. The North Eastern Council, Government of India

(2015) reports that there are 9.2 million farmers and farm labourers in northeast India (gender ratio: 513 females for 1000 male workers).

The region's fruit crop area is approximately 0.45 million hectares, yielding 4.34 million tonnes of fruit, or 6.94% of the country's total area and 4.46 % of its overall fruit production (Anon, 2018). In addition to other significant crops including citrus, bananas, passion fruit, kiwis, strawberries, cashews, and low-chilling peaches and plums, pineapple is one of the most important commercial fruits in the area. Pineapple is the second most produced fruit in the region (19.91%), after banana (30.32%), and it accounted for 15.72 per cent of all the land planted for fruit in 2013–14 (Anon, 2015) (Figure 1.4).

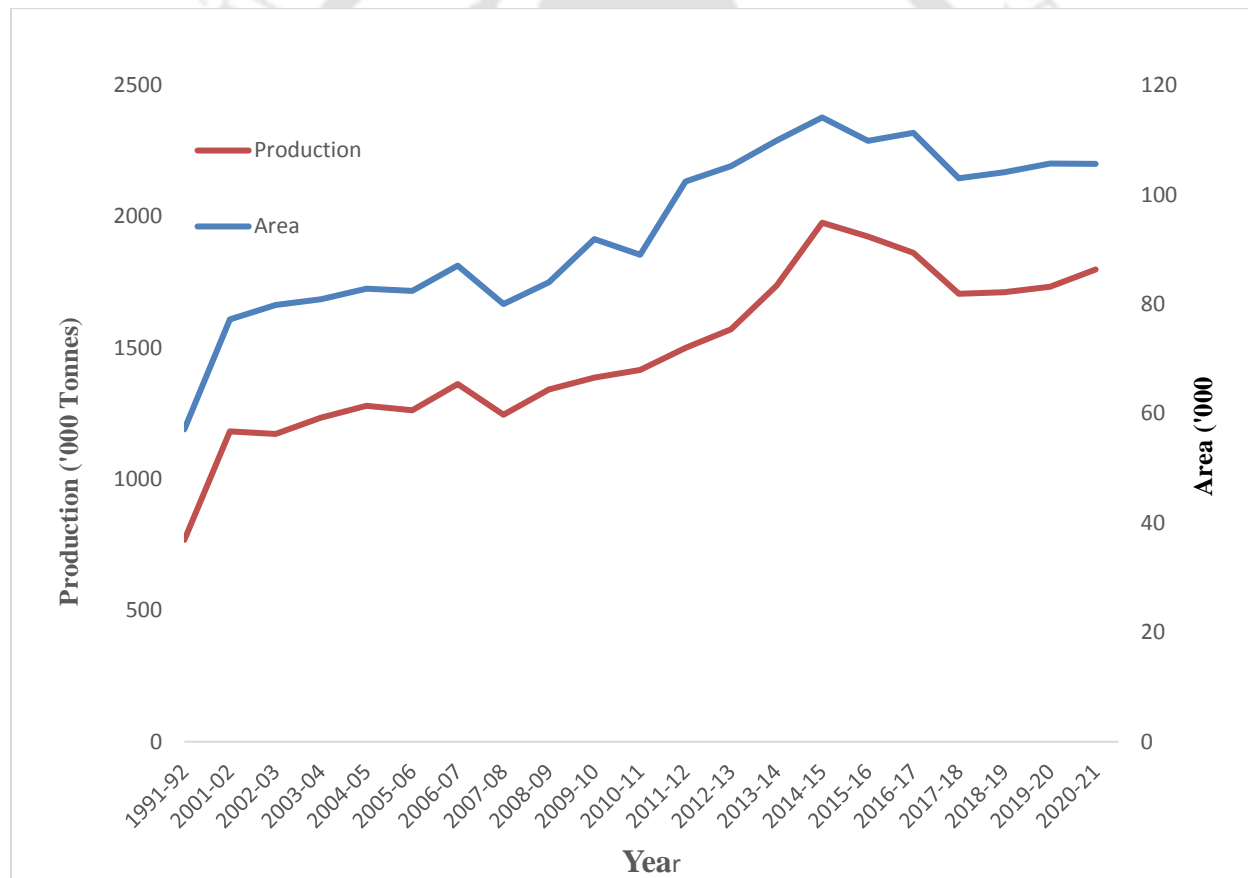


Figure 1.1. Time series of pineapple production and area in India
(Anon, 2017a; Anon, 2018 and Anon, 2023)

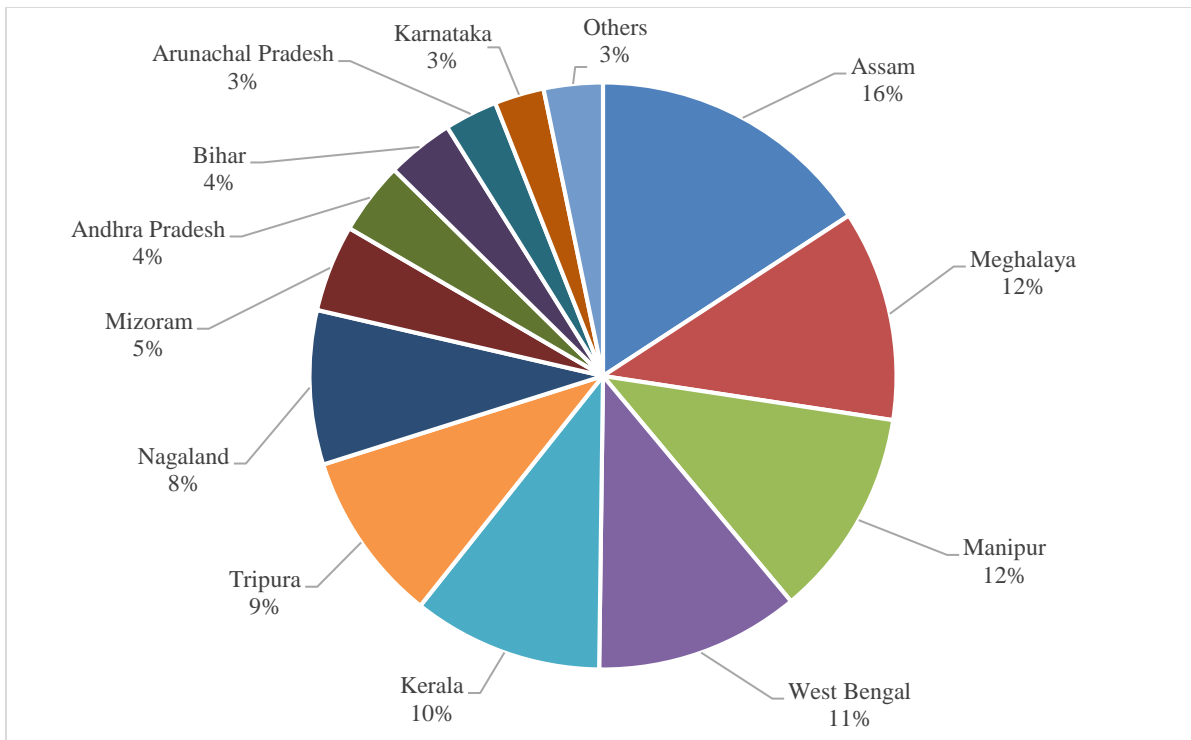


Figure 1.2. Leading pineapple-growing states in India during 2020-21 (Anon, 2023)

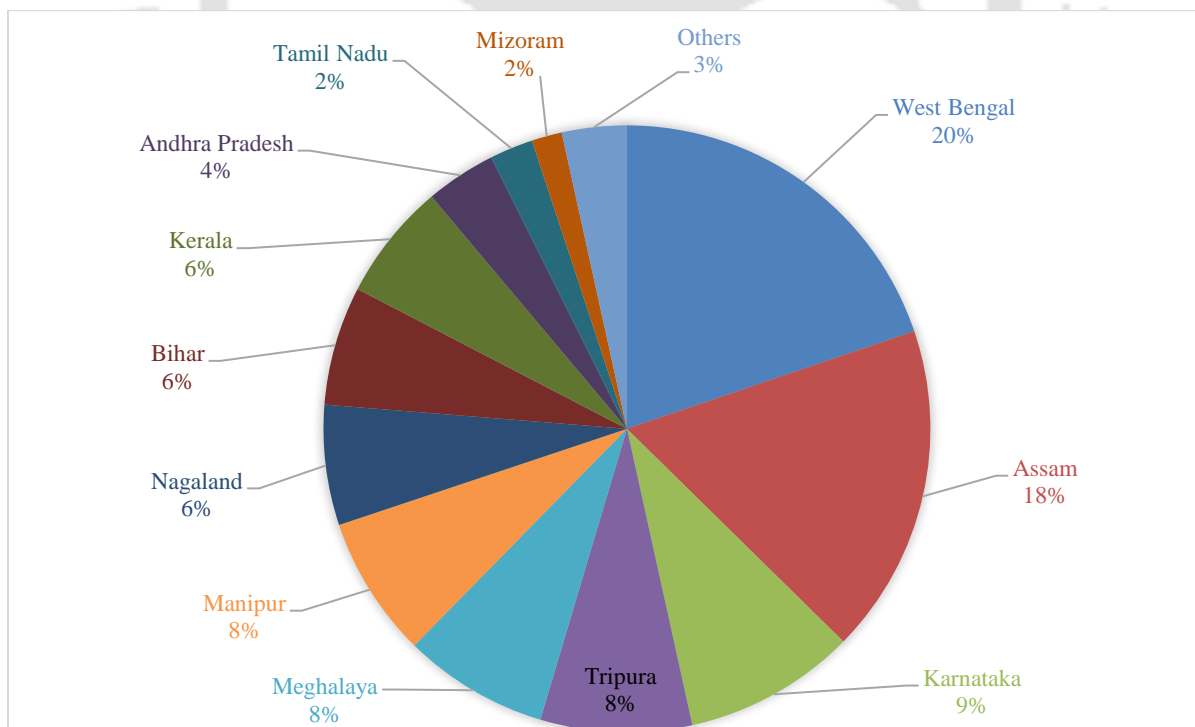


Figure 1.3. Leading pineapple producing states in India during 2020-21 (Anon, 2023)

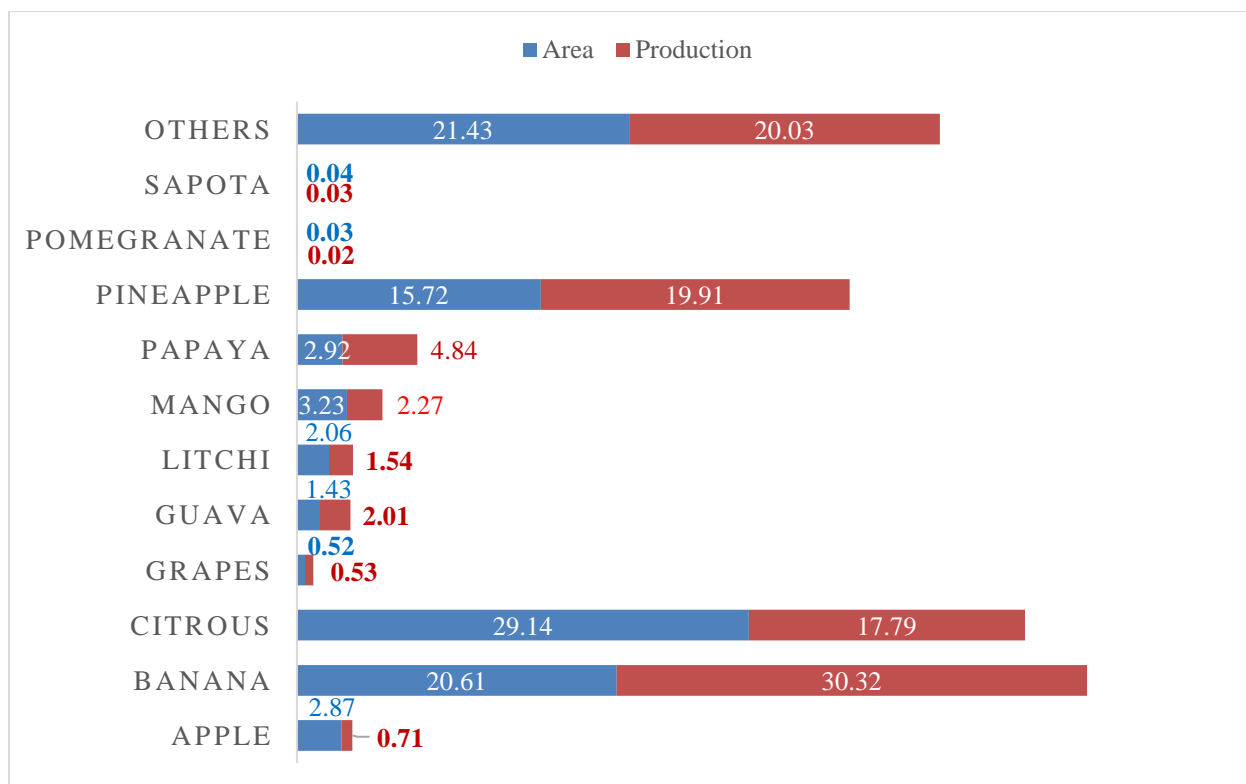


Figure 1.4. Area and production shares (%) of fruits in NE states during 2013-14 (Anon, 2015)

In northeast India, pineapple is mostly cultivated on hill slopes or foothills and under rain-fed conditions. Traditionally, they are planted along the slopes using locally evolved hand tools such as *Dao/Thangjou* for slashing/cleaning the forest, spades for land preparation, and making pits. Pineapple is cultivated with limited management practices and inputs. The unsystematic approach, or single-row system with a large gap between subsequent rows, is the most widely used technique among pineapple growers. This conventional approach could only support 8,000–10,000 plants per hectare. Furthermore, in this area, pineapples are primarily grown organically. Low production may therefore have come from pineapple plantations that did not adhere to the suggested package of farming techniques or from inadequate management practices (Sema *et al.*, 2011). Under high-density planted conditions, the yield might be increased from the 15 t/ha national optimal yield to roughly 50–60 t/ha. The Indian government saw the northeast as a promising area for pineapple cultivation and launched the "Horticulture Technology Mission" initiative in 2001. In terms of area and pineapple output, the project also increased by 140.7% (Sema *et al.*, 2009; Saloni *et al.*, 2017). Plantation usually occurs from February to April, with two harvest seasons: July to September

(main season) and December to January (off-season). Farmers have begun implementing systematic techniques like the double-row plantation method (across or along the slope) in response to state and federal programme interventions. The goal of these techniques is to increase productivity and make it easier to harvest in a single pass between the rows.

In the region, varieties such as *Queen* and *Kew* are the most popular and extensively grown varieties on hill slopes or foothills in hilly areas under rain-fed conditions across the northeastern states. Pineapple maturity stages and peak harvesting season across the states in the region are shown in Figures 1.5 and 1.6. The availability of pineapple fruits varies across the states depending upon the type of variety cultivated. Because pineapples are available in states like Manipur for eight months, the state is well-positioned in the process and adds value for export (Sema *et al.*, 2011). Nevertheless, a small amount of the gathered produce is transferred to the processing facility and is sold at wholesale markets or on the state/national highway's roadside. This can be the result of the region's disorganized marketing system and inadequate market infrastructure. Numerous initiatives are being implemented to support the pineapple growers and realize the region's full potential.

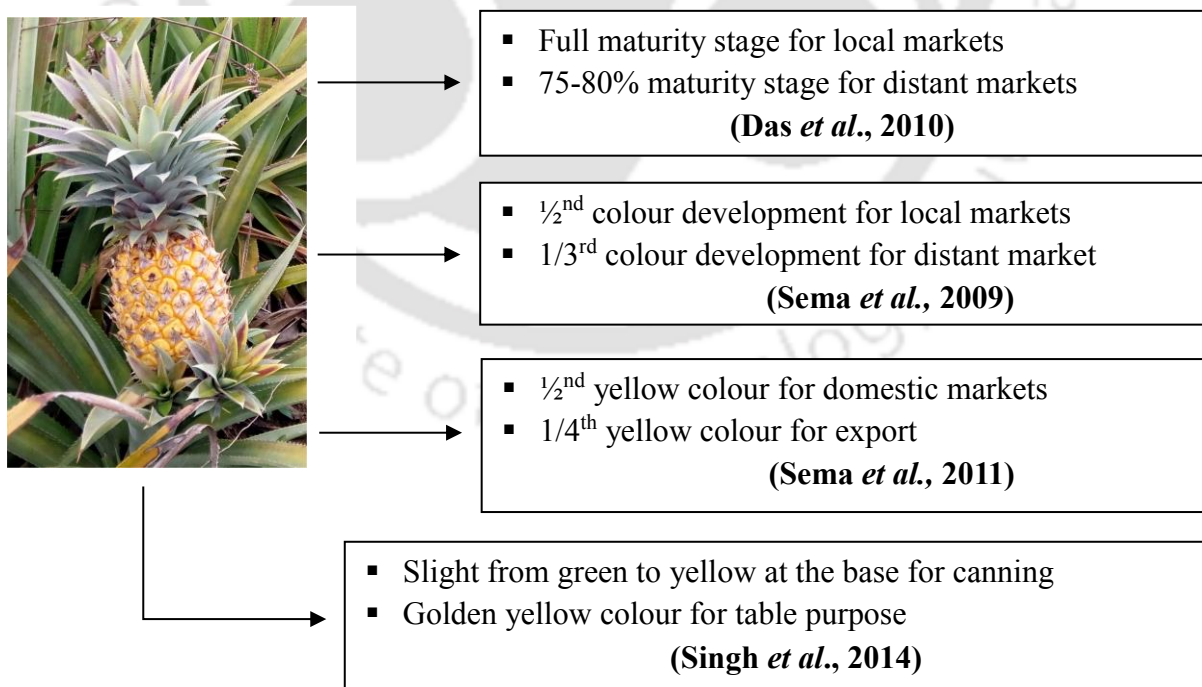


Figure 1.5 Pineapple maturity stages for harvest

States	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Arunachal Pradesh							Lean	Peak				
Assam							Peak	Peak	Lean		Lean	Lean
Manipur	Lean					Lean	Peak	Peak	Peak	Lean		Lean
Meghalaya	Lean					Lean	Peak	Peak	Lean			Lean
Mizoram							Lean	Peak				
Nagaland					Lean	Peak						
Tripura					Lean	Peak	Lean					

Lean season
 Peak season

Figure 1.6 Peak pineapple harvesting season across NE states (Anon, 2015)

1.2 Prevalent Harvesting Methods

Conventionally, pineapples are harvested by hand so that the fruit is not harmed, and the crown is kept. The maturity stages of pineapple for harvest depend on the target market and purpose as shown in Figure 4. The harvesting of ripe fruits is done by the farmers by cutting it or breaking the stalk using a sharp machete or a cutting tool with a bamboo basket strapped over their shoulders, or a poly/gunny bag (Nazri and Pebrian, 2017). The peduncle should be cut 5-7 cm below the fruit base using a sharp knife (Das *et al.*, 2011); and harvested with a 5 cm stalk and the crown attached (Sema *et al.*, 2009). Joy and Rashida (2016) also reported that pineapples meant for export were cut with a knife to leave a sizeable stalk and the stalk was used for holding the fruit during movement from the field. According to reports, the harvesting process is mechanized in top pineapple-producing nations namely Malaysia, the Philippines, Costa Rica, Thailand, Indonesia, etc., using heavy machinery like boom harvesters (Rukunudin *et al.*, 2011). Moreover, some researchers in India have also attempted individual pineapple fruit picking using semi-manual harvesters (Singh *et al.*, 2014; Singh *et al.* 2022) and robotic harvesters in China (Xia *et al.*, 2011; Wang *et al.*, 2012; Xia *et al.* 2012). However, they are mostly in experimental stages and have not

been successful so far at the farm level. While the potential for employing extensive machinery or robotic harvesters exists in numerous leading pineapple-producing nations, its feasibility does not apply to the Indian context, especially in northeast India. This is attributed to inherent challenges such as challenging hilly terrain, diverse hill slopes, varying altitudes, distinct land tenure systems, and the prevalence of traditional cultivation practices in the region. Consequently, pineapple farmers in this area are compelled to adhere to time-honoured traditional methods, relying on locally developed or fabricated hand tools.

1.3 Drudgery Associated with Harvesting Task

The process of manual harvesting in pineapple cultivation not only demands a significant amount of time and labour, estimated at 20-30 man-days per hectare (Anon, 2017b) but it also poses risks of injuries to farmers. The spines and sharp tips of the leaves contribute to easy injuries as reported in various studies (Wang *et al.*, 2012; Li and Wang, 2013; Singh *et al.*, 2014; Nazri and Pebrian, 2017). The manual method also exposes farmers to health hazards and body strain due to repetitive tasks (Earle-Richardson *et al.*, 2006; Fathallah, 2010; Gonzaga *et al.*, 2016; Rani *et al.* 2016; Salleh and Sukadarin, 2018a and 2018b; Ya'acob *et al.*, 2018; Salleh *et al.*, 2019). Moreover, the harvesting task was categorised as the highest-risk task in terms of ergonomic hazards (Rani *et al.*, 2016) with eminent risk factors such as poor postures and heavy lifting (Salleh and Sukadarin, 2018b). Furthermore, Mathew *et al.* (2011) highlighted that the recommended package of practices was not followed in most plantations in states like Meghalaya (India). Due to the de-suckering of excess suckers and slips, intercultural operations as well as harvesting of fruits were hindered during the weeding and harvesting seasons. So, the pineapple farmers used wooden planks and placed them over the plants to walk and move into the pineapple plantations for manual harvesting of matured pineapple fruits. Besides, the short-handle sharp-edged cutting tools being used further aggravate the drudgery and safety risks to farmers engaged. As pineapple is grown low to the ground, the harvesting process necessitates farmers to bend down and adopt a stooping position during the harvesting task. Engaging in such awkward postures and consistently carrying out repetitive tasks contribute to body strain and can result in the development of various Musculoskeletal Disorders (MSDs). Despite all these ergonomic and safety issues, insignificant corrective actions/measures in this context have been made. There is very limited literature available on studies such as pineapple harvesting systems (both traditional and improved

tools/equipment); the prevalence of musculoskeletal disorders (MSDs); and other related problems being faced by pineapple farmers in India and northeast India in particular for harvesting pineapple fruits.

1.4 Summary of literature

Harvesting systems can be categorised to be either manual, semi-manual, mechanical, or robotic harvesting systems. Various fruit-picking mechanisms have been developed globally for manual, semi-manual, mechanical, and robotic harvesting systems to increase the efficiency and effectiveness of fruit harvesting and to reduce fruit damage and associated human drudgery. However, mechanical harvesting systems developed so far for fruit and vegetable harvesting were mostly suitable for large-scale production with hectares of land. Moreover, robotic fruit harvesting would be viable through a multidisciplinary approach to understand both crop factors as well as machine factors as each target crop has a unique nature of biological systems.

It was observed from the study that in major pineapple-growing countries, pineapple is harvested with heavy machinery such as boom conveyer harvesters. The topography and size of those countries allow for the usage of such large machines. However, the sole purpose of these machines was to gather harvested fruits from the field into a temporary collection area following field workers' laborious harvesting of individual fruits off the plants. To maximize the utilization of mechanical systems, the field plot must also be configured with proper plot dimensions for mechanization, with adequate provision of headlands and farm roads. It was also reported that with some relevant assumptions, the viable acreage for the implementation of mechanization is a minimum of 40 ha. Some researchers attempted to address the problem of individual pineapple picking using a semi-manual harvester and robotic pineapple harvesters. Research on individual pineapple fruit picking is mostly in the design and experimental stages. Though large machinery or robotic harvesters have their place in other major pineapple-producing nations, it is not applicable in the Indian context and northeast India in particular. Pineapple harvesting in India still follows the traditional method of manual harvesting by using a sharp knife/sickle/*dao* for plucking individual pineapple fruit.

Further, studies related to the ergonomic evaluation of the pineapple harvesting process were also not readily found in the literature, although injuries (due to spines and tips of the leaves), and back pain and body strain to farm workers (due to awkward postures and repetitive task) were reported. So, ergonomic studies on the pineapple harvesting process need to be undertaken to assess the risk factors involved in pineapple harvesting to incorporate the findings and recommendations in design interventions for mechanized pineapple harvesting. Therefore, there is scope for mechanizing pineapple harvesting tasks where, small hand tools are being used resulting in human drudgery, intensive labour, and time consumption. Mechanization might necessarily not be with the costly automatic equipment but with ergonomically designed hand tools/equipment suited to local conditions. Literature indicates a noticeable gap in the comprehensive examination of socio-demographic characteristics, orchard environment, and obstacles hindering the adoption of advanced tools and techniques in pineapple cultivation and harvesting tasks. The absence of in-depth research and a nuanced understanding of the practical challenges makes it challenging to formulate effective interventions. Whether they be engineering, socio-technical, or behavioural, addressing the labour-intensive nature of pineapple farming in northeast India and simultaneously improving pineapple production necessitates a thorough investigation into the ground realities faced by the farmers.

1.5 Research Gaps

The literature revealed that in major pineapple-growing countries, pineapple is harvested with heavy machinery such as boom conveyer harvesters. The dimensions of the fields and the topography prevalent in certain countries allow for the utilization of heavy machinery, primarily to collect harvested fruits from the field. However, these machines are limited to gathering fruits after individual chopping is performed manually by field workers. Furthermore, the feasibility of mechanization is contingent upon the field plot's configuration, necessitating well-planned farm roads, headlands, and optimal dimensions for the efficient deployment of machinery systems. The minimum viable acreage for implementation of mechanization in pineapple harvesting process is around 40 hectares under certain assumption (Rukunudin *et al.*, 2011). Some researchers have explored semi-manual and robotic pineapple harvesters as potential solutions to address the challenge of individual pineapple picking. However, these endeavours are largely in the design and experimental stages and have not achieved success at the farm level. While the application of

large machinery or robotic harvesters is feasible in other prominent pineapple-growing countries, it is not applicable in the Indian context, particularly in northeast India. Pineapple harvesting in India still follows the traditional method of manual harvesting by using a sharp knife/sickle/*dao* for plucking individual pineapple fruit.

Further, studies related to ergonomic interventions of pineapple harvesting tasks were also not readily found in the literature, although occupational health and safety-related issues were reported by many such as back pain body strain of farmers (due to awkward postures repetitive tasks) and injuries (due to spines tips of the leaves). So, ergonomic studies on pineapple harvesting tasks also need to be undertaken to assess the prevalence of MSDs and risk factors involved in pineapple harvesting tasks so that the findings and recommendations can be incorporated in design interventions work to improve mechanization and reduce drudgery in pineapple harvesting task. Therefore, there is scope for design interventions with an ergonomics perspective in pineapple harvesting tasks where traditional hand tools are being used resulting in excessive human drudgery, intensive labour, and time consumption. Interventions might necessarily not be with the costly large or automatic equipment but with ergonomically designed tools/equipment suited to local conditions. State-of-art and potential research gaps in pineapple harvesting tasks in northeast India are given in Figure 1.7.

1.6 Research Questions

RQ 1: Who are the pineapple farmers and what are their working conditions?

RQ 2: What are the problems associated with pineapple harvesting tasks in northeast India?

RQ 3: What would be the best feasible solutions for ease and safe pineapple harvesting specifically for pineapple farmers in northeast India?

RQ 4: What would be the strategy of design solutions from an ergonomics perspective for pineapple harvesting adoptable for the needs among pineapple farmers in northeast India?

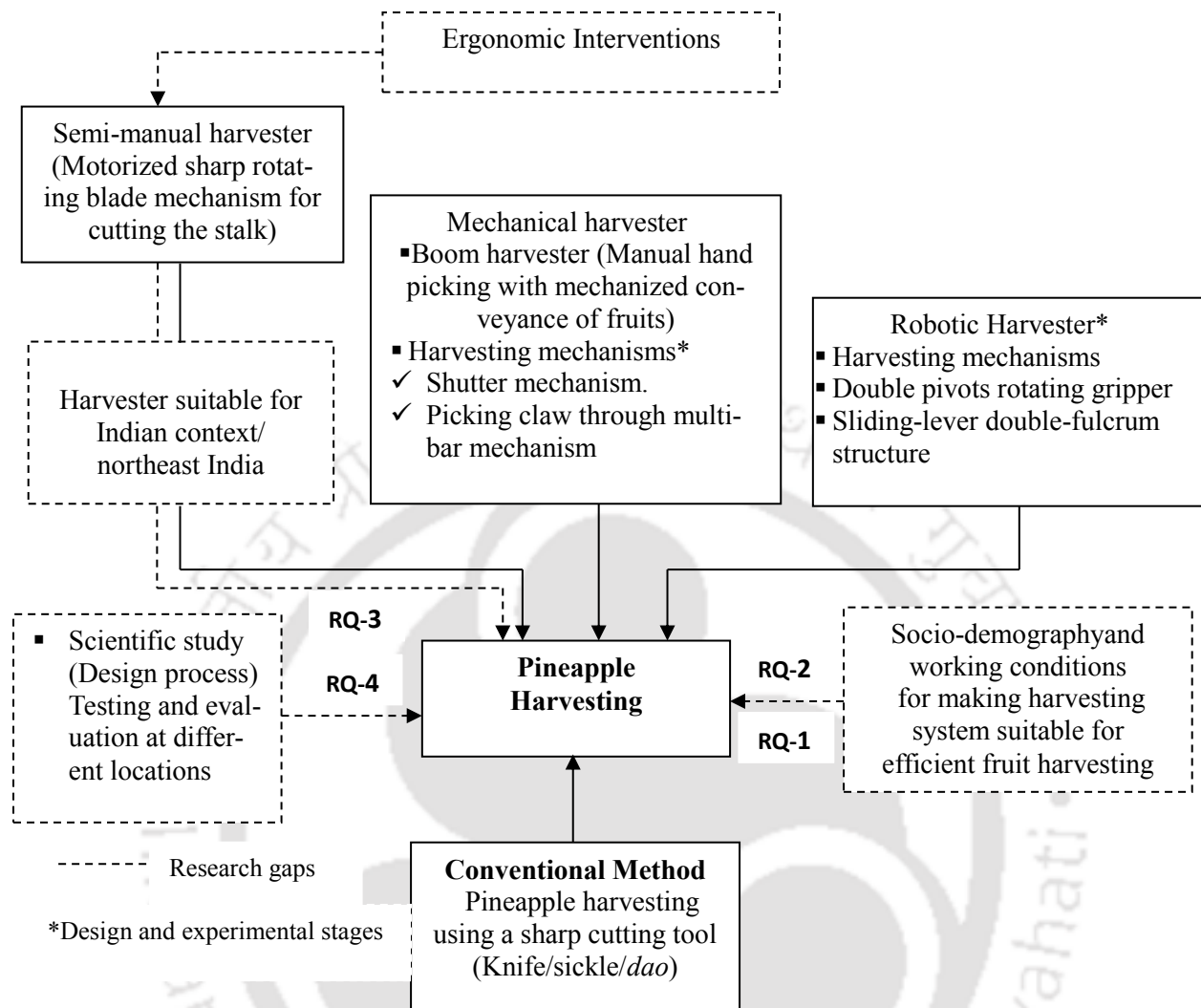


Figure 1.7. State-of-art and potential research gaps in pineapple harvesting task

1.7 Pilot Study

1.7.1 Study area and sampling

This study was carried out at pineapple farms in Manipur covering five villages (Angtha, Tamararam, Karpusungpa, Ngarangphung and Thayong). The selection of villages was based on purposeful sampling to cover villages where most of the villagers were pineapple farmers. The pineapple farmers in a village were then selected based on simple random sampling. Those farmers who were 18 years and above and had at least one year of farming experience in pineapple cultivation were considered. A total of 50 pineapple farmers participated in the study. All participating farmers

signed a written informed consent form before participation, approved by the ethical review board of the Indian Institute of Technology, Guwahati.

1.7.2 Data Collection

Data were collected through an interview schedule and a questionnaire. The interview schedule and questionnaire were administered by interviewing the participants and it consisted of items prevalent harvesting practices, tools/equipment being used (mechanization status), and any other constraints being faced by them in pineapple harvesting tasks and related activities. The survey was followed by direct observation of a subset of the participants (20 pineapple farmers) to explore more and uncover minute details during their work at their respective pineapple farms. The assessment of Musculoskeletal Disorders (MSDs) was conducted through the utilization of the SNQ questionnaire (Kourinka *et al.*, 1987). Prior to participation, each pineapple farmer involved in the study had given their approval and formally consented to their participation by signing a written informed consent. Descriptive statistical methods, including mean \pm standard deviation (SD) and frequency/proportion, were applied to analyse the data obtained from the MSDs assessments.

1.7.3 Prevalent Harvesting Techniques

Harvesting of pineapple fruit took place in June and September (main season) and December February (off-season) for around 8 long months. Before entering the pineapple plantation, farmers adhere to proper attire, including long pants or trousers, full-sleeve shirts, and optionally, hand gloves and jungle boots or water boots. This attire is crucial to prevent injuries caused by the sharp tips of leaves, spines, and prickles on the fruit surface. Once appropriately dressed, farmers sequentially enter the pineapple plantation along the rows to harvest ripe pineapple fruits. Equipped with either a bamboo basket secured over their shoulders or heads or a poly bag/gunny bag, farmers carefully select and harvest ripe fruits one at a time. The harvesting process involves either breaking the fruit by hand or using a cutting tool (Figure 1.8). Subsequently, the freshly harvested fruit is placed inside the bamboo basket or poly bag/gunny bag, and this process is repeated until the container is full of the gathered fruits.

To facilitate transportation, the basket or bag filled with fruits is then emptied at a designated location within the farm (Figure 1.9). This organized approach ensures an efficient and systematic harvesting procedure for ripe pineapple fruits. After that, the farmers enter into the pineapple rows

with empty baskets or bags and repeat the process until they harvest the target number of fruit only to avoid post-harvest losses due to insufficient market infrastructure and limited processing facilities. A farmer can harvest about 150 fruits per hour by traditional method.



Figure 1.8. Pineapple harvesting task



Figure 1.9. Emptying of harvested pineapple fruit at a place within the farm

1.7.4 Hand tools/equipment used

In the pineapple harvesting process, hand tools that have been developed locally and created by local craftsmen are currently in use in northeast India. Farmers have modified some hand tools to fit their tasks. For instance, the handle of the local sickle has been modified into a long handle (65 cm) so that fruit may be harvested effectively without injury from pineapple leaf tips and spines. It was found that there were two broad different types of hand tools being used for harvesting pineapple. They were: sickle (conventional sickle and modified sickle with a long handle); and knife (kitchen knife and carving knife with long handle locally named *Sanggai* in Manipuri). *Sanggai* is a short, sharp-edged slightly curved blade commonly used in valley areas of Manipur. After completion of fruit harvesting, the hand tools were cleaned and kept in proper places (Figure 1.10). Hand tools were never kept in touch with the soil or ground to avoid rusting. Serrated sickle got sharpened once or twice a year from a local artisan @ Rs. 80/- (~0.96 USD). Other tools could be sharpened by farmer themselves at their home using a whetstone as and when needed.



Figure 1.10. Hand tools being used in pineapple harvesting in Manipur

1.7.5 Personal Protective Equipment Used

During the study, the personal protective equipment (PPEs) being used by pineapple farmers were also studied. PPE used included trousers, full sleeve shirts or jackets, hand gloves of length up to the elbow (self-made from old and torn cotton or jeans trousers), and protective footwear (rubber

boot or jungle boot) as shown in Figure 1.11. Many farmers were seen or reported to have harvested pineapple without wearing hand gloves as it hindered them from accomplishing the tasks. There were occurrences of injuries due to perforations by pineapple leaf tips and spines at several body segments during fruit harvesting. So, PPE was found ineffective and failed to achieve worker protection.



Hand gloves used in pineapple harvesting



Protective foot wears used in pineapple harvesting

Figure 1.11. Personal Protective Equipment Used

1.7.6 Local transportation

Pineapple farms are predominantly situated in remote areas, often on hill slopes and foothills. Consequently, farmers are required to either descend or traverse on foot over some distance while carrying the harvested fruits. As a result, the local transportation of harvested pineapple fruits involves two distinct stages. The initial stage of local transportation occurs between the production site and a designated transit location. A transit place may be a farmers' home, village roadsides, state highways, national highways etc. During the harvesting of pineapple fruits by one family member, additional family members, relatives, or friends actively participate in the transportation

process. The harvested fruits, usually stacked at specific locations within the farm, are carried from the production site to a transit location. To cover distances of up to 500-600 meters, individuals employ bamboo baskets secured over their heads or poly bags/gunny bags carried on their shoulders or heads (refer to Figure 1.12). This collaborative effort ensures the efficient and coordinated transfer of the harvested pineapple fruits within the farming community. The cost of transit transportation may be discussed in different ways. One way is helping each other when they harvest and transport from the production area to the local transit location. Another way is by paying the transportation charges @ Rs.1.00/- (~0.012 USD) per fruit and Rs. 2.00/- (~0.024 USD) per fruit at nearby and distant transit locations, respectively.



Figure 1.12. Transportation from the production area to transit location

1.7.7 Prevalence of musculoskeletal Disorders (MSDs)

Out of 50 pineapple farmers who participated in the study, 44 (88 %) of them have an overall prevalence of MSDs. About 37 (74 %), 7 (14%) and 6 (12 %) pineapple farmers complained of MSDs in 2 to 6 body parts, only one body part and no pain/discomfort, respectively. The three most affected body parts were lower back (84 %), neck (48 %) and shoulders (44 %). The prevalence of MSDs among the respondents is tabulated in Table 1.1.

Table 1.1: Distribution of MSDs prevalence among the pineapple farmers during last 12 months

Variables	n=50	
	Frequency	Per cent (%)
Overall MSDs	44	88
No pain/discomfort	6	12
Only one body part	7	14
2-6 body parts	37	74
Neck	24	48
Shoulders	22	44
Elbows	13	26
Wrists/hands	10	20
Upper back	3	6
Lower back	42	84
One or both thighs/hips	8	16
One or both knees	13	26
one or both ankles/feet	6	12
Whole body	0	0

1.8 Problem Statement

Pineapple fruit harvesting with heavy machinery or robotic harvesters is not applicable in the Indian context particularly in northeast India though there is scope for such systems in other major pineapple-growing countries. This is due to topography and attempts of individual pineapple fruit picking using improved lightweight tools or equipment are not successful at the farm level. Therefore, pineapple farmers in India still follow the traditional method of manual harvesting. They do not have adoptable improved tools or equipment for pineapple harvesting tasks. However, the existing traditional method of manual harvesting is not only labour-intensive and time-consuming but, also induces easy injuries to farmers due to spines and sharp leaf tips. The manual method also exposes farmers to occupational health issues (due to awkward working postures, repetitive tasks and heaving lifting work). Though occupational health and safety issues are prevalent, suitable interventions are often not implemented. However, there is very limited literature available on studies such as pineapple harvesting systems (both traditional and improved tools/equipment); prevalence of musculoskeletal disorders (MSDs); and other related problems being faced by pineapple farmers in India and northeast India in particular for harvesting pineapple fruits. Considering the aforesaid observations in mind, the aim and objectives of the proposed study were articulated as given in the following sub-sections.

1.9 Aim

The proposed research work aims to investigate the socio-demography of pineapple farmers, and problems associated with pineapple harvesting tasks and to come up with innovative design solutions adoptable for the needs of pineapple farmers in northeast India.

1.10 Objectives

To achieve the aim of this proposed research work, the following objectives have been laid down:

- i. To assess the socio-demography of pineapple farmers, working conditions, and problems associated with pineapple harvesting tasks in northeast India
- ii. To explore innovative design solutions for ease and safe pineapple harvesting in the context of northeast India
- iii. To develop and evaluate the performance of the prototype pineapple harvester from an ergonomic perspective
- iv. To study the effect of a newly developed pineapple harvester on productivity, efficiency and manual labour

1.11 Research Hypothesis

The equipment which facilitates easy holding of pineapple fruit and allowing cutting from a certain location to avoid awkward working posture and injury from leave tips and spines would significantly reduce drudgery thereby improving productivity and efficiency of pineapple harvesting.

1.12 Research Framework

This thesis has attempted to apply and consider numerous tools, techniques, and theories from a design and ergonomics perspective for design intervention suitable for small and marginal pineapple farmers in hilly areas of northeast India. The research work has been designed as shown in Figure 1.13 to achieve the aim and objectives of this thesis work. The detailed research questions attempted, the objectives of the present study and the scholarly output are disclosed in Table 1.2. The proposed aim of the study was to assess the socio-demography of pineapple farmers, problems associated with pineapple harvesting tasks and to come up with innovative design solutions adoptable for the needs of pineapple farmers in northeast India. A pilot study was also conducted

as a preliminary study to understand the prevalent practices before starting the full-scale field study. This study attempted to find a suitable alternative solution to traditional methods. Therefore, the socio-demography of pineapple farmers and their working conditions were systematically studied, and problems associated with pineapple harvesting tasks in northeast India were identified for necessary design intervention from an ergonomics perspective.

A manual pineapple harvester was designed and developed as per the requirements of the farmers suited to the given local context. Field trials and testing of the newly developed pineapple harvester were carried out for necessary adjustment and design modification. The modified pineapple harvester was evaluated in the farmers' field and compared with the existing traditional method. Various tools and techniques used for assessment were Heart rate monitor, body pain map, Borg's pain scale, REBA, usability index, etc. Thus, the research design can be broadly divided into three phases i.e., i) field study for data collection on the socio-demography of pineapple farmers, prevalent cultivation practices and problems associated with pineapple harvesting task, ii) design intervention of pineapple harvester, and iii) evaluation of the proposed intervention.



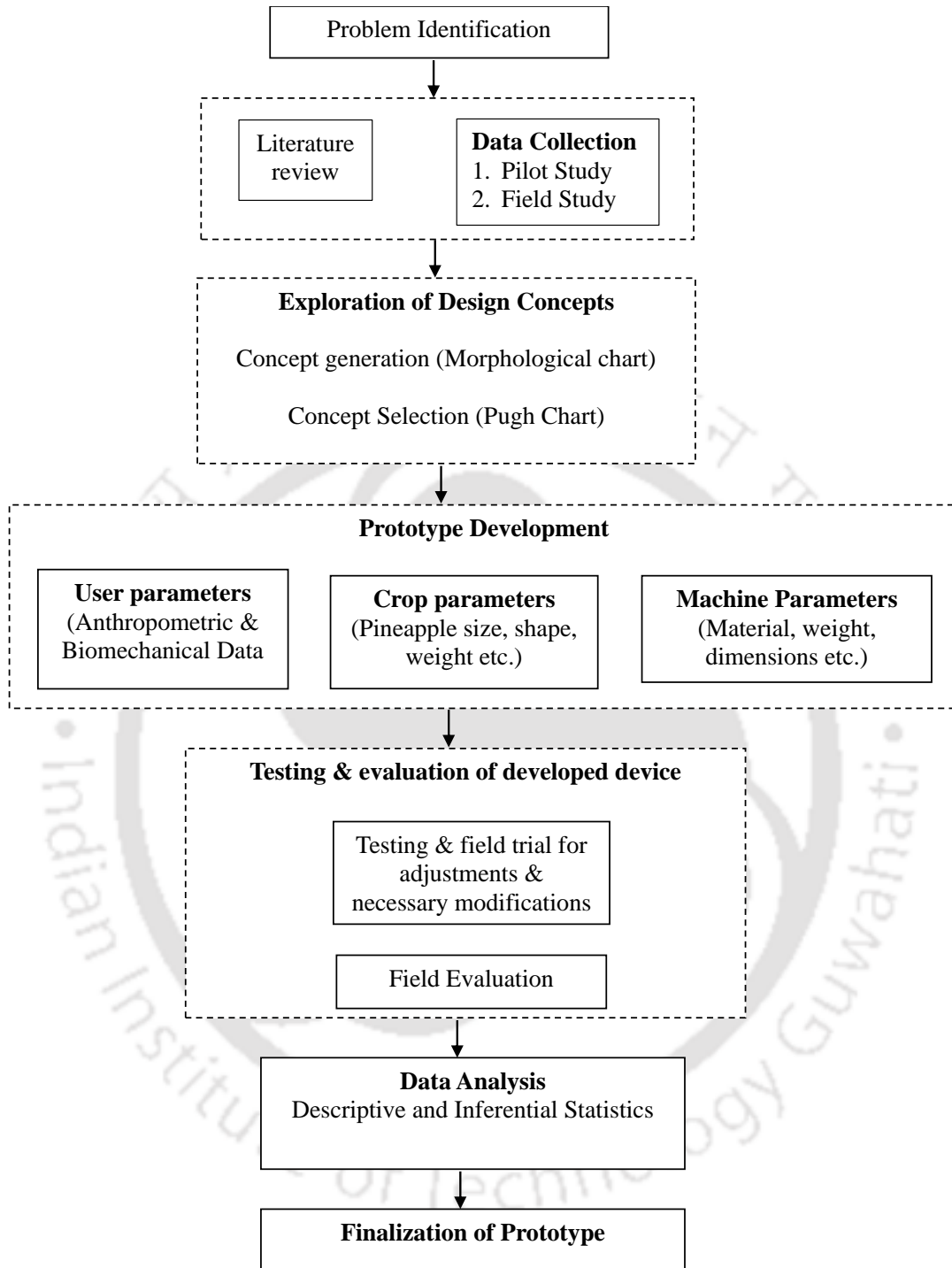


Figure 1.13. Schematic diagram of research design adopted for the present study

Table 1.2. Details of research questions, objectives and scholarly outputs of the present study

Chapters	Research Questions	Objectives	Publications/ Patents/ Design Registrations
2,3, 4	<p>RQ 1: Who are the pineapple farmers and what are their working conditions?</p> <p>RQ 2: What are the problems associated with pineapple harvesting tasks in northeast India?</p>	<p>Objective 1: To assess the socio-demography of pineapple farmers, working conditions, and problems associated with pineapple harvesting tasks in northeast India</p>	<p>Singh, H. J., Singh, H.D., Chauhan, J.S. and Karmakar, S. 2020. Progress on Research and Development in Pineapple Harvesting: Special Emphasis on Indian Scenario. <i>Science and Culture</i>, 86(5-6): 178-187.</p> <p>Singh, H.J. and Karmakar, S. 2022. Socio-demography, working conditions and musculoskeletal ailments among the pineapple farmers in northeast India. <i>Journal of Agromedicine</i>,27(2):245-257. https://doi.org/10.1080/1059924X.2021.1920529</p> <p>Singh, H.J., Chauhan, J.S., Karmakar, S. 2022. Ergonomic Risk Factors Associated with Pineapple Harvesting Task in Northeast India. In: Chakrabarti, D., Karmakar, S., Salve, U.R. (eds) Ergonomics for Design and Innovation. HWWE 2021. Lecture Notes in Networks and Systems, vol 391. Springer, Cham. https://doi.org/10.1007/978-3-030-94277-9_65.</p>
5, 6	<p>RQ 3: What would be the best feasible solutions for ease and safe pineapple harvesting specifically for pineapple farmers in northeast India?</p> <p>RQ 4: What would be the strategy of design solutions from an ergonomics perspective for pineapple harvesting adoptable for the needs among pineapple farmers in northeast India?</p>	<p>Objective 2: To explore innovative design solutions for ease and safe pineapple harvesting in the context of northeast India</p> <p>Objective 3: To develop and evaluate the performance of the prototype pineapple harvester from an ergonomic perspective</p> <p>Objective 4: To study the effect of a newly developed pineapple harvester on productivity, efficiency and manual labour</p>	<p>IIT Guwahati, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. 2021. Hand-held pineapple fruit harvester. Design No: 343374-001 [Granted]</p> <p>IIT Guwahati, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. Hand-held pineapple harvester. Design No.345481-001. [Granted]</p> <p>IIT Guwahati, Singh, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. 2021. Ergonomic pineapple harvester. Design No.346195-001. [Granted]</p> <p>IIT Guwahati, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. 2021. Hand-operated pineapple harvester. Design No: 346209-001. [Granted]</p> <p>Ergonomic pineapple harvesting device for small and marginal farmers [Indian Patent, yet to be filed]</p> <p>Design and development of a pineapple-harvesting device for small farmers of Northeast India: A systematic design process [Yet to be published]</p> <p>Ergonomic evaluation of pineapple harvesting device for small pineapple farmers of Northeast India [Yet to be published]</p>

1.13 Layout of the Thesis

The thesis has been divided into 7 chapters as per the chronology of research work activities undertaken during the research work. A brief description of the chapters is presented below:

Chapter 01: Introduction

Chapter 02: Literature Review

Chapter 03: Socio-demography, working conditions and problems associated in pineapple farming in northeast India

Chapter 04: Ergonomic risk factors among pineapple farmers in northeast India

Chapter 05: Design and development of pineapple harvesting device

Chapter 06: Evaluation of developed pineapple harvesting device

Chapter 07: Summary and Conclusions

The first Chapter of the thesis outlines the background, motivation, and rationale of the research. This chapter is a justification of the research, which establishes the need and requirement for an innovative pineapple harvesting device suited to prevailing local conditions in northeast India. The final section of this chapter explores the various research gaps for posing the specific research questions leading to the aim of the present research, objectives to achieve the aim and hypotheses for this thesis work.

The second Chapter on literature review serves as a critical cornerstone and unveils a meticulous analysis and synthesis of existing research and published materials pertinent to the subject at hand. This chapter functions as a comprehensive map, guiding readers through the evolving landscape of knowledge while highlighting gaps, trends, and key findings within the existing methods of fruit harvesting systems i.e., manual (fruit removal by human hand) and mechanical system (fruit removal by a mechanical machine or mechanism) and occupational health-related problems.

The third Chapter describes the details of the field study conducted on cultivation practices or methods being followed in pineapple production systems that involve the preparation of pits, plantation of suckers, weeding, harvesting of fruits, and transportation of fruits. The chapter also

discusses the sampling plan for field study including sampling technique, study sites and details of subjects.

The fourth Chapter analyses the posture adopted and associated ergonomic risk factors among pineapple farmers in northeast India. This chapter also defines tools and techniques for the assessment of work posture analysis and associated ergonomic risk factors.

The fifth Chapter discusses the development steps of the pineapple harvesting device. In this chapter product design method demonstrated that was used for the development of the pineapple harvesting device. Design exploration and selection of suitable designs using the Pugh chart have been described in this chapter. The chapter also describes the prototype fabrication and development processes of the newly developed pineapple harvesting device.

The sixth Chapter describes the detailed prototype evaluation, observations and results, and discussion of the research work. The workout involved field trials, modification, evaluation and comparison of the ease, safety, comfort, portability, and other advantages of the developed device over the existing ones and traditional methods.

The seventh Chapter highlights the overall summary and discussion of the study. Conclusions based on the salient findings of the study have been placed here. Moreover, the limitations, key findings, and novel contributions along with validation of the hypothesis of the present research are presented.

2 Literature Review

The literature for the present study was gathered using an organized search strategy that combined offline and online electronic searches. Using combinations of the keywords or phrases "fruit picking," "machine fruit harvesting," "pineapple harvesting," and "pineapple cultivation in India," an online electronic search was conducted via Google Scholar, Scopus, and Web of Sciences to find research articles, proceedings, newsletters, reports, etc. During an internet search, combinations of the Boolean functions such as AND, OR, and NOT were used as well between words or phrases to further narrow the results. The website of the Department of Agriculture Cooperation and Farmers Welfare (Govt. of India) and web portals of All India Coordinated Research Projects (AICRP) on Farm Implements and Machinery (FIM) were also visited to collect information on pineapple cultivation and research progress on pineapple harvesting in India. In addition, offline hand searching from hard copies of AICRP project reports for relevant documents was also performed.

The literature screening was based on various inclusion/exclusion criteria (relevancy, originality, English language, year of publication, full text availability, etc.). The present study included publications from 1983 to 2023 (40 years) in the English language only. A total of 97 articles (soft copy) from electronic databases and 3 relevant publications (hardcopy) potentially met the selection criteria. Full texts of the screened articles/reports were read thoroughly; and systematically, segregated and presented under different heads in the following sections. The flowchart of the literature survey process for the inclusion/exclusion of articles, reports, books etc. for the present study is given in Figure 2.1.

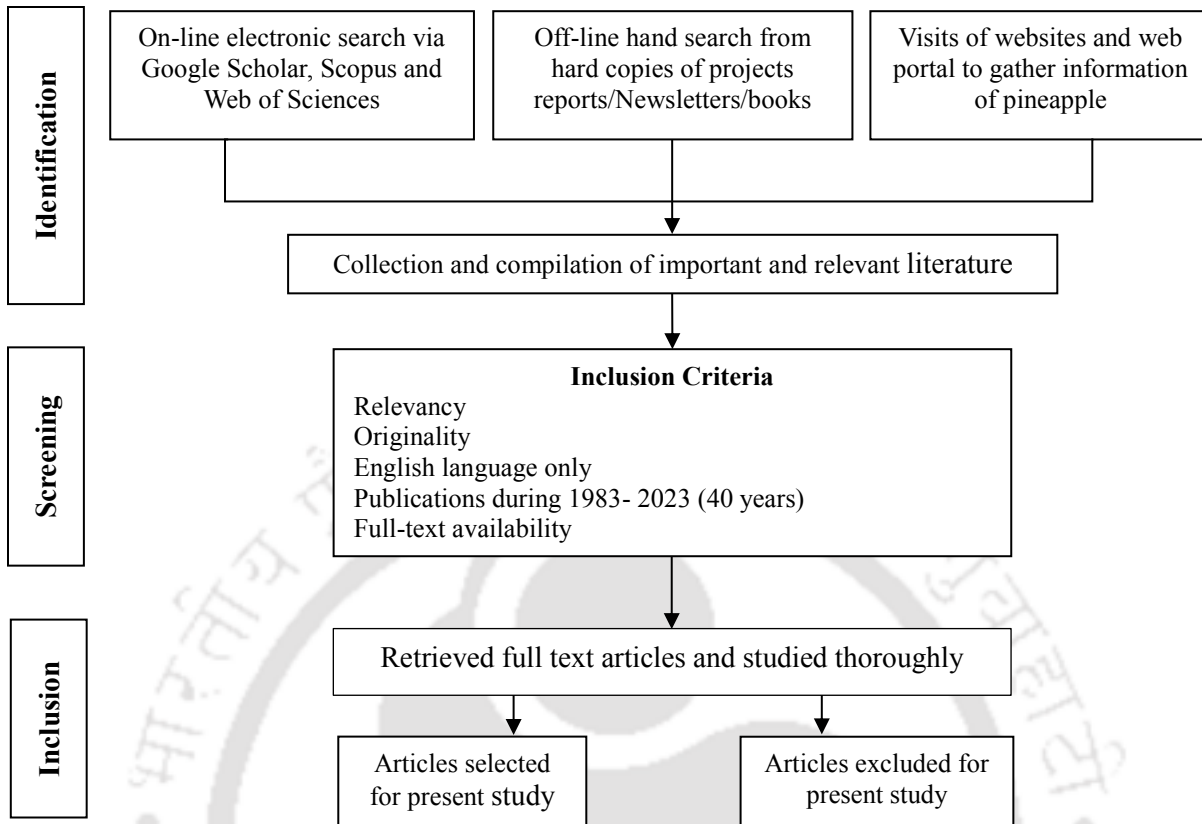


Figure 2.1. Flowchart of literature survey process for inclusion/exclusion of articles

2.1 Fruits Harvesting Systems

Before going to pineapple harvesting, it is important and critical to study the existing fruit harvesting systems that can be adopted for pineapple harvesting. Fruits are not only a vital component of our diets but also contribute significantly to global economies and livelihoods. The traditional methods of fruit harvesting have evolved over centuries, but the modern agricultural landscape demands innovative solutions to meet the growing demand for fruits, reduce labour intensity, minimize waste, and ensure the highest quality produce. Fruit harvesting systems encompass a wide spectrum of methodologies that aim to optimize the harvesting process. These systems not only address the need for increased efficiency but also tackle issues such as labour scarcity, post-harvest losses, and environmental sustainability. From orchards of apples and oranges to vineyards laden with grapes, different fruits demand tailored approaches, prompting the development of diverse harvesting techniques. From traditional hand-picking techniques to automated robotic systems, the evolution of fruit harvesting reflects a dynamic blend of traditional wisdom and cutting-edge engineering. Traditional methods of hand-picking fruits have been the

backbone of agriculture for centuries. However, the advent of automation and robotics has introduced a paradigm shift. Robotic fruit harvesting systems, equipped with computer vision, AI algorithms, and gentle manipulation mechanisms, can detect ripe fruits, delicately detach them from branches, and carefully place them in containers. This not only reduces the reliance on a large labour force but also minimizes the potential for damage during harvest.

Moreover, technological integration extends beyond robotics. Remote sensing technologies, such as drones and satellite imagery, enable farmers to monitor fruit maturity and distribution across vast orchards or fields. This data-driven approach enhances decision-making, allowing for precise timing of harvest to ensure optimal fruit quality and yield. Sustainability is a central consideration in modern agriculture, and fruit harvesting systems are no exception.

However, the adoption of fruit harvesting systems is not without challenges. The initial investment cost, technological learning curves, and compatibility with various fruit varieties pose obstacles for some farmers. Additionally, the balance between efficiency and the preservation of delicate fruits remains a critical aspect of system design. This exploration delves into the multifaceted world of Fruit Harvesting Systems, elucidating the challenges they address, the technologies that underpin them, and the impact they have on the agricultural sector and beyond.

By combining technology, sustainability, and precision, fruit harvesting systems are reshaping the landscape of agriculture, paving the way for a future where the innovation of human engineering enhances the natural abundance of the land. Sanders (2005) broadly categorised fruit harvesting systems by methods of fruit removal. They were manual (fruit removal from tree branch by human hand) and mechanical (fruit removal from tree branch by a mechanical machine or mechanism) harvesting systems. An overview of different harvesters for fruit harvesting is discussed in the following sub-sections.

2.1.1 Manual Fruit Harvesters

In the global arena, India holds the second position in fruit production. The conventional techniques employed for fruit harvesting involve manual plucking or the utilization of a customary harvesting apparatus. There is a potential for the fruit to incur damage during these operations, leading to a diminished yield or financial return. Additionally, the conventional methods are characterized by a time-intensive nature. Manual fruit harvesters are tools designed to aid in the

process of picking fruits from trees or plants. These tools are used to make the harvesting process more efficient and less labour-intensive compared to traditional hand-picking. They are commonly used in agricultural settings where large quantities of fruits need to be harvested in a relatively short period.

Manual harvesters having hold twist type (Agarwal *et al.*, 2003); push cut type (Dixit and Ali, 2017); scissor-type pruning secateurs) (Sabale *et al.*, 2017); scissor-inspired shearing type (Rameez *et al.*, 2018); and cutting/sniping blade type (Sangster *et al.*, 2017) mechanisms were developed and evaluated for harvesting different fruits. Researches were focused on avoiding fruit damage, reducing drudgery, and increasing the efficiency and effectiveness of fruit harvesting for small and marginal farmers (Agrawal *et al.*, 2003). Materials were selected by adopting the weight point method (Rameez *et al.*, 2018); availability in local markets (Dixit and Ali, 2017); and expected prototype properties, design and intended environment (Sangster *et al.*, 2017). Design considerations were ease of use, lightweight, low cost and simple design (Dixit and Ali, 2017; Sangster *et al.*, 2017). Other considerations like anthropometric data of farm workers were reported apart from fruit crop characteristics (Sabale *et al.*, 2017). These harvesters are mostly developed for tall tree fruits, not for fruit crops like pineapple that grows low on the ground. A pineapple-picking device was also created in China based on the structural features of pineapple plants (Qing, 2020). The connecting rod principle was skilfully paired in the design scheme to create a flexible and adaptive mechanical claw mechanism that can pick pineapples of different sizes. This design can help speed up the method of picking, decrease the risk of pineapple leaves cutting the pickers, and increase picking efficiency.

Manual fruit harvesters offer benefits such as increased efficiency, reduced labour costs, and reduced physical strain on workers. However, they might not be suitable for all types of fruits or agricultural setups. Some considerations when using manual fruit harvesters include the type of fruit, the height of the trees, the terrain, and the frequency of harvesting. It is also important to note that while manual fruit harvesters can be effective, technological advancements in automation have also led to the development of robotic and mechanical harvesters that can further increase efficiency and reduce the need for manual labour in large-scale fruit harvesting operations.

2.1.2 Semi-manual Fruit Harvesters

Semi-manual fruit harvesters are tools or machines that combine manual labour with some level of automation to aid in the process of harvesting fruits. These tools are designed to enhance efficiency, reduce labour requirements, and speed up the harvesting process while still maintaining a certain level of human control and precision. Semi-manual harvesters comprise hand tools where cutting mechanisms are not actuated by human power but by some other power source. Design considerations are more or less similar to manual harvesters. The attempts had been to make available simple in design, low cost, flexible, easy, and safe, and effective harvesters suitable for home gardens and small farms (Al-Widyan *et al.*, 2006). Jhala *et al.*, (2018) reported that the problems and limitations of manual harvesting by hand picking and manual harvesters (fruit damage, time-consuming effort in operation) were addressed by semi-manual harvesters and ergonomically safe harvesters for long-duration operation as fruit picking mechanisms were actuated by the electrical power source. These harvesters having cutting mechanisms actuated by battery-operated motors for different fruits have been developed and evaluated globally (Table 2.1).

Table 2.1. Reported fruit picking mechanisms of semi-manual harvesters

Researchers	Target Fruit	Country	Picking Mechanism
Al-Widyan <i>et al.</i> (2006)	Picking tree-top and high-to-reach fruits	Jordan	Pruner (cutter) and DC motor-driven extension mechanism
Hamam <i>et al.</i> (2011a)	Peach	Egypt	Electrical picking hook electrical picking holder type
Hamam <i>et al.</i> (2011b)	Washingtonia, valencia, mandarin lemon	Egypt	Rotary cone electrical scissors harvesting heads
Dress and Ibrahim (2017)	Prickly Pear	Libya	Motor actuated scissor type cutter producing reciprocating motion /manual
Dixit and Ali (2017)	Apple	India	Clutch lever mechanism and head with a flexible basket for fruit collection

Sabale <i>et al.</i> (2017)	Orange	India	<ul style="list-style-type: none"> ▪ Pruning secateurs as a cutting mechanism fitted at one end of an extension pipe (telescopic pipe) ▪ Micro camera fitted behind the cutting mechanism to locate the fruits
Jhala <i>et al.</i> (2018)	Mango	India	Motor operated circular blade for cutting

Al-Widyan *et al.* (2006) designed and built a customizable fruit picker for collecting fruits from trees that are located higher up and difficult to reach. It weighed 5 kg and effectively harvested fruits from numerous common tree species. Initial field testing showed that it could effectively regulate height with simple components. At about 100 USD, the gadget was affordable and offered an environmentally responsible way to reduce fruit waste and injuries resulting from traditional methods of harvesting. Furthermore, by attaching the proper accessories, it may be used for a variety of jobs, including spraying and pruning.

Due to low productivity and poor fruit quality, Hamam *et al.* (2011a) found that traditional hand harvesting practises involving hooks and manual picking still pose substantial obstacles for Egyptian peach growers. Two affordable mechanical harvesting prototypes (an electric picking hook and holder) were made for delicate fruit collection in order to address this. Experiments were carried out at private farms in the Egyptian regions of EL-Arish and Meet-Ghamr during the peach seasons of 2007 and 2008. In comparison to the electric holder, manual hook, and hand picking, it was discovered that the electric picking hook increased picker productivity by 91.32%, 146.92%, and 46.30%. This resulted in 47.73%, 62.29%, and 41.38% cheaper harvesting costs (average percentages for different peach types). Furthermore, compared to other methods, electric hook produced the lowest rates of bruising (3.0%) and damage (1.0%), with 96.0% of good quality fruit (Grade I). It was advised to manufacture the electric picking hook locally and use it to increase output, cut expenses, and enhance fruit quality, which would benefit both domestic and international markets and raise national income.

Additionally, Hamam *et al.* (2011b) planned, produced, and assessed two prototypes to improve

citrus fruit harvesting. A variety of skilled labourers evaluated the second prototype, an electrical scissors harvesting head, while the first, a rotary harvesting head, was tested with various cone types and rotational speeds. The productivity of Washingtonia and Valencia oranges was increased from 0.111/0.084 ton/h (traditional) to 0.208/0.154 ton/h by using rotary cone type IV (metal cone with rubber inner surface, no upper edge) at 600 rpm. This resulted in a decrease in Grade IV damage (1.20-4.31%) and an increase in Grade I fruits (65.96-73.01%) while maintaining fruit quality. Additionally, the productivity of Washingtonia, Valencia, Mandarin, and Lemon fruits was enhanced by the electrical scissors head. Additionally, productivity was found to have increased from the traditional 0.111/0.084/0.053/0.013 ton/h to 0.153/0.129/0.084/0.016 ton/h. Furthermore, there were lower percentages of damaged fruit (1.97-6.71%) and higher percentages of Grade I fruit (twig length < 0.5 cm) (43.35-23.00%). When compared to traditional methods, mechanical harvesting decreased costs by 25.85-59.58% (Washingtonia) and 53.00-67.99% (Valencia). To lower harvesting costs and the risks connected with using conventional methods, the researchers also recommended manufacturing and using these harvesting heads locally. This would boost productivity, exports, and farmer income.

A height-adjustable fruit picker was created as a creative way to reduce the tiresome nature of traditional fruit picking (Dixit and Ali, 2017). This simple yet incredibly efficient tool has a cutting mechanism, an extension mechanism, a clutch wire, a flexible basket-equipped head for collecting fruits, and a clutch lever. The device demonstrates its effectiveness by reaching heights of 5–6 metres and weighing only 1480 grams (including the handle). The fruit picker performed admirably in real-world tests. Pear harvesting produced 45–55 kg/h, while apple picking produced 55–65 kg/h. Remarkably, very little damage happened during the picking process, highlighting the meticulous design of the apparatus. This invention was reasonably priced at Rs. 750, so even small-scale orchard owners in the region could afford it.

Dress and Ibrahim (2017) designed, built, and assessed a mobile mechanical harvesting device for prickly pear fruits. The inefficiency of hand harvesting prickly pear fruits stemmed from their slowness, high cost, and difficult field conditions. For inexperienced workers, the plant's thorns and the fruit's detachable microscopic hairs can be dangerous and discouraging. The machine was designed with important fruit properties in mind, and its performance was evaluated at various power sources and speeds. The machine lowered energy consumption by 13.28 times, reduced

fruit damage by 42.4%, increased productivity by 171.4%, and decreased picking costs by 29.8% when compared to manual picking. An ergonomic manual harvesting system was developed which had a mounted harvester with a micro camera display to reduce stress, and an adjustable aluminium tripod (Sabale *et al.*, 2017). In tests, the improved system performed significantly better than the conventional techniques, with harvest rates of 37.12-45.70 kg/h compared to 49.26-64.12 kg/h and significantly less fruit damage (14% compared to minimal). The invention increased productivity and lessened labourer stress.

To address the challenges and limitations inherent in the manual harvesting methodology, a novel battery-operated harvesting mechanism was conceptualized and developed (Jhala *et al.*, 2018). This innovative tool includes a lightweight pole, conveyor assembly, 12V DC battery, high-speed DC motor, galvanized iron blade, integrated 2-megapixel camera, 7-inch display, and control switch. The main goal was to enhance efficiency and operator comfort. The camera and display eliminated the need for constant upward gaze, streamlining harvesting. The circular blade attached to the motor facilitated easy cutting. The battery-operated harvester significantly outperformed manual methods, achieving around 350 fruits per hour, boosting productivity. This advancement addresses traditional challenges, improving efficiency and operator ease, marking a noteworthy achievement in mango harvesting technology.

Semi-manual fruit harvesters aim to strike a balance between the advantages of automation and the need for human oversight and control. They can improve efficiency, reduce physical strain on workers, and potentially enhance the quality of harvested fruits by minimizing damage during the harvesting process. It is also worth noting that the design and capabilities of semi-manual fruit harvesters can vary widely based on the type of fruit, the orchard layout, the level of automation, and other factors. The goal is to leverage technology to streamline the harvest while still maintaining the skills and judgment of human workers.

2.1.3 Mechanical Fruit Harvester

A mechanical fruit harvester is a machine designed to automate the process of harvesting fruits from trees or plants. These machines are developed to increase efficiency, reduce labour costs, and accelerate the harvesting process in large-scale agricultural operations. Mechanical fruit harvesters

are particularly valuable when dealing with crops that require a significant amount of labour for manual harvesting, such as tree fruits (like apples, pears, and peaches) and berries (like strawberries and blueberries). The mechanical harvesting techniques are trunk shaking, air shaking, canopy shaking, limb shaking, and the use of an abscission chemical agent to loosen the fruits (Sanders, 2005; Torregrosa *et al.*, 2009; Li *et al.*, 2011). Researchers have also reported pneumatic cut-clamp litchi picking (Liu *et al.* 2011); self-propel shaker, mechanical beater with a catching frame (reversed umbrella) for olive (Famiani *et al.*, 2014); lateral canopy shaker for olive harvesting (Sola-Guirado *et al.*, 2016); tractor operated trunk shaker for almond harvesting (Pascuzzi and Santoro, 2017); mobile platform for orange harvesting (Feirara *et al.*, 2018) and motorized variable length plucking/cutting machine for coconut (Kemparaju *et al.*, 2017).

It is also reported that major pineapple-growing nations including Malaysia, the Philippines, Thailand, Costa Rica, and Indonesia use heavy machinery like boom harvesters to speed up the pineapple harvesting process (Rukunudin *et al.*, 2011; Joy and Rashida, 2016). However, a group of field workers manually chopped the fruits from the plants, and a boom harvester was used only to mechanically gather the chopped fruits onto a collecting trailer that was positioned on the farm road. A minimum of 40 hectares of land were needed to perform mechanized field operations. To ensure effective and efficient usage of machinery systems, the orchard environment must also be appropriately configured to meet the needs of the harvesting system (Rukunudin *et al.*, 2011; Li *et al.*, 2011). Burks *et al.* (2005) also highlighted the major aspects of cultural practices (field conditions, plant population and spacing, and plant shape and size) that affected the mechanical harvesting of fruits.

For individual pineapple fruit picking, Wang *et al.* (2018) designed a structure for individual pineapple picking mechanisms based on the principle of shutter mechanism to achieve the purpose of picking pineapples of different sizes. Zhang *et al.* (2018) also designed a structure of a semi-automatic pineapple-picking machine. The harvester consists of a picking (picking claw through a multi-bar mechanism), a lifting part, a conveying part, and a collecting part. However, research on pineapple fruit picking is mostly in the design and experimental stages. Mechanical fruit harvesters have several advantages, including increased efficiency, reduced labour costs, and the ability to harvest large quantities of fruits in a shorter amount of time. However, they also require careful

management and maintenance to ensure that the machinery is operating effectively and that the harvested produce meets quality standards. The choice of a specific mechanical fruit harvester depends on factors such as the type of fruit, orchard layout, terrain, and the scale of the operation. While these machines can significantly improve harvesting efficiency, there are still situations where manual or semi-manual harvesting methods are more appropriate.

2.1.4 Robotic Fruit Harvester

A robotic fruit harvester is an advanced automation technology that uses robotics, artificial intelligence, and computer vision to identify, assess, and harvest ripe fruits from trees or plants. These robots are designed to perform tasks traditionally carried out by human labour, offering increased efficiency, precision, and the potential to reduce labour costs and post-harvest losses. Robotic fruit harvesters are particularly valuable for crops that are labour-intensive to pick, such as tree fruits and berries. Robotic fruit harvesters are equipped with cameras, sensors, and other detection technologies that allow them to identify ripe fruits based on colour, size, shape, and other visual cues. Some advanced systems can even detect fruit quality indicators, such as sugar content or firmness. These robots are often equipped with robotic arms or manipulators that replicate the movement of a human arm. These arms are designed to delicately reach and pick the fruit without damaging it or the tree. Robotic fruit harvesters utilize specialized gripping mechanisms to gently detach the fruit from the tree while minimizing bruising or damage. These mechanisms can include soft paddles, suction cups, or grippers with adjustable pressure. Depending on the orchard layout, robotic harvesters may be mounted on tracks, wheels, or even aerial platforms (drones) to navigate through rows of trees or plants. The robots use AI algorithms to process the information gathered by their sensors and cameras in real-time. This enables them to make decisions about which fruits to harvest and how to approach each fruit. Advanced robotic systems are capable of selectively harvesting only ripe fruits while leaving unripe ones on the tree. This helps maintain product quality and reduce post-harvest sorting. Robotic harvesters can also collect data about the health of the plants, the yield, and other relevant agricultural information. This data can be valuable for optimizing crop management practices. Once harvested, the fruits are usually transported to a sorting and packaging system where they can be further processed, sorted, and packed for distribution.

In robotic fruit harvesting, the main tasks are the detection of fruit location, gripping and picking. Researchers have reported robotic harvesting of apples (De-an *et al.*, 2011; Silwal *et al.*, 2017); citrus fruits (Ceres *et al.* 1998; Li *et al.*, 2011); sweet pepper under protected cropping systems (Lehnert *et al.*, 2017); tomatoes (Feng *et al.*, 2015); strawberry (Feng *et al.*, 2012); spherical fruits (Liu *et al.*, 2007); and coconut (Mohanraj *et al.* 2014; Mani Jothilingam, 2014; Abraham *et al.*, 2014; Senthil Kumar *et al.*, 2015; Lalitha *et al.*, 2015); and pineapple (Xia *et al.*, 2011; Wang *et al.*, 2012; Xia *et al.* 2012). Fruit detachment mechanisms used were an arm with a circular saw (common for coconut), oscillating blade, electric cutter, screwing operation, grasping and laser cutting device. Burks *et al.* (2005) also highlighted that the reason for the lack of success of robotic harvesting was due to technical, economical, horticultural (crop-specific biological systems), and producer acceptance issues.

At this point, research on mechanical pineapple harvesting is just getting started. Some researchers (mostly from China) have initiated works on robotics in pineapple harvesting. Pineapple harvesting manipulator (comprising of grabbing mechanism, hand driving mechanism, and rotating mechanism) (Xia *et al.*, 2011; Wang *et al.*, 2012) and pineapple picking end-actuator (sliding-lever double-fulcrum structure suitable for pineapple fruit clamping) (Xia *et al.* (2012) were designed and tested. Pineapple fruit parameters such as physical (size, shape and weight) and mechanical (compressive-deformation characteristics) properties dependent on factors like fruit maturity stage and variety are critical for the design of high clamping accuracy and no damage picking end-actuator. Information on physical and mechanical properties is important and essential in the design process of machines (Ardebili *et al.*, 2012; Shahbazi and Nazari Galedar, 2012). Further, Liu *et al.* (2022) also studied to provide an approach and design for a roller pineapple harvester with multiple flexible fingers. The evaluation function for the critical damage condition of the fruit was also established based on the mechanical and physical properties of pineapples. The ideal parameters for pineapple harvesting were determined by our experimental results: the harvesting mechanism's rollers should be inclined at a 35° angle; the left flexible fingers should measure 120 mm in length, with a 30 mm gap between each one; the right flexible fingers should measure 150 mm in length, with a 10 mm gap between each one. In the laboratory, the rate of harvesting was 85%, while the rate of damage was 5%. In the natural environment, these figures were 78% and 8%, respectively, and the rate of harvesting was approximately one second per fruit. These results showed that the harvesting machinery was able to adequately meet the demands of pineapple

harvesting. Mismatched flexible finger length, fruit size, and harvesting posture and position were the main causes of harvesting failure in unsuccessful cases. However, there are also challenges associated with robotic fruit harvesting, such as the need for sophisticated algorithms, the adaptability to different fruit varieties, and the potential complexity of operating in diverse environments. Overall, robotic fruit harvesters represent a cutting-edge solution that has the potential to revolutionize fruit harvesting by enhancing efficiency, improving product quality, and reducing the labour-intensive nature of the process.

2.2 Work Related to Pineapple Harvesting Task in India

A study was reported on the mechanization of pineapple cultivation in the NEH region of India during 2016-17 (Anon, 2017b). The study revealed that all the farmers were using locally made hand tools in Meghalaya and other neighbouring pineapple-growing states of the NEH region. Among various cultivation operations, weeding and harvesting were two major operations, which require a higher amount of manual energy. To address the issues of manual pineapple harvesting, a semi-manual pineapple harvester was developed and evaluated at CAU Imphal (Singh *et al.*, 2014). The harvester consisted of a sharp serrated rotating blade powered by a petrol engine; and a lever-operated finger to hold the fruit after cutting from the stalk. The harvester could harvest about 250 to 280 per hour without much drudgery and fatigue as compared to 150 fruits that can be harvested by conventional method.

A prototype of a semi-automatic pineapple harvester consisting of a grabbing unit with a linear actuator, cutting unit (cutting blade and DC motor), handle, and battery was designed and developed (Singh, *et al.*, 2022). The harvester was powered by a 12V 7Ah lead acid battery. The overall weight of the harvester was found to be 3.5 kg. In northeast India, pineapple is cultivated on hill slopes. Therefore, farmers have to go uphill and downhill with baskets on their backs to harvest and collect the harvested fruits. Therefore, it would be very difficult to carry this device (3.5 kg excluding fruit) by one hand to operate and collect the fruit by another hand of the same person. The pineapple fruit has an average weight of 1.12 kg. So, the farmer has to hold a total weight of 4.62 kg in one hand. Moreover, this device would not be possible to harvest the lodged crop.

2.3 Ergonomics Investigations in Pineapple Harvesting Task

Pineapple plant grows with a maximum height of 1.5 meters from the ground (Salleh and Sukadarin, 2018b). Therefore, pineapple farmers have to be in positions which are defined as awkward postures for different field operations such as cultivating, weeding, harvesting and preparation which lead to pain and discomfort in many body parts (Tamrin and Razak, 2014). Therefore, ergonomics investigations in pineapple harvesting tasks were needed to study the interaction between workers, the tools they use, and the work environment to ensure that the work is efficient and safe and minimizes the risk of injuries or musculoskeletal disorders. Farm activity like pineapple harvesting can be physically demanding, and applying ergonomic principles can help improve worker well-being and productivity.

A study was conducted to determine the prevalence of musculoskeletal disorders (MSDs), analyse the body's postural risks related to work tasks and identify relevant MSDs risk factors among pineapple plantation workers in Johor, Malaysia (Rani *et al.*, 2016). The study revealed that there was 87 % prevalence of MSDs and the highest for the lower back (64.8%). Also, harvesting was the task with the highest risk among field operations. The prominent risk factors identified were high exertion force, highly repetitive hand motion and prolonged stooping with cutting and collecting, and heavy & awkward lifting for transportation to pack house (Salleh and Sukadarin, 2018b). Moreover, the harvesting task was found to be the most risky in terms of health hazards and safety issues (Rani *et al.*, 2016). Another study from certain regions of Malaysia reported work related to ergonomic risks and musculoskeletal disorders (MSDs) in pineapple harvesting tasks (Mezlan *et al.*, 2019). To potentially lessen discomfort and physiological workload during a simulation of harvesting activity, an intervention study developed and tested a prototype of an ergonomic harvesting basket. The upgraded basket featured foam padding for the back, movable straps for the straps, and a fruit-unloading aperture. Human subjects were used to simulate harvesting with an improved and pre-existing basket, and discomfort was measured with questionnaires. Heart rate and energy expenditure were used to measure physiological workload. Twelve male respondents in all, ages averaging 22.4 (2.2) years, took part in the harvesting simulation. The improved basket's mean (standard deviation) was 4.13 (6.1) compared to the existing basket's 12.26 (11.2); $p < 0.05$) showing a significant decrease in discomfort. The mean heart rate increased from 89.05 to 94.13 beats per minute, and the energy expenditure increased from 5 to 6 kJ per minute. The overall workload and level of discomfort were found to decrease

with the use of the upgraded basket. Enhancing the design of agricultural hand tools could potentially enhance worker health and prevent MSDs. Future production of the enhanced basket using lightweight materials could be extended beyond the pineapple plantation industry in Malaysia and throughout Asia.

Occupational hazards due to manual labour, repetitive tasks, and use of improper tools and techniques have also been reported for Malaysian oil palm fruit harvesters (Ng *et al.*, 2015), Sri Lankan rubber tappers (Stankevitz *et al.*, 2016), Latino sweet potato farmworkers (Kearney *et al.*, 2016), Indian manual-working rice farmers (Jain *et al.*, 2018a 2018b; Ojha *et al.*, 2016), Cambodian fruit farm workers (Thetkathuek *et al.*, 2018), Iranian apple harvesting labourers (Houshyar and Kim, 2018), Brazilian banana harvesting workers (Merino *et al.*, 2019), and labour-intensive agricultural workers in general (Fathallah *et al.*, 2010; Koekoeh *et al.*, 2016; Dianat *et al.*, 2020; Ojha *et al.*, 2018). Some researchers also reported on the effectiveness of personal protective equipment (PPEs) commonly used by rural workers for pineapple farm workers (Gonzaga *et al.*, 2016 and Abrahão *et al.*, 2017). The study results highlighted that most of them were considered obstructive to task execution and so, the need for the conception of PPEs especially designed for pineapple farmers. Therefore, the pineapple cultivation process involves several ergonomic stressors. Despite the potential risks associated with Musculoskeletal Disorders (MSDs), there is a notable absence of prior studies documenting the prevalence of MSDs or the correlated risk factors among pineapple farmers in India, especially in the northeastern region. Additionally, it is acknowledged that both the working environment and socio-economic factors play a significant role in influencing the adoption and transfer of agricultural technologies (Lestrelin *et al.*, 2012). The socio-economic conditions of farmers are intricately linked to their diverse socio-demographic characteristics. The various activities, be they farming or non-farming, undertaken by an individual are closely associated with their socio-economic status (Ganesh *et al.*, 2007). Recognizing these factors is crucial for a comprehensive understanding of the challenges faced by pineapple farmers and for developing targeted interventions to improve their working conditions and overall well-being.

2.4 Ergonomics Considerations in Hand Tool Design

The study of ergonomics, which focuses on developing tools and systems that maximize human performance and well-being, is essential to the creation of numerous items, including hand tools. For an array of tasks, including agricultural work, hand tools are important. Ergonomics-focused

hand tool design not only enhances user comfort but also makes a major contribution to overall productivity, safety, and user happiness. A thorough grasp of human anatomy, biomechanics, and cognitive processes is necessary for integrating ergonomic concepts into the design of hand tools. Hand tool designers may produce effective, secure, and comfortable instruments that are easy to use for lengthy periods by designing them in accordance with the inherent strengths and limits of the human body. The reduction of physical strain on users during operation is one of the main objectives of ergonomics in hand tool design. Over time, musculoskeletal diseases and muscular fatigue can be brought on by awkward postures, overuse of force, and repetitive actions. To create tools that promote neutral, natural postures, designers must carefully analyze the range of motion needed for tool use. This lessens the cumulative effects of extended tool use on the user's body in addition to preventing immediate discomfort.

User comfort and control are significantly impacted by the way a tool's handle is designed. An ergonomic handle should be easy for the user to grasp and provide a firm hold without putting undue strain on the fingers or palm. The shape, size, material, and texture of the handle are some of the factors that affect how useful the tool is overall. Designers frequently use non-slip surfaces and curved curves in their designs to guarantee a secure hold and lessen the possibility of unintentional falls or slides. Furthermore, employing force when using hand tools is typical, but if it's not managed properly, it might cause strain and tiredness. Designing ergonomic hand tools includes giving the user feedback and maximizing force transmission. Overexertion is reduced when tools enable users to apply force using their stronger muscle groups or body mechanics. As a result, adding ergonomics into the design of hand tools has an immediate influence on productivity, safety, and user experience in addition to aesthetics. A well-made hand tool reduces physical strain while simultaneously improving the user's capacity for correct and timely work completion. The significance of ergonomics in hand tool design is growing as industries develop, ultimately leading to a more salubrious and efficient work environment.

Human-machine interaction is heavily influenced by anthropometric body measurements. When utilizing farm equipment and tools in hilly terrain, the overall effectiveness of the human-machine environment and the discomfort that follows have a significant impact. Hand anthropometry for hand tool design needs to take into account different hand measurements for male and female

subjects at different percentiles (5th, 50th, and 95th). Gender differences in hand dimensions include variations in both size and toughness. According to research by Fransson and Winkel (1991), differences in hand dimensions may account for 35% of the variation in hand hardness between sexes. Workers should have handles of different sizes to accommodate different hand anthropometry. Larger handles accommodate males falling within the 50th to 95th percentile range, while smaller handles are suitable for females within the 5th to 95th percentile range.

Roughly 90% of people are right-handed, a proportion that is constant across genders and social classes. It is noteworthy that non-dominant hands (Konz, 1995) retain 94% of the grip strength of the dominant hand. Notably, Chakrabarti (1997) assembled anthropometric data for both genders from various locations of India, using a sample size of 961, and made a significant contribution to the nation's ergonomic design standards. Chakrabarti's data included hand measurements for male and female populations at the 5th, 50th, and 95th percentiles. Agrawal (2010) examined 1027 subjects—566 men and 461 women—to get anthropometric data about the agricultural labourers in Meghalaya, northeast India. This information would be used to develop or alter better tools and technology that would be appropriate for the region's residents.

2.4.1 Hand Grips

Depending on the ergonomics of the hand tool and the user's posture, different grip styles are used when handling objects. The power grip, which is comparable to grasping a hammer in that the fingers surround the object and the thumb rests on top, is frequently employed. The thumb is positioned on the first finger for tools such as medium to big screwdrivers and hacksaws. Power tools are the main tool utilized with this grip. According to Mital and Kilbom (1992), it is advised that tools be made with a weight of roughly 1.1 kg, not to exceed 2.3 kg. A different type of grip is the lateral grasp, which involves holding the object between the thumb and the first finger's side.

2.4.2 Handle Length

The length of the handle depends on the end-user population and the style of grip utilized. It is advised that the handle length be at least 10 cm, but 12.5 cm is more comfortable. Precision grips are suited for the 10 cm length. The handle should just barely extend past the palm in precision

grasps so as not to obstruct the wrist. To avoid the handle digging into the palm, a length of 12.5 cm is advised, with an extra 1.25 cm for gloves (Selan, 1994). Skin shear stress and abrasion are decreased by optimizing the hand/handle contact area during design. Dewangan (2008) added that the handle's length ought to allow for the thumb's maximal hand width. The dimension mentioned above has a 95th percentile value of 9.8 cm. The length of the handle is 10.8 cm when 0.5 cm is allowed on either side of the grip; this value is advised for the handle's length.

2.4.3 Handle Diameter

When designing a handle tool, handle size is quite important. An excessively large handle diameter may cause fingertip pressure to surpass the pressure applied by the base of the fingers, hence elevating tendon pressure and causing tiredness in the muscles (Kroemer *et al.*, 1994). On the other side, an inadequate handle constricts the finger flexor muscles, making it more difficult for them to produce enough tension and pressure. For both genders, the ideal handle size is around 4.1 cm in diameter (calculated using a circumference of 13.0 cm). Based on real-world experience, it is recommended in a range of 3.0-4.0 cm for power grips and 0.8-1.6 cm for precision grips, with 1.2 cm being preferred (Anon, 1983).

In hill agriculture, a significant portion of tools is operated manually, requiring a precise grip to effectively apply force during their usage (Agrawal *et al.*, 2010). It is essential to reassess the dimensions of the grip for various hand tools like dao, spade, sickle, and handles of wheel hoes based on anthropometric measurements. An investigation conducted on male and female agricultural workers from Meghalaya depicted that the grip diameter (inside) at the 5th, 50th, and 95th percentiles for males were 3.7 cm, 4.2 cm, and 4.7 cm, respectively, while for females, the corresponding values were 3.3 cm, 3.6 cm, and 4.1 cm. To ensure comfortable handling, the grip design should allow a person with the 5th percentile body dimensions to securely grasp the handle. Consequently, the recommended minimum grip diameter is 3.7 cm for males and 3.3 cm for tools operated by female workers.

A study by Dewangan *et al.* (2008) centred on the anthropometric analysis of female agricultural workers in northeastern India and its implications for the design of agricultural tools and equipment. To enhance grip, the diameter of the handle should not surpass the internal grip diameter of

the operator. Consequently, the handle diameter should align with the 5th percentile value of the internal grip diameter to accommodate a broader range of the population, which is 3.82 cm for female workers. Considering an ergonomic evaluation of various hand tools alongside household appliances for both men and women, Nag *et al.* (1980) deduced that the handle's diameter should slightly be less than the internal grip diameter to facilitate a comfortable grip. Therefore, the recommended handle diameter for female farmers is 3.32 cm (Dewangan, 2008).

Similarly, Dewangan *et al.* (2010) examined the impact of male agricultural labourers in north-eastern India on the development of agricultural machinery and tools. According to their research, the handle's diameter should be made such that, when grasping it, the operator's longest finger stays outside of the grip diameter without touching the palm. As a result, the optimal handle diameter falls between 3.1 and 4.2 cm, where 3.1 cm is the middle finger palm grip diameter's 95th percentile value and 4.2 cm is the interior grip diameter's 5th percentile value.

2.4.4 Handle Shape

Power grip effectiveness is greatly influenced by handle form, where maximum surface contact reduces hand force per unit area. Increased torque may result from handles with a circular cross-section. Counter-torque can be used to prevent the user's hand from rotating the handle. It's also important to optimize the coefficient of friction of the handle. Rectangular handles with a height-to-thickness ratio of 1 to 1.25 are appropriate for combined orthogonal pushing and pulling operations because they accommodate the convex surface of the thumb and heel of the hand (Selan, 1994). Power grips are made easier by some curvature, particularly when the instrument extends from the top of the hand. The form of a tool directly affects a person's capacity to hold something firmly. By bending the instrument, one can get a neutral wrist position that improves grip strength (Konz, 1995).

2.4.5 Handle Holding Height

The appropriate height for holding a handle relies on the elbow height of the population and the permissible range of elbow angles. According to insights from Grandjean (1988), a comfortable elbow angle range falls within 100-110 degrees. Analyzing the standing elbow height of male and

female agricultural workers in Meghalaya, it was observed that the measurements for the 5th, 50th, and 95th percentiles for males were 94.7 cm, 101.6 cm, and 107.6 cm, respectively. For females, the corresponding figures were 90.6 cm, 96.1 cm, and 101.2 cm. Utilizing the known elbow grip length, the handle's height can be calculated for elbow angles ranging from 100 to 110 degrees.

For instance, at an elbow angle of 100 degrees, the recommended handle height is 89.5 cm for males and 85.7 cm for females with 5th percentile body dimensions. Conversely, for workers with 95th percentile body dimensions, the handle heights should be 95.6 cm and 101.2 cm above the ground for males and females, respectively. In scenarios where maintaining an elbow angle of 110 degrees is preferable, the corresponding handle heights for the 5th percentile group are 81.0 cm and 84.6 cm, while for the 95th percentile group, they are 89.0 cm and 95.6 cm for males and females, respectively

2.4.6 Handle Material

Handle material is a crucial factor in determining surface abrasion characteristics and grip capability. Abrasion properties depend on hand pressure, surface smoothness, and contamination type. Sweat increases the coefficient of friction, while oil decreases it. Flexible materials like rubber, wood, and soft plastic are preferable over rigid materials like metal or hard plastic. Non-conductive materials such as wood and rubber are advantageous, as they dissipate heat slowly, reducing the risk of injuries due to heat buildup (Konz, 1995).

3 Socio-demography, working conditions and problems associated in pineapple farming in northeast India

Chapter Abstract

This research was carried out to examine the socio-demography, working conditions, and resulting musculoskeletal disorders of farmers growing pineapples in northeast India. The study involved 152 pineapple farmers in total (92 men and 60 women). Data were collected by utilizing a pre-tested structured schedule and a standard Nordic questionnaire through in-person interviews and direct observation. Using SPSS software 16.0, chi-square (χ^2) analysis and multiple logistic regression were used to investigate the relationship between different independent factors and their effects on the musculoskeletal disorders (MSDs) scores. According to the study, over 85 % of pineapple farmers in northeast India earned between low and medium amounts annually, and over 95% of them fell into the small and marginal category. Further, the low back (76.32%) was the most affected body part, and MSDs were highly prevalent among farmers (79.61%). The Chi-square (χ^2) analysis revealed a significant ($p < 0.05$) relationship between the incidence of total MSDs among pineapple farmers and their age, education level, and farming experience. Only age and gender were found to have a significant impact on the likelihood of complaints for the lower back (OR = 2.54, 95% CI: 1.00 – 6.47, $p \leq 0.05$) and farmers' neck (OR = 6.62, 95% CI: 1.29 – 34.02, $p \leq 0.05$). This study's findings demonstrated the need for the urgent exploration of sustainable and innovative interventions to reduce the occurrence of MSDs and improve the working conditions of pineapple farmers in northeast India.

3.1 Introduction

Pineapple (*Ananus comosus*) is an important tropical fruit originating from South America and subsequently spread worldwide (Singh *et al.*, 2016; Saloni *et al.*, 2017). Pineapple is cultivated as one of the most important commercial fruit crops (third among tropical fruits after banana and citrus) in the world (Rohrbach *et al.*, 2003). India ranks second after Nigeria in terms of area covered under pineapple cultivation (about 0.11 million hectares) and fifth in terms of production (1.96 million tons) in the world, with productivity of 17.85 tons per hectare against Indonesia's maximum production of 132.15 tons per hectare (Anon, 2018). It has been reported that the average

yield of pineapple in India could be increased by about 50–60 tons/ha under high-density planting (Sema *et al.*, 2011). Therefore, the Government of India initiated the project “Horticulture Technology Mission” in 2001 to promote horticultural crops (Saloni *et al.*, 2017; Sema *et al.*, 2011) in northeast India, considering the region’s potential for horticultural produce. According to the North Eastern Council, Government of India (North Eastern Council, 2015), a total of 9.2 million farmers and farm labourers (gender ratio: 513 females per 1000 male workers) are involved in farming in northeast India though there is no data available for a number of farmers involved in the farming of a particular crop like pineapple. Further, most of the farm activities in northeast India are equally shared by both genders (Singh *et al.*, 2001).

In the region, pineapple has the second-highest production (19.91%) after banana (30.32%), and it covers about 15.72% (third after citrus and banana) of the total area under fruit cultivation during 2013–14 (Anon, 2018). Moreover, it has been reported that northeast India contributed more than half of the country’s pineapple production in 2010–11. Six states (Assam, Meghalaya, Tripura, Manipur, Mizoram, and Nagaland) of northeast India consistently featured among the top ten pineapple-producing belts of the country. Moreover, pineapples are cultivated organically in this region (Sema *et al.*, 2011; Paul *et al.*, 2016). However, agriculture in northeast India has inherent constraints, such as difficult hilly terrain, varying hill slopes and altitudes, land tenure systems, and traditional cultivation practices (Agrawal *et al.*, 2010). The prevalent traditional cultivation techniques of pineapple on hill slopes without following the recommended modern cultivation techniques or with limited management practices might have resulted in low productivity in this part of the country (Sema *et al.*, 2011).

Pineapple growing is considered the most challenging agricultural task in terms of associated risk factors for human labour involved in its cultivation (Gonzaga *et al.*, 2016). Among field operations, pineapple harvesting is one of the most critical, labour-intensive, and time-consuming field operations. Harvesting of mature pineapple out of pointed and sharp leaf tips is usually done manually with a knife or by hand breaking (Sema *et al.*, 2011; Nazri *et al.*, 2017; Das *et al.*, 2011; Ojha and Kwatra, 2016). Manual harvesting of pineapple is not only time-consuming and labour-intensive (20–30 man-days/ha) (Anon, 2017b) but also induces easy injuries to farmers due to the spines and sharp tips of the leaves (Nazri *et al.*, 2017; Li *et al.*, 2013; Singh *et al.*, 2014). However, safety

practice is not often implemented or followed. As pineapple is a ground crop, harvesting tasks require farmers to stoop or squat while harvesting. Adoption of such awkward postures and performing repetitive tasks induce body strain (Singh *et al.*, 2014; Tamrin and Razak, 2014; Rani *et al.*, 2016; Salleh and Sukadarin, 2018a). A study on Malaysian pineapple farmers reported an 87.0% prevalence of musculoskeletal disorders (MSDs) with the highest symptoms in the lower back (64.8%) (Rani *et al.*, 2016). Moreover, the harvesting task was found to be the most risky in terms of health hazards and safety issues. Occupational hazards due to manual labour, repetitive tasks, and use of improper tools and techniques have also been reported for Malaysian oil palm fruit harvesters (Ng *et al.*, 2015), Sri Lankan rubber tappers (Stankevitz *et al.*, 2016), Latino sweet potato farmworkers (Kearney *et al.*, 2016), Indian manual-working rice farmers (Jain *et al.*, 2018a and 2018b; Ojha and Kwatra, 2016), Cambodian fruit farm workers (Thetkathuek *et al.*, 2018), Iranian apple harvesting labourers (Houshyar and Kim, 2018), Brazilian banana harvesting workers (Merino *et al.*, 2019), and labour-intensive agricultural workers in general (Fathallah *et al.*, 2010; Koekoeh *et al.*, 2016; Dianat *et al.*, 2020; Ojham and Singh, 2018). Various ergonomic stressors are involved in the pineapple cultivation process (Salleh and Sukadarin, 2018a). Despite the risk potential of MSDs, no previous studies have reported the prevalence of MSDs or associated risk factors among pineapple farmers in India.

Further, the working environment and socioeconomic factors significantly influence the adoption and transfer of agricultural technologies (Lestrelin *et al.*, 2012). The socioeconomic conditions of the farmers are influenced by their diverse socio-demographic characteristics. Furthermore, any farming or non-farming activity of an individual is closely associated with their socio-economic status (Ganesh *et al.*, 2007). Few researchers have attempted to find the reason for the relatively low production of pineapple—despite conducive climatic and terrain conditions in northeastern states—and the prevalence of musculoskeletal disorders (MSDs) among pineapple growers.

It is noticed from the literature that there is a lack of a detailed study on socio-demographic characteristics, orchard environment, and hindrances to adopting advanced tools and techniques for pineapple cultivation. Without in-depth research and an understanding of ground reality, it is not possible to propose any intervention—either an engineering, a socio-technical, or a behavioural one—to ameliorate the pineapple farmers' drudgery in northeast India along with the enhancement

of pineapple production. Hence, it is imperative to initiate research to bridge the existing knowledge gaps regarding the life of pineapple farmers, existing pineapple cultivation practices, topo-geography of the cultivation land, mechanization level of the presently used tools/ equipment, and availability of power sources for farm operation in northeast India.

3.2 Methodology

3.2.1 Study area and sampling

A cross-sectional study was conducted from June to November 2019 in seven districts from the top three pineapple-growing states of northeast India (Assam, Manipur, and Meghalaya) to reduce the bias for generalization of the research findings across northeast India (Figure 3.1). The districts were purposively selected based on area, cultivation practice, and proximity. Then, a minimum of two villages from each district with the maximum number of pineapple farmers were purposively selected from the seven selected districts (Assam-2, Manipur-3, and Meghalaya-2). The pineapple farmers were selected randomly, and eligible pineapple farmers were identified from these villages after due consideration of inclusion criteria of the study. A farmer who was 18 years or above involved in pineapple farming for at least one year, and who had no history of accidents, or any chronic disease was considered as the inclusion criteria of this study. A sample of 100 farmers is required to maintain a data collection error below 5% for manual harvesting tasks (Jain *et al.*, 2018). A similar study in Johor, Malaysia, also considered a sample size of 108 pineapple farm-workers (Rani *et al.*, 2016). Therefore, a total of 162 pineapple farmers were invited, and out of which only 152 pineapple farmers (92 males and 60 females) were considered in the present study due to incomplete responses from the remaining 10 farmers. The study area and sampling of pineapple farmers are detailed in Table 3.1.

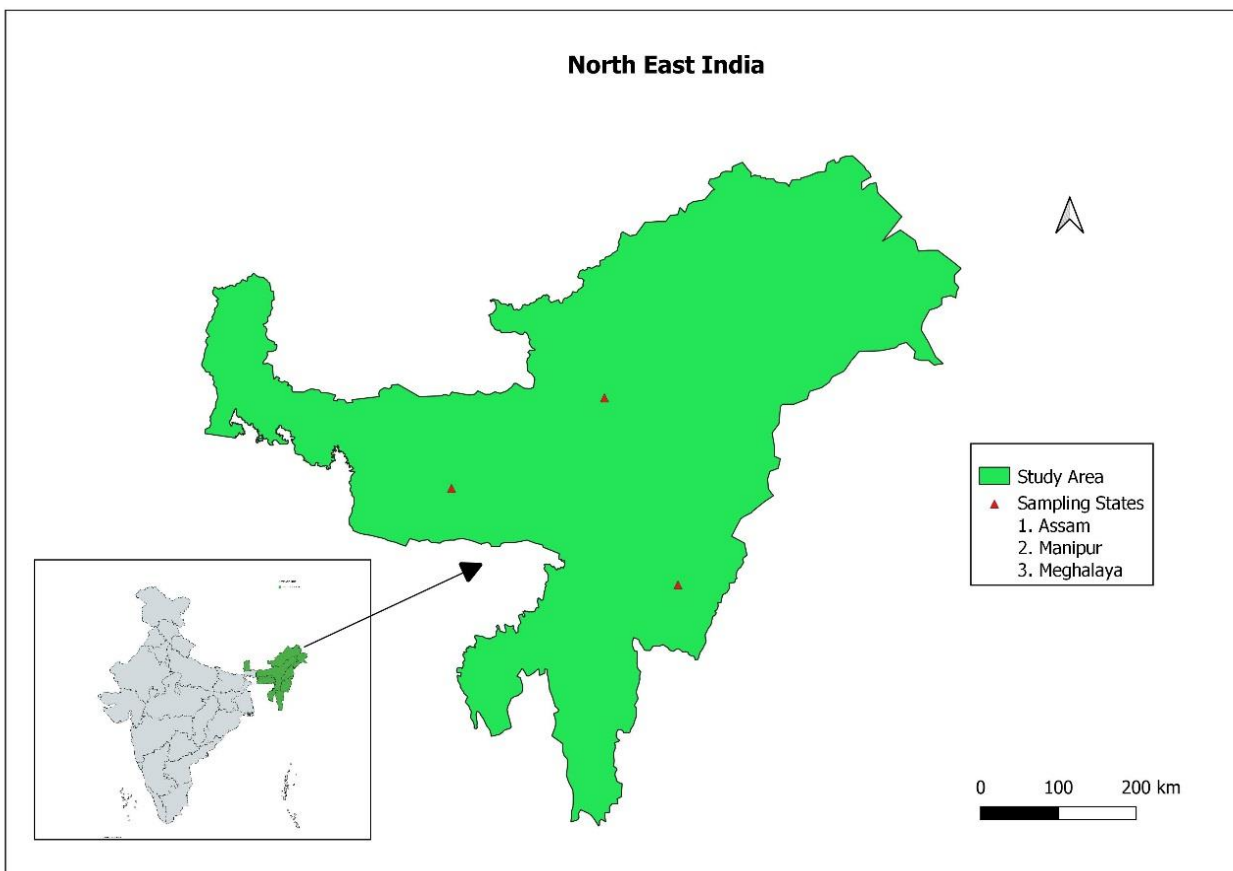


Figure 3.1. Study area

Table 3.1. Distribution of respondents from northeast India

State	District	Village	No of farmers invited
Assam	1. Kamrup 2. Gaolpara	Malang Salbari, Jakuwapara, Borjhora No.1 and Nolanga Pahar (4 villages)	36
Manipur	1. Imphal-East 2. Kangpokpi 3. Churachandpur	Angtha, Tamaram, Karpu Sungba, Ngarangpung, Thayong, and Khousesabung (6 villages)	54
Meghalaya	1. Ri Bhoi 2. West Garo Hills	Purangang, Nalapara, Lalumpam, Borkhatsari, Borgang, Umtham, Asanang and Konchi Gittim (8 villages)	72
Total	7 districts	18 villages	162 farmers

3.2.2 Data Collection

The data pertaining to the pineapple harvesters' socio-demographic characteristics and task-activities details were collected using a pre-tested structured schedule. The schedule was pilot tested on 30 farmers for clarity and necessary modification before giving to all the respondents. The scales of measurement in the schedule are discussed in this section. The age (18–25, 25–40, and >40 years), body mass index (<18.5, 18.5–24.9, 25, 29.9 and ≥ 30 kg/m²), education (illiterate, primary school, high school, and graduate levels), work experience (≤ 5 , 5–15, and ≥ 15 years), and daily working hours (≤ 6 and ≥ 7 hours) were recorded using scales adopted by Jain *et al.* (2018a). Similarly, stature/ height (short, medium, and tall), family size (small, medium, and large), and income group (low, medium, and high) were categorized according to the scale adopted by Singha *et al.* (2016). Landholdings (marginal, small, semi-medium, medium, and large) of the pineapple growers were grouped according to Agriculture Census 2015-16 (Anon, 2019), as presented in Table 3. The multi-method ergonomic review technique (MMERT) consisting of three levels (low, moderate, and high) was adopted for assessing perceived work fatigue, satisfaction in hand tool use, and satisfaction in terms of income (Jain *et al.*, 2018a).

3.2.3 Prevalence of Musculoskeletal Disorders (MSDs)

MSDs was measured using the SNQ questionnaire developed by Kourinka *et al.* (1987). All the respondents were requested to report either “Yes” or “No” to whether they had any ache, pain, or discomfort in their body parts (neck, shoulders, elbows, wrists/hands, upper back, low back, hips/thighs, knees, and ankles/feet) in the last 12 months. If the answer “Yes” was reported, the respondents were further asked to indicate any disruption of normal activities due to MSDs. The study was approved by the Institutional Human Ethics Committee (IHEC) of the Indian Institute of Technology, Guwahati, Assam (India), and was conducted according to the Helsinki guidelines (World Medical Association, 2001). Each participating pineapple farmer also approved the study and signed a written informed consent before participation.

3.2.4 Statistical Analysis

SPSS software 16.0 was used for the statistical analysis. Descriptive statistics of the socio-demographic and work-related variables of the farmers were given as mean \pm standard deviation (SD)

and frequency/proportion for different groups of each factor. A χ^2 analysis was conducted to check the association of the MSDs scores with the socio-demographic and work-related factors, and their significance was reported at $p \leq 0.05$. The odds ratios (ORs) of the associated risk factors were determined using multiple logistic regression for the pain/discomfort scores on different body parts. The significance of the OR was determined at $p \leq 0.05$, with a 95% confidence interval (CI).

3.3 Results

3.3.1 Socio-demographic details

The farmer's ages ranged from 18 to 76 years, with an average of 44.43 (SD: 13.37) years. Most of the respondents (59.21%) were aged above 40 years, irrespective of gender (Table 3). So, the pineapple farmers involved were mostly middle-aged and senior members of their families. The average BMI of the respondents was 23.57 kg/m² (23.99 for males and 22.93 for females), which was within the healthy BMI category (Table 3.2). A high proportion of the respondents (93.74%) were married, and 41% were identified as smokers.

The educational levels of the pineapple farmers varied from illiterate to graduate—13.81% were illiterate (7.60 % for male and 23.33 % for female), 36.18% had primary school education (34.78 % for male and 38.33 % for female), 41.45% had high school education (47.83 % for male and 35 % for female), and 8.55% went to college (9.78 % for male and 3.33 % for female) (Table 3.2). Accordingly, the figures revealed that there was a slight disparity in the education level of the respondents based on gender.

Among the respondents, 53.95 %, 40.79 %, and 5.26 % of respondents belonged to the small size family (1 to 5 members), medium-size family (6 to 10 members), and large size family (above 10 members), respectively. The average family size of the respondents was 6 (SD: 2) members out of which only 3 (SD: 1) members of the families, on average involved in pineapple cultivation practices.

The pineapple farmers from the three northeastern states under study belonged to different ethnic groups—*Meitei, Tangkhul, Kabui, Kom, Gangte*, and *Maring* in Manipur; *Bhoi Khasi* and *Garo* in Meghalaya; and *Assamese, Garo, and Rabha* in Assam. The majority of the pineapple farmers

belonged under the scheduled tribe's category except Meitei in Manipur and Assamese in Assam. In Manipur, God *Pakhangba* is the supreme God of the Meitei traditional beliefs and mythology preceding to Hinduism. The Meitei people believe that pineapple and sickle belong to the same family of God *Pakhangba*. So, it is considered inauspicious to use a sickle for cutting or harvesting pineapple. Therefore, elderly farmers used to advise the newcomers to opt for other farm tools for cutting or harvesting pineapple for fruitful pineapple farming in the long run.

Among the respondents, as many as 61.18 % of respondents had grouped themselves under the medium-income group of Rs. 50,000/- (~603.30 USD) to 1 lakh (~1206.60 USD) annually followed by the low-income group (25.66 % below Rs. 50,000/-) and high-income group (13.16 % above Rs.1 lakh). Pineapple cultivation, along with allied agricultural activities was the primary occupation.

Table 3.2. Factors associated with overall MSDs among pineapple farmers in northeast India (n=152)

Independent Factors	Frequency (%)	Mean (SD)	Overall MSDs		χ^2 Test	
			Yes (%)	No (%)	χ^2 value	<i>p</i>
<i>Gender</i>						
Male	92 (60.53)	-	75.0	25.0	3.05	0.08
Female	60 (39.47)	-	86.7	13.3		
<i>Age in years</i>					8.60	0.01*
18-25	15 (9.87)	Male: 44.80 (14.13)	53.3	46.7		
26-40	47 (30.92)	Female: 43.85 (12.21)	76.6	23.4		
> 40	90 (59.21)		85.6	14.4		
<i>Height in cm</i>					0.57	0.75
Short (<164)	111 (73.03)	Male: 162.14 (7.97)	81.1	18.9		
Medium (164 – 169.99)	13 (8.55)	Female: 154.67 (4.72)	76.9	23.1		
Tall (\geq 167)	28 (18.42)		75.0	25.0		
<i>Body Mass Index in kg/m²</i>					2.55	0.47
<18.5 (underweight)	3 (1.97)		66.7	33.3		
18.5–24.9 (normal)	99 (65.13)	Male: 23.99 (3.77)	81.8	18.2		
25–29.9 (overweight)	46 (30.26)	Female: 22.93 (2.42)	73.9	26.1		
\geq 30 (obesity)	4 (2.63)		100.0	0.0		
<i>Education level</i>					9.94	0.02*
Illiterate	21 (13.82)	-	81.0	19.0		
Primary school	55 (36.18)	-	90.9	9.1		
High school	63 (41.45)	-	73.8	26.2		
Graduate	13 (8.55)	-	54.5	45.5		
<i>Hand domination</i>					0.05	0.82
Left	4 (2.63)	-	75.0	25.0		
Right	148 (97.37)	-	79.6	20.3		

<i>Smoking</i>						
Yes	41 (26.97)	-	78.4	21.6	0.38	0.54
No	111 (73.03)	-	82.9	17.1		
<i>Operational land holdings</i>						
<1 ha (marginal)	86 (56.58)		76.7	23.3	2.03	0.57
1-2 ha (small)	60 (39.47)		83.3	16.7		
2-4 ha (semi-medium)	5 (3.29)	0.92 (0.73)	66.7	33.3		
4-10 ha (medium)	1 (0.66)		100.0	0.0		
>10 ha (large)	0 (0)		0.0	0.0		
<i>Farming experience</i>						
≤5 years	21 (13.82)		61.9	38.1	6.40	0.04*
5-15 years	36 (23.68)	19.16 (11.96)	75.0	25.0		
≥15 years	95 (62.50)		85.3	14.7		
<i>Daily working hours</i>						
≤6 hours	131 (86.18)	4.73 (1.49)	80.2	19.8	0.18	0.68
≥7 hours	21 (13.82)		76.2	23.8		
<i>Income satisfaction</i>						
Low	37 (24.34)	-	75.7	24.32	2.96	0.23
Moderate	92 (60.53)	-	84.8	15.22		
High	23 (15.13)	-	86.9	13.04		
<i>Hand tool satisfaction</i>						
Low	87 (57.24)	-	70.3	29.7	3.03	0.64
Moderate	38 (25.00)	-	81.5	18.5		
High	27 (17.76)	-	87.0	13.0		
<i>Perceived work fatigue</i>						
Low	0 (0)	-	0.0	0.0	1.05	0.31
Moderate	4 (2.63)	-	100.0	0.0		
High	148 (97.37)	-	79.1	20.9		

Note: MSDs = Musculoskeletal Disorders; SD = Standard Deviation; *Significant at $p < 0.05$

3.3.2 Prevalent cultivation practices and land holdings

Various activities are performed by the pineapple farmers including new pineapple plantations, intercultural operations (weeding, earthing-up, and de-suckering) of the existing crop, and harvesting activities. Pineapple plantation season varies among states in India. In northeast India, pineapple was mainly planted at the monsoon's onset by manually digging pits (0.1-0.15 m depth) using a spade. Approximately 98% of the respondents mentioned that the single-row method of pineapple plantation (50.66% across the slope, 35.53% along, and 13.82% for both) is generally being followed in the region (Figure 3.2 – 3.4). The double-row plantation method (either across or along the slope) has been started recently by some farmers to facilitate harvesting in one pass between the rows. The double-row method across the hill slope may be a staggered or non-staggered plantation. Farmers also maintained roughly 0.45–0.60 m plant-to-plant spacing and 0.76–1.5 m row-to-row spacing depending on soil fertility. In northeast India, the commonly grown and most popular varieties were Kew (62.50%) and Queen (30.26%).



Pineapple plantation at foothills hill slope



Depth of pit (0.1 to 0.15 m)



Diameter of pit (0.25 to 0.30 m)

Figure 3.2. Practices of pineapple plantation in northeast India



Row-to-row spacing (0.45–0.60 m)



Plant-to-Plant spacing (0.76–1.5 m)

Figure 3.3. Spacing maintained in pineapple cultivation in northeast India



Single row + across the slope plantation



Double row + along the slope plantation



Double row + across the slope + staggered plantation



Pineapple plantation on hill slopes in NE India

Figure 3.4. Different methods of pineapple plantation in northeast India

After plantation, fruits become ready for harvest in 15-18 months depending on the variety, type of planting material (sucker/slip), temperature, etc. Pineapple fruits are harvested with a knife or by breaking the pineapple stalk from July to September. Besides, the fruits from off-season flowers are harvested during winter. After 1st harvest, the pineapple plants are retained as ratoon crops with an economic life of 5-6 years. Then, the old plants are uprooted for new plantations. Northeast India is a heavy rainfall region, weed poses a serious problem for plants' growth. Therefore, hand weeding or weeding using hand tools is done at least two to three times a year. Soon after fruit harvesting, earthing up operation is essential to provide good anchorage to the plant, followed by

de-suckering (thinning out of excessive suckers and slips). Only two to three suckers are left with the mother plants for the next fruiting. The suckers are removed periodically to maintain the plants' health and avoid hindrance during intercultural operations and fruit harvesting.

The operational landholding of pineapple farmers ranged between 0.25 ha to 5.00 ha, with an average of 0.92 (SD: 0.73) ha (Table 3.2). The study revealed that more than 95 % of the farmers belonged to small and marginal farmers (< 2 ha). Pineapple farms were located in the remote and inaccessible hilly areas. The land available in this region for pineapple cultivation could be classified into plain valleys, foothills (gentle slope), and hill slopes (moderate to steep slopes). More than 94 % of the pineapple farms were under the category of hill slopes followed by foothills (5.26 %) and plain valleys (0.66 %).

3.3.3 Work-related details

The average pineapple farming experience was 19.16 (SD: 11.96) years, with average daily working hours of 4.73 (SD: 1.49) hours a day (Table 3). It was observed that the majority of the respondents (62.50 %) had been working for more than or equal to 15 years followed by 23.68 % (5 to 15 years) and 13.82 % (≤ 5 years). About 87.50 % of the respondents worked for less than or equal to six hours a day. The majority of the respondents (97.37 %) used their right arms for holding farm tools and considered pineapple harvesting tasks as high (97.37 %) in terms of perceived work fatigue. Within the villages, there were strong local traditions of cooperation, coordination, and mutual help for centuries among the pineapple farmers of the villages under study. These helping nature of the farmers were mutual and rotational among themselves for any work.

Pineapple farmers were multi-tasked and undertook all sorts of operations, starting from land preparation to harvesting and transportation mostly by themselves. However, workers based on daily wages were also found in farming. In case, farmworkers/ labourers are hired, they are paid either a daily basis or based on the number of fruits harvested in case of harvesting. The reason is that villagers started opting for other non-farming occupations with higher education like Govt. jobs, business, etc. in search of better living standards and quality of life.

3.3.4 Prevalent Harvesting Practices

Harvesting of ripened pineapple fruit commences in the month of June and continues till January for around 8 long months considering both the main season and off-season as discussed in the introduction section. Before entering the plantation, the farmers dress up properly: long pants/trousers, full sleeve shirt, with or without hand gloves, and jungle boots/water boots to avoid injury from leaf tips and spines, and prickles on the fruit surface. After properly dressed, the farmers get into the pineapple plantation along the rows one after another to harvest ripe pineapple fruits. With a bamboo basket strapped over their shoulders/heads or a gunny bag, farmers select and harvest the ripe fruits (one at a time) by breaking them with their hands or cutting them with a tool (Figure 3.5). Then, the harvested fruit is placed inside the bamboo basket or gunny bag and continues until the basket or bag is full of harvested fruits. The basket or bag with fruits is then emptied at some place within the farm itself for further transportation (Figure 3.6). After that, the same process continues until the target fruit numbers get harvested.



Figure 3.5. Steps involved in the pineapple harvesting task

The flowchart of pineapple harvesting process is also given in Figure 3.6.

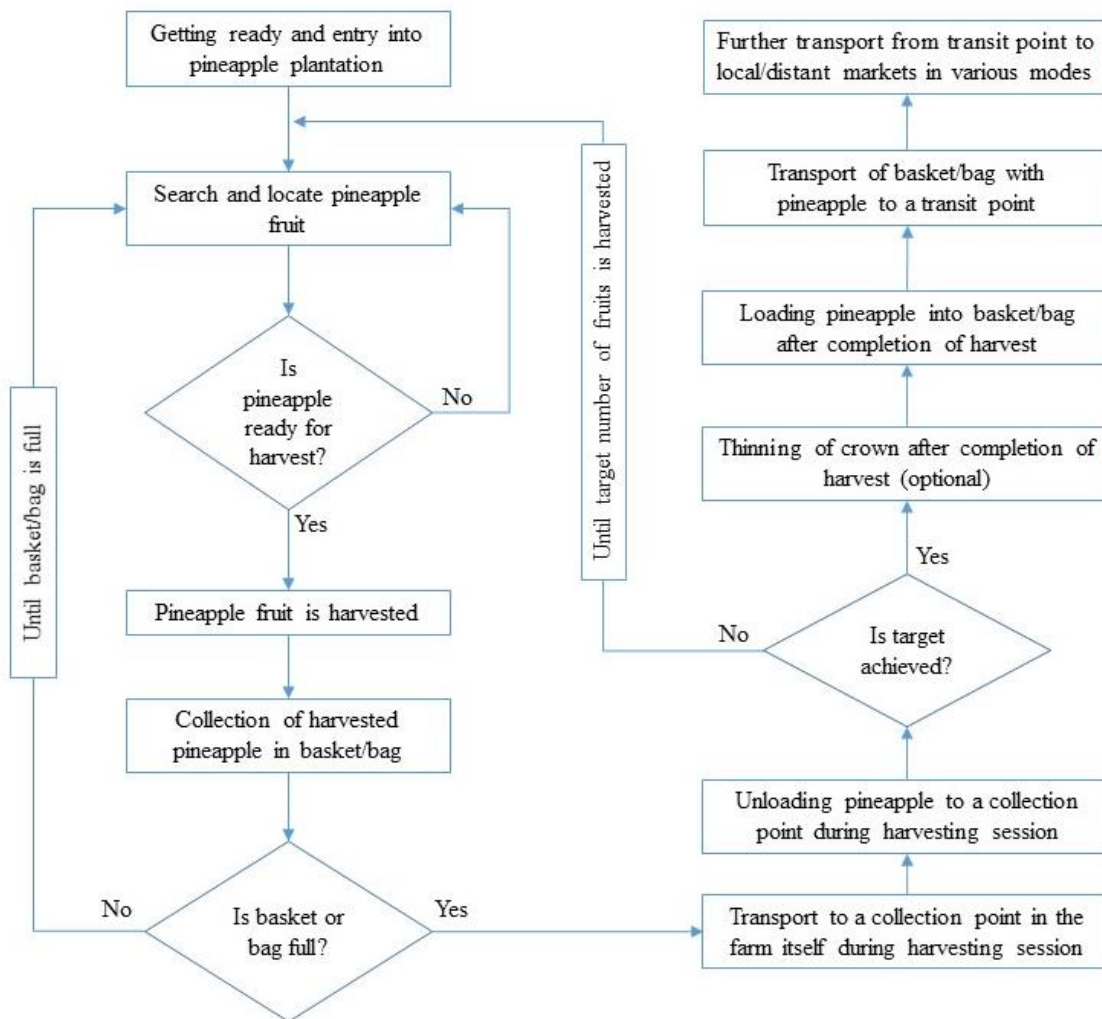


Figure 3.6. Flowchart of pineapple harvesting process

3.3.5 Farm Power Sources

Humans, animals, power tillers, tractors and self-propelled machines are the sources of mobile farm power while engines and motors can be used for stationary works. The average farm power availability in the region was estimated at 0.67 kW/ha, which was much below the national average of 1.15 kW/ha in the country (Kaul, 2001). However, for any type of work, all of the respondents were found using locally evolved indigenous hand tools like a sickle, knife, spade, and different designs of short and long-handled machetes among pineapple farmers in northeast India.

Generally, pineapple farmers carry their tools while they are going to work. A noticeable difference in the tools used by left and right-handed workers was not found. Further, the same type of locally available tools was found to be used by both genders except bamboo baskets. Bamboo baskets used for carrying the harvested fruits were different in size depending on their fruit-carrying capacity for men and women. The human power source was used for any farm activities involved in pineapple cultivation (Figure 3.7). The majority of farmers (57.24 %) had low satisfaction with existing hand tools. Moreover, perceived work fatigue was reported high by 97.37 % of them due to long working hours, poor postures, and highly repetitive tasks.

The main reason for only human power might be due to remote and inaccessible pineapple farms on hill slopes (more than 94 % as mentioned earlier). These farms are also cut off from the village roads. So, tractors, power tillers, or any self-propelled machines could not reach there for pineapple cultivation practices thereby limiting the introduction of power from these sources. There have been constraints experienced in the adoption of improved machinery being utilized in other parts of the country (Agrawal *et al.*, 2010). It was also reported that human labour was the appropriate source of farm power sustainable for hill slopes (Yadav, 2002). However, pineapple farming activities involved considerable drudgery and discomfort. There were safety issues and risks for long-term health hazards. This situation has to be improved by exploring innovative tools/equipment suited to local conditions, not necessarily with the costly and large automatic machines.



Figure 3.7: Human as the only farm power source

3.3.6 Local transportation and market

Pineapple farms are mostly located far-flung on hill slopes and foothills. So, farmers have to climb down or walk on foot for some distance with harvested fruits. Thus, local transportation of harvested pineapple fruits comprises two stages. The first stage of local transportation takes place between a production place and a transit place. A transit place may be a farmers' home, village roadsides, state highways, national highways, etc. While the pineapple fruits are harvested by one member of a family, other members of the family or relatives or friends help in the transportation of harvested fruits (piled up at some places within the farm) from the production place to a transit location using bamboo basket strapped over their heads or poly bag/gunny bag on their shoulders or heads for distant up to 500-600 m. The cost of transit transportation may be discussed in different ways. One way is helping each other when they harvest and transport from the production area to the local transit location. Another way is by paying the transportation charges @ Rs.1.00/- (~0.012 USD) per fruit and Rs. 2.00/- (~0.024 USD) per fruit at nearby and distant transit locations, respectively.

After the harvested pineapple fruits have reached the transit location (village roadside), they will be transported to the local or distant market by either by-cycle, two-wheelers, rickshaws, or four-wheelers depending on farmers' target market (Figure 3.8). Pineapple fruits are sold by farmers themselves on roadside of state highways or local markets. Otherwise, brokers arrive at local transit locations and purchase the fruit at wholesale rate for further sale at distant markets or the main market of the state. In state like Manipur, some parts of the farm produce get airlifted by big firms like Big Basket (Delhi) and Northeast Agro Products (Gurgaon) under the aegis of Manipur Organic Mission Agency (MOMA), Manipur.



Figure 3.8. Post-harvest sequence of activities

3.3.6 Locally evolved Traditional tools

Jungle cutting and slashing of trees, twigs and shrubs were the first steps for the beginning of any farm operations in pineapple cultivation in northeast India. The farm tools used differed from state to state. *Dao* (Assam and Meghalaya) and *Thangjou* or *Haothang* (Manipur) were used for clearing the forest. Then, the dried biomasses were burnt, and the charred remains were cleared off. The resulting ash was used as fertilizer for crop cultivation. Slashing and burning of biomass appeared

to be the only way to incorporate nutrients from biomass into the soil and prepare the land for cultivation. After land preparation, pits were dug by using a spade for planting a single sucker manually.

In the pineapple harvesting process, locally evolved hand tools fabricated by local artisans are being used in the state. Farmers have modified some hand tools to fit their tasks. For instance, the handle of the local sickle has been modified into a long handle (65 cm) so that fruit may be harvested effectively without injury from pineapple leaf tips and spines. The different types of hand tools being used for harvesting pineapple were sickle (conventional sickle and modified sickle with a long handle), short-handled kitchen knife, carving knife with long handled locally named *Sanggai* in Manipuri and *dao* in Assam and Meghalaya. *Sanggai* is a short, sharp-edged with slightly curved blade commonly used in valley areas of Manipur. After completion of fruit harvesting, the hand tools were cleaned and kept at proper places (Figure 3.9). Hand tools were never kept in touch with the soil or ground to avoid rusting. Serrated sickle got sharpened once or twice a year from local artisan @ Rs. 80/- (~0.96 USD). Other tools could be sharpened by farmer themselves at their home using a whetstone as and when needed.

Brief specifications of hand tools being used in pineapple harvesting in northeast India is given below:

1. Serrated and non-serrated sickle (*Thangol*)

Raw materials used

- (a) Blade : MS sheet
 (b) Handle : Wooden

Dimensions of blade

Length x Width x Thickness : 200-250 x 18-20 x 1.5-2 mm

Dimensions of handle

- (a) Diameter : 25-30 mm
 (b) Length : 150-175 mm

Cost : Rs. 200-250/- (2.4 – 3.02 USD)



2. Non-serrated sickle (modified sickle with a long handle)

Raw materials used

- (a) Blade : MS sheet
(b) Handle : Bamboo

Dimensions of blade

Length x Width x Thickness : 200-250 x 18-20 x 1.5-2 mm

Dimensions of handle

- (a) Diameter : 25-30 mm
(b) Length : 400-650 mm

Cost : Rs. 200-250/- (2.4 – 3.02 USD)



3. Kitchen Knife (Chhuri)

Raw materials used

- (a) Blade : Spring steel/MS sheet
(b) Handle : Wood

Dimensions of blade

Length x Width x Thickness : 370-425 x 40-100 x 8-10 mm

Dimensions of handle

- (a) Diameter : 35-40 mm
(b) Length : 250-300 mm

Cost : Rs.150-200/- (1.8 - 2.4 USD)



4. Folding Knife (Tari ling in Khasi)

Raw materials used

- (a) Blade : Angle iron, MS flat, saw blade
(b) Handle : Wood

Dimensions of blade

Length x Width x Thickness : 180-250 x 30-50 x 1.5-3 mm

Dimensions of handle

- (a) Length : 160-220 mm
(b) Width : 10-20 mm
(c) Thickness : 5-10 mm

Cost : Rs.150-200/- (1.8 - 2.4 USD)



5. Carving knife with a long handle (*Sanggai*)

Raw materials used

- (a) Blade : Spring steel/MS sheet
(b) Handle : Wood

Dimensions of blade

Length x Width x Thickness : 140-180 x 0-20 x 1-5 mm

Dimensions of handle

- (a) Diameter : 19-24 mm
(b) Length : 400-600 mm
Cost : Rs.150-200/- (1.8 - 2.4 USD)



5. Khasi Dao/Dao

Raw materials used

- (a) Blade : Spring steel
(b) Handle : Wood/Bamboo

Dimensions of blade

Length x Width x Thickness : 300-350 x 40-50 x 8-10 mm

Dimensions of handle

- (a) Diameter : 20-40 mm
(b) Length : 300-350 mm
Cost : Rs.250-300/- (3.02 - 3.6 USD)



6. Spade (*Mohkhiew in Khasi*)

Raw materials used

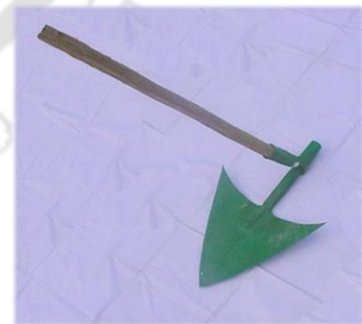
- (a) Blade : Angle Iron
(b) Handle : Wood

Dimensions of blade

Length x Width x Thickness : 420-450 x 300-350 x 4-5 mm

Dimensions of handle

- (a) Diameter : 35-50 mm
(b) Length : 800-900 mm
Cost : Rs.400-500/- (4.8 - 6.03 USD)



7. Thangjou (Manipuri)

Raw materials used

- (a) Blade : Spring steel
(b) Handle : Bamboo

Dimensions of blade

Length x Width x Thickness : 300-350 x 40-50 x 8-10 mm

Dimensions of handle

- (a) Diameter : 20-40 mm
(b) Length : 300-400 mm
Cost : Rs.200-300/- (2.4 – 3.6 USD)



Figure 3.9. After use maintenance practices

Bamboo baskets with straps have been used for carrying farm produce by hill tribes as they are handy in carrying farm produce up and down the hill slopes. Pineapple is one of the most important farm products. Bamboo baskets are conical in shape and tapered towards the bottom section. The top opening section is circular in shape and the base section is either squarely or rectangular in

shape. The body of the basket is made of bamboo and the strap is made of either cane or fibres from Mesta crop (*Shougri* in Manipuri) or plastics nowadays. The bamboo basket is made by weaving (criss-cross pattern) the finely knifed bamboo splits locally referred as *Paya* in Manipuri. The *payas* can be used directly for making bamboo baskets or it can be used as conditioned *payas* if stored above the fireplace to avoid getting spoiled from stem borers. The bamboo baskets made of conditioned *payas* are spongy in nature due to the closely weave patterns. The base of the bamboo basket is strengthened by placing two sticks in crossed diagonals on the base, in which the tips of the sticks get hidden into the weave. Bamboo baskets used in pineapple harvesting and transportation may be broadly classified into three groups based on size (small and large), weaving pattern (loosely woven and closely woven), and provision for stand (with or without stand) at the base of the basket (Figure 3.10).



Closely woven bamboo basket

Loosely woven bamboo basket

Bamboo basket with stand



Large

Small

Bamboo baskets:

- Circular opening at one end and rectangular base at another end
- Classification based on size, weaving pattern and provision for stand at the base of the basket
- Dimensions bamboo baskets
- ✓ **Small size:** 400-450 mm diameter at top circular opening, 200×200 to 250×250 mm rectangular base with 400-500 mm basket height
- ✓ **Large size:** 450-500 mm diameter at top circular opening, 200×200 to 250×250 mm rectangular base with 500-600 mm basket height

Figure 3.10. Traditional bamboo baskets used in pineapple harvesting

3.3.8 Prevalence of musculoskeletal symptoms

The characteristics of MSDs and disruption of normal activities due to MSDs are presented in Table 3.3. The results show that 79.61% of the farmers reported the overall MSDs on one or more body parts over the last 12 months. The most affected parts were the low back (76.32%), followed by the neck (46.71%), shoulders (46.05%), knees (33.55%), and wrists/hands (27.63%), as presented in Table 3.3. Normal activities of farmers were disrupted due to the high prevalence of MSDs, as reported by 65.13% of the respondents (for the occurrence of discomfort during the last 12 months). Disruption of normal activities was mainly due to MSDs symptoms at low back (58.55%), neck (36.18%), shoulders (34.87%), knees (27.63%), and wrists/hands (21.71%). Four farmers reported medication relief from low back pain. This result proves that MSDs is highly prevalent among pineapple farmers in northeast India. Further, farmers also reported itchininess and injuries on various body parts due to the spines and leaf tips of the pineapple plant.

Table 3.3. Characteristics of MSDs among pineapple harvesters in northeast India (n=152)

Body part	Prevalence of MSDs (Last 12 months)		Disruption of normal activities due to MSDs (Last 12 months)	
	Frequency	Proportion (%)	Frequency	Proportion (%)
Neck	71	46.71	55	36.18
Shoulder	70	46.05	53	34.87
Elbows	23	15.13	17	11.18
Wrists/hands	42	27.63	33	21.71
Upper back	17	11.18	12	7.89
Low back	116	76.32	89	58.55
Hips/thighs	12	7.89	9	5.92
Knees	51	33.55	42	27.63
Ankles/feet	23	15.13	18	11.84
Any body part	121	79.61	99	65.13
Number of body parts with complaints				
0	31	20.39	-	-
1	14	9.21	-	-
2	25	16.45	-	-
≥3	82	53.95	-	-
Total	152	100	-	-

3.3.9 MSD and their associated factors

According to Chi-square (χ^2) analysis, factors, such as age [$\chi^2(2, n = 152) = 8.60, p = 0.01$], education level [$\chi^2(3, n = 152) = 9.94, p = 0.02$], and farming experience [$\chi^2(2, n = 152) = 6.40, p = 0.04$] were significantly associated ($p < 0.05$) with the prevalence of overall MSDs among pineapple farmers in northeast India. The MSDs were more likely to be prevalent with farmers' age (53.3% to 85.6%) and farming experience (61.9% to 85.3%). However, there was a reverse trend between the occurrence of MSDs and the education levels of the farmers. While the incidence of MSDs was found among 90.0% of the farmers who had primary school education, only 54.5% of the farmers with a graduate level of education reported their MSDs.

Multiple logistic regression was performed with the demographic data and work-related risk factors (gender, age, education level, farming experience, and daily working hours) to ascertain their effect on the likelihood of MSDs (Tables 3.4 and 3.5) at four upper body parts (neck, shoulders, low back, and knees). Hosmer-Lemeshow test was adopted for goodness of fit and calibration for logistic regression models. Table 3.4 indicates that among all the factors, only the age of the pineapple farmers was significantly associated with neck complaints in such a way that the farmers aged above 40 years were 4.97 times more likely to experience symptoms (OR = 4.97, 95% CI: 1.12–22.09, $p < 0.05$), compared with the farmers below 25 years of age. Moreover, gender significantly influenced the MSDs risk for low back issues, which was more likely for females (OR = 2.54, 95% CI: 1.00 – 6.47, $p = 0.05$) than males at $p \leq 0.05$.

Table 3.4. Multiple logistic regression of factors associated with MSDs on neck and shoulders

Independent Factors	Neck (n=71)		Shoulders (n=70)	
	OR (95 % CI)	p value	OR (95 % CI)	p value
<i>Gender</i>				
Male	1		1	
Female	1.69 (0.82 – 3.45)	0.15	1.12 (0.55- 2.30)	0.78
<i>Age in years</i>				
18-25	1		1	
26-40	2.45 (0.58 – 10.44)	0.23	1.40 (0.37 – 6.30)	0.62
> 40	4.97 (1.12 – 22.09)	0.04*	0.85 (0.22 – 3.37)	0.82
<i>Education level</i>				
Illiterate	1		1	
Primary school	1.78 (0.62 – 5.13)	0.29	1.16 (0.40 – 3.36)	0.78
High school	1.37 (0.45 – 4.15)	0.58	0.43 (0.14 – 1.34)	0.15
Graduate	1.77 (0.34 – 9.33)	0.50	0.17 (0.03 – 1.17)	0.07
<i>Farming experience</i>				

≤5 years	1		1	
5-15 years	1.24 (0.37 – 4.12)	0.73	0.97 (0.28 – 3.35)	0.97
≥15 years	1.02 (0.32 – 3.18)	0.98	1.47 (0.45 – 4.78)	0.52
<i>Daily working hours</i>				
≤6 hours	1		1	
≥7 hours	1.24 (0.47 – 3.24)	0.63	1.64 (0.61 – 4.40)	0.33

Note: OR = Odds Ratio; CI = Confidence Interval; *Significant at $p < 0.05$

Table 3.5. Multiple logistic regression of factors associated with MSDs on low back and knees

Independent Factors	Low back (n=116)		Knees (n=51)	
	OR (95 % CI)	<i>p</i> value	OR (95 % CI)	<i>p</i> value
<i>Gender</i>				
Male	1		1	
Female	2.54 (1.00 – 6.47)	0.05*	0.84 (0.39- 1.82)	0.66
<i>Age in years</i>				
18-25	1		1	
26-40	2.98 (0.79 – 11.27)	0.11	4 (0.45 – 35.81)	0.22
> 40	3.56 (0.89 – 14.28)	0.07	5.53 (0.62 – 49.21)	0.13
<i>Education level</i>				
Illiterate	1		1	
Primary school	3.30 (0.84 – 12.96)	0.09	0.78 (0.28 – 2.24)	0.65
High school	1.70 (0.45 – 6.45)	0.43	0.36 (0.11 – 1.13)	0.08
Graduate	0.95 (0.15 – 5.88)	0.95	0.28 (0.04 – 1.92)	0.19
<i>Farming experience</i>				
≤5 years	1		1	
5-15 years	1.81 (0.50 – 6.51)	0.37	0.90 (0.21 – 3.89)	0.89
≥15 years	2.06 (0.59 – 7.23)	0.26	1.29 (0.35 – 4.83)	0.71
<i>Daily working hours</i>				
≤6 hours	1		1	
≥7 hours	0.98 (0.30 – 3.22)	0.98	1.19 (0.43 – 3.29)	0.74

Note: OR = Odds Ratio; CI = Confidence Interval; *Significance at $p \leq 0.05$

3.4 Discussion

Most of the respondents (62.50%) in this study had been working for more than or equal to 15 years, and 86.18% of them worked for less than 6 hours a day (average: 4.73 hours). Their working hours are relatively less compared with other major pineapple-producing counties, such as Malaysia, where pineapple farmers work for 6–7 hours daily, as reported by Rani *et al.* (2016). Approximately 97.37% of the respondents in the current research rated their perceived workload/fatigue under the category “high”. Earlier studies on manual harvesting and manual farming activities in India reported a moderate level of workload (Jain *et al.*, 2017 2018). It is presumed that the drudgery of pineapple farmers in northeast India is higher than manual farming practices for cereal crops in India. Thus, the prevailing condition demands an improvement of tools or techniques for various

pineapple cultivation practices in the region. Notably, the pineapple farmers in northeast India are not habituated to following any pre-defined work-rest schedule because the harvesting activities belong to the informal sector. Hence, in this study, pineapple farmers reported random breaks according to requirements during their working hours.

This study indicated that the pineapple farms were cut off or distant from the village roads and remotely located on uneven, hilly slopes (more than 94%). Therefore, there was no direct access to electrical power or indirect access from available sources, such as tractors and power tillers, to operate motorized harvesting equipment in the orchards. The average farm power availability in the region is estimated at 0.67 kW/ha only, which is much below the national average of 1.15 kW/ha in the country (Kaul, 2001). Moreover, constraints have been experienced in the adoption of improved machinery being utilized in other parts of India (Agrawal *et al.*, 2010). Human power/manual operation is the most sustainable source of farm power for hilly areas of northeast India, as reported by previous researchers (Yadav, 2002; Pranav and Patel, 2016). Therefore, the available farm power source should be considered during the design and development of any farm tools/equipment/devices in the context of northeast India.

It was noticed that 79.61% of the farmers reported an overall MSDs on one or more body parts over the last 12 months. This data is higher than the rate of MSDs prevalence (76.9%) among farmers from the reviews conducted by Osborne *et al.* (Osborne *et al.*, 2012a and 2012b; Mcmillan *et al.*, 2015). A similar study also reported a prevalence of a higher rate of overall MSDs (87%) with a lesser percentage of low-back pain (64.8%), although the symptoms of pain/discomfort in the lower back were the most common among the pineapple farmers in Malaysia (Rani *et al.*, 2016). Various other studies also indicated more or less similar scenarios of the predominance of MSDs among agricultural workers—manual rice harvesters (Jain *et al.*, 2018a; Jain *et al.*, 2018b), rubber tappers (Stankevitz *et al.*, 2016), sweet potato farm workers (Kearny *et al.*, 2016), apple harvesting labourers (Houshyar and Kim, 2018), oil palm harvesters (Ng *et al.*, 2015), fruit farm-workers (Thetkathuel *et al.*, 2018) and agricultural workers in general (Fathallah, 2010; Dianat *et al.*, 2020). Previous researchers (Rani *et al.*, 2016; Ng *et al.*, 2015; Stankevitz *et al.*, 2016; Kearney *et al.*, 2016; Jain *et al.*, 2018a; Jain *et al.*, 2018b; Thetkathuek *et al.*, 2018; Houshyar and Kim,

2018; Dianat *et al.*, 2020; Osborne *et al.*, 2012a and 2012b; Mcmillan *et al.*, 2015) reported that the low back was the most affected site among all body parts, which is in line with this study.

According to Chi-square (χ^2) analysis, demographic factors, such as age, education level, and farming experience, were significantly associated ($p < 0.05$) with the prevalence of overall MSDs among pineapple farmers in northeast India. These findings corroborate the observation from the study by Jain *et al.* (2018b). The results of this study indicated that educated farmers were less likely to experience MSDs compared with others. It was also found that educated farmers were more open to adopting new technology/interventions to ease out and facilitate their farm activities than the uneducated or less-educated farmers. Therefore, farmers' education/training is recommended to impart knowledge focusing on ergonomic stressors and their association with MSDs (Rani *et al.*, 2016; Jain *et al.*, 2018a; Jain *et al.*, 2018b). Multiple logistic regression revealed that age and sex significantly influenced the risk factors for ailments at the neck and low back, respectively. Age was observed as a likely risk factor for MSDs in many previous investigations (Ng *et al.*, 2015; Jain *et al.*, 2018a; Jain *et al.*, 2018b; Jadhav *et al.*, 2015; Jadhav *et al.*, 2016). Moreover, it is also reported that the prevalence of MSDs increased sharply with age (Engholm and Holmstorm, 2005), and the strength of the musculoskeletal system declined by 25% from 30 to 65 years of age (Weigel *et al.*, 2014). In the case of low back symptoms, a similar study for pineapple plantation workers in Malaysia predicted that workers with higher farming experience and daily working hours were more likely to experience MSDs in the low back (Rani *et al.*, 2016).

During field observations, it was noticed that ergonomic stressors, such as excessive bending, twisting, repetitive and monotonous work, and carrying heavy loads during the harvesting process might be linked to the occurrence of MSDs among farmers. These observations are in line with the studies reported by Rani *et al.* (2016) and Gupta and Tarique (2013). The issues at the low back may also be aroused from awkward and excessive bending postures during the cultivation of shoot and manual weeding operations (Rani *et al.*, 2016). In addition, other aspects of the working environment, such as unstable hill slopes, cause them to slip, trip, and fall easily, thereby leading to additional injuries in their body parts. It is believed that innovative methods/interventions might help in reducing ergonomic risks among pineapple farmers in northeast India. A study by McMil-

lan *et al.* (2015) suggested that interventions could be structured as engineering changes or behavioural modifications. Although it is challenging to effectively implement the behavioural changes, it could be adopted by motivated workers to reduce their risk of MSDs.

Following the field survey and analysis, it was envisaged that a combination of engineering intervention and behavioural modifications could be recommended for a more realistic solution for the targeted population (pineapple farmers). Therefore, the possibility of developing context-specific innovative tools/equipment or design modification of locally evolved indigenous hand tools should be explored. It might reduce the problems being faced by the farmers by avoiding awkward working postures. It was also essential to impart awareness among the pineapple farmers through suitable training/ education camps related to basic ergonomics to avoid awkward working postures, heavy load lifting, and inappropriate rest-pause during the entire working days. A participatory approach should be adopted by involving the farmers to make these initiatives successful. It was expected that such awareness programs might change their attitude toward work and perform their work efficiently.

3.5 Conclusions

It can be concluded that most pineapple farmers (>85%) in northeast India had low to medium annual income, with more than 95% of the farmers belonging to the small and marginal farmer categories. The results of this study proved overall, MSDs is highly prevalent (79.61%), particularly at the low back (76.32%), neck (46.71%), shoulders (46.05%), and knees (33.55%), among pineapple farmers in northeast India. The Chi-square (χ^2) analysis revealed that age, education level, and working experience of farmers were significantly associated with the prevalence of musculoskeletal outcomes in various body parts. From the regression statistics, it was observed that only age (> 40 years) and gender (female) significantly influenced the risk for neck and low back complaints, respectively, among the study population. This study indicates that there is an urgent need to explore innovative interventions suited to local conditions for reducing the risk of occurrence of MSDs and improving the working conditions in northeast India.

4 Ergonomic risk factors among pineapple farmers during pineapple harvesting task in northeast India

Chapter Abstract

Manual pineapple harvesting is one of the most critical and challenging tasks for farmworkers involved in its cultivation. This study intends to investigate the ergonomic stressors associated with the pineapple harvesting task in the context of northeast India. The Rapid Entire Body Assessment (REBA) tool was employed to assess the key working postures adopted during the entire pineapple harvesting task involving a sub-set of the respondents (12 males and 8 females) at their respective pineapple farms. The postures adopted during the pineapple harvesting task with a high-risk score of 8-10 (action level 3) and a very high-risk score of 11 or more (action level 4) were about 30 % and 70 %, respectively. This study also highlighted a high-risk score of 8-10 (action level 3) for more than 80 % of participants during the pineapple loading task for local transportation. Farmworkers were exposed to various ergonomic stressors, which include awkward work posture, repetitive tasks, heavy load carrying on their head, and improper rest-pause might be linked to the prevalence of MSDs among the pineapple farmworkers. Moreover, walking uphill or downhill on uneven, hilly terrain during the harvesting task imposed an additional burden on the farm workers. Based on the results, there is an urgent need to explore effective preventive interventions suited to local conditions for improving the working conditions and occupational wellness of the pineapple farmworker population in northeast India.

4.1 Introduction

Pineapple is cultivated commercially in almost all the states of northeast India. Among the major fruits in the region, pineapple ranked 2nd (19.91 %) after banana (30.32 %) in terms of production, and 3rd (15.72 %) after citrus and banana in terms of area under fruit cultivation during 2013-14 (National Horticulture Board, 2014). Northeast India also contributed more than 40 % of total pineapple production in India (Sema *et al.*, 2011; Paul *et al.*, 2016; Saloni *et al.*, 2017). Moreover, out of eight states in northeast India, six of them had been placed consistently among the top ten pineapple-producing belts of the country (Paul *et al.*, 2016). Although pineapple is an important crop, it is also a very challenging crop in terms of associated risk factors for human labour involved

in its production processes (Gonzaga *et al.*, 2016). Among the processes, harvesting is very critical, has high labour requirements, and time-consuming process. It is usually done manually using small hand tools. Though there is scope for improved and large machines in developing countries for pineapple harvesting, it is not applicable in India and northeast India in particular due to inherent constraints of the region, such as difficult hilly terrain, small farm size, land tenure systems, traditional ways of cultivation practices, etc.

As pineapple grows on the ground crop, farmworkers have to bend down while harvesting and it also induces easy injuries to farmworkers because of the spines and leaf tips (Singh *et al.*, 2014). A study in Malaysia reported 87.0% prevalence of musculoskeletal symptoms (MSDs) and the most prominent symptom was at low back (64.8%) (Rani *et al.*, 2016). Moreover, the harvesting task was reported to be the most risky task in terms of health hazards and safety issues. Similar studies have also reported occupational hazards due to work stressors such as awkward postures, repetitive tasks, etc., and the use of improper tools and techniques by Malaysian oil palm fruit harvesters (Ng *et al.*, 2015), Cambodian fruit farm workers (Thetkathuek *et al.*, 2018), Iranian apple harvesting labourers (Houshyar and Kim, 2018), Brazilian banana harvesting workers (Merino *et al.*, 2019). From the literature, it is noticed that there is a lack of studies on ergonomic risk factors or stressors associated with pineapple harvesting in the context of India. Despite the high-risk potential of occupational health and safety issues among pineapple farmworkers, no previous studies have been reported from any parts of India. Therefore, it was aimed to investigate ergonomic stressors associated with pineapple harvesting tasks in northeast India.

4.2 Methodology

4.2.1 Study Area and Data Collection

This study was carried out during June to November 2019 in Northeast India (Assam, Manipur and Meghalaya). As discussed in the previous chapter (Chapter 3), the respondents were selected from seven districts (two from Assam, three from Manipur, and two from Meghalaya) and the same respondents were considered for this study.

4.2.2 Postural Analysis

During the study, a sub-set of farmworkers (12 males and 8 females) was involved in postural analysis by the REBA method to identify the potential risk postures adopted by the pineapple farmworkers that could contribute to the prevalence of MSDs among the farmworkers. For this analysis, the pineapple farmworkers were observed and recorded their work postures while carrying out their farm activities at their respective farms. Then, the REBA score was calculated using the REBA body part diagrams and the REBA score sheet. The REBA score ranges between 1 and 15. A REBA score of 1 suggests that the risk is negligible, meanwhile, a score between 2 -3 suggests a low risk and changes may be needed; a REBA score of 4 to 7 indicates a medium risk and changes are needed; a REBA score of 8 to 10 indicates a high risk, in which investigation is needed to implement changes; and lastly, a REBA score of 11 or more suggest a very high risk and changes are needed immediately. Descriptive statistics was used to summarize and interpret the MSDs data and REBA scores for various body parts of the participants in the study.

4.3 Results and Discussion

4.3.1 Postural Analysis

In this analysis, the pineapple harvesting task was divided into two sub-tasks: sub-task 1 (pineapple harvesting and collection) and sub-task 2 (local transportation). From these two sub-tasks, the key potential risk postures were identified and analyzed using REBA as shown in Figures 4.1 and 4.2. The number and percentages of participants with REBA scores (Score A for neck, trunk, and legs and Score B for upper arms, lower arms and wrists) are given in Tables 4.1 and 4.2. The upper arm mean scores of 2.95 and 3.5 indicated a flexion between 45-90° in the harvesting task and a slightly abducted and more flexed upper arm (>90°) during the pineapple loading task for local transportation, respectively. The mean score of lower arms below 2 in both sub-tasks indicated the lower arms movement in the range of 60-100°. The wrist score of 3 indicated a twisted/deviated wrist with more than 15° flexion in sub-task 1, while a general wrist score of 1 in sub-task 2 showed a normal wrist flexion/extension of 0-15° without any twist/deviation. The neck and trunk scores of 2 and between 3-4, respectively for the majority of the participants highlighted that the farmworkers adopted a forward inclined posture during harvesting. Lastly, a leg score of more than 2 indicated a stressful position due to awkward bending postures while performing the tasks. It was also found from the grand REBA score that the postures adopted with a high-risk score of 8-10 (action

level 3) and a very high-risk score of 11 or more (action level 4) were about 30 % and 70 %, respectively in sub-task 1. Whereas a REBA score of 8-10 (action level 3) was found for more than 80 % of the farmworkers in sub-task 2. The result is in line with the findings of the study conducted in Malaysia by Rani *et al.* (2016) in which 23.8 % of high-risk scores and 76.8 % of very high-risk scores were reported in pineapple harvesting in Malaysian conditions.



Figure 4.1. Postures adopted during pineapple harvesting and collection



Figure 4.2. Postures adopted during loading fruits for local transportation

Table 4.1. REBA scores of sub-task for different body regions (n1 = 20)

REBA Score	Body parts n1 (%)						Score A	Score B	Grand Score
	Upper arms	Lower arms	Wrists	Neck	Trunk	Legs			
1	2 (10)	2(10)	-	3 (15)	-	-	-	-	-
2	2 (10)	18 (90)	-	17 (75)	1 (5)	13 (65)	-	-	-
3	11 (55)	-	20 (100)	-	11 (55)	5 (25)	-	-	-
4	5 (25)	-	-	-	8 (40)	2 (10)	-	3 (15)	-
5	-	-	-	-	-	-	1 (5)	1 (5)	-
6	-	-	-	-	-	-	5 (25)	11 (55)	-
7	-	-	-	-	-	-	8 (40)	-	-
8	-	-	-	-	-	-	5 (25)	5 (25)	-
9	-	-	-	-	-	-	1 (5)	-	3 (15)
10	-	-	-	-	-	-	-	-	3 (15)
11	-	-	-	-	-	-	-	-	5 (25)
12	-	-	-	-	-	-	-	-	9 (45)
13-15	-	-	-	-	-	-	-	-	-
Weighted mean score	2.95	1.9	3.0	1.85	3.35	2.45	7	6.15	11

Note: Score A (Combined score for neck, trunk, and legs) and Score B (combined score for arms and wrists)

Table 4.2. REBA scores of sub-task 2 for different body regions (n2 = 8)

REBA Score	Body parts n2 (%)						Score A	Score B	Grand Score
	Upper arms	Lower arms	Wrists	Neck	Trunk	Legs			
1	1 (12.5)	2 (25)	8 (100)	2 (25)		2 (25)	-	1 (12.5)	-
2	-	6 (75)	-	6 (75)		6 (75)	-	-	-
3	2 (25)	-	-	-	1 (12.5)	-	-	-	-
4	4 (50)	-	-	-	7 (87.5)	-	1 (12.5)	3 (37.5)	1 (12.50)
5	1 (12.5)	-	-	-	-	-	3 (37.5)	3 (37.5)	-
6	-	-	-	-	-	-	4 (50)	1 (12.5)	-
7	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	2 (25)
9	-	-	-	-	-	-	-	-	4 (50)
10	-	-	-	-	-	-	-	-	1 (12.5)
11-15	-	-	-	-	-	-	-	-	-
Weighted mean score	3.5	1.75	8.0	1.7	3.9	1.75	5.4	4.25	8.25

Note: Score A (combined score for neck, trunk, and legs) and Score B (combined score for arms and wrists)

4.3.2 Ergonomic risk factors

The farmworkers were also exposed to several ergonomics' stressors (forceful exertions, highly repetitive motion, excessive bending, prolonged stooping, heavy load carrying etc.) during the pineapple harvesting task in northeast India as presented in Table 4.3. These stressors might be linked to the prevalence of MSDs among pineapple farmworkers which is in line with the studies reported by Rani *et al.* (2016) and Gupta and Tarique (2013). Moreover, other aspects of the working environment such as walking uphill or downhill on uneven hilly terrain during the harvesting task imposed an additional burden on the farmworkers. Therefore, this study suggested an urgent investigation to implement necessary changes for improving working conditions and occupational wellness of the pineapple farmworker in northeast India. It is believed that the introduction of innovative and sustainable interventions might help in reducing ergonomic risk factors. McMillan *et al.* (2015) also suggested that structured interventions could be engineering changes or behavioral modifications. Though effective implementation of behavioral changes is very challenging, motivated workers might adopt it to reduce their risk of MSDs (McMillan *et al.*, 2015).

Table 4.3. Ergonomic risk factors in pineapple harvesting task

Sub-activity in harvesting	Risk factors	Possible consequences
Harvesting and collection	Forceful exertion on the shoulder	Shoulder pain
	Highly repetitive deviation and twisting of the wrist from a neutral position (> 20 times in a minute)	Wrist pain
	Excessive bending posture during harvest	Low back pain
	Carrying heavy load (40-50 kg uphill or downhill at a time, a total of 400-500 kg in a day)	Pain in neck and Low back
	Prolonged stooping during unloading of pineapple from the basket/gunny bags at the collection point.	Low back pain
Transportation to a local transit point from the collection point	After completion of the harvest session, prolonged stooping during the loading of pineapple into the basket/gunny bag with or without post-harvest operations	Low back pain
	Carrying heavy load (40-50 kg downhill at a time, a total of 400-500 kg in a day to the transit point away from the farm)	Pain in neck and low back pain

4.4 Conclusions

This study highlighted that the pineapple farmworkers were exposed to various ergonomics risks, which include awkward work posture, repetitive tasks, heavy load carrying on their head, and improper rest-pause might be linked to the prevalence of MSDs among the pineapple farmworkers. The present study also highlighted the high prevalence of MSDs (79.61%) and the prominent part of the body affected was low back (76.32 %) among pineapple farmworkers in northeast India. The postures adopted during the pineapple harvesting task with a high-risk score of 8-10 (action level 3) and a very high-risk score of 11 or more (action level 4) were about 30 % and 70 %, respectively. This study also highlighted a high-risk score of 8-10 (action level 3) for more than 80 % of participants during the pineapple loading task for local transportation. Moreover, walking uphill or downhill on uneven, hilly terrain during the harvesting task imposed an additional burden on the farmworkers. Therefore, the present study suggested that there is an urgent need to explore effective preventive interventions suited to local conditions for improving the working conditions and occupational wellness of the pineapple farmworker population in northeast India.

5 Design and development of manual pineapple harvester

Chapter Abstract

This study focuses on the variability in growth and physical properties of pineapple plants, specifically the Kew variety cultivated in northeast India. It was observed that scattered heights of pineapple plants ranged from 630 mm to 950 mm, attributing this variation to soil conditions, climate, and individual plant characteristics. Detailed insights into the Kew variety's fruit characteristics reveal variations in weight (0.75 kg to 1.45 kg), diameter, length, and crown length. Considering the design and development of pineapple harvesting tools, the research emphasizes the importance of customization based on fruit parameters. Ergonomic considerations, including grip dimensions and handle lengths, are vital for tool usability. Machine parameters, such as adaptable cutting mechanisms and lightweight materials, contribute to the efficacy and user-friendliness of tools. The study identifies sub-functions and sub-components critical for the device's functionality, ensuring a comprehensive exploration of potential concepts. The chosen prototype features a coordinated fruit grabber and cutter blade mechanism, ensuring a controlled and efficient harvesting process. Practical demonstrations and field trials in pineapple-growing villages provide valuable insights into the performance of the prototypes, particularly highlighting the need for modifications to enhance usability. Farmer feedback emphasizes the importance of user-centric design considerations, ensuring the device's technical effectiveness and ergonomic practicality in real-world conditions. In conclusion, this research presents a holistic approach to pineapple harvesting tool design, considering crop parameters, user parameters, and machine parameters. The systematic concept generation and evaluation process, along with field trials and user feedback, contribute to the development of an effective and user-friendly pineapple harvesting device tailored to the needs of farmers in northeast India.

5.1 Introduction

The design and development of a specialized pineapple harvesting device tailored to the local conditions of Northeast India is imperative for addressing the region's unique agricultural challenges. Considering the topographical and climatic variations in the area, the device must be robust and adaptable. The design should incorporate features that account for the hilly terrain and diverse

weather patterns, ensuring optimal performance across different regions of Northeast India. Moreover, the device must be user-friendly and cost-effective to cater to the predominantly small-scale farming communities in the region. Localized expertise and input from farmers should be integral to the development process, ensuring that the device aligns with their specific needs and practices. Emphasis on sustainability is crucial, promoting eco-friendly materials and energy-efficient mechanisms. By integrating technology with a deep understanding of the local context, the design and development of a specialized pineapple harvesting device have the potential to revolutionize agricultural practices in Northeast India, fostering increased efficiency and economic growth within the pineapple cultivation sector.

5.1.1 Need for pineapple harvesting device

In Northeast India, the cultivation of pineapples holds immense economic significance for local farmers, contributing substantially to the region's agricultural sector. However, the traditional method of pineapple harvesting in this region involves manual labour, which is not only time-consuming but also physically demanding. The need for a specialized pineapple harvesting device arises from the labour-intensive nature of the current practices and the increasing demand for efficiency in agricultural operations. Such a device would not only alleviate the burden on farmers but also enhance overall productivity by streamlining the harvesting process. Additionally, the introduction of a mechanized harvesting solution could potentially attract more individuals to engage in pineapple cultivation, thereby boosting the agricultural economy in Northeast India. As the region continues to face challenges related to labour shortages and the need for increased agricultural output, the development and adoption of a pineapple harvesting device tailored to the unique conditions of the area can play a pivotal role in transforming the pineapple industry and fostering sustainable agricultural practices.

5.1.2 Challenges in existing solutions

The existing methods of pineapple harvesting in Northeast India face several challenges that impede the efficiency and sustainability of this crucial agricultural practice. Primarily, the reliance on manual labour for harvesting is a significant bottleneck, as the labour-intensive process is time-consuming and physically demanding. The scarcity of skilled labour further exacerbates this challenge, leading to delays in harvesting and potential losses for farmers. Additionally, the traditional

methods are often less precise, resulting in damage to the fruit and decreased overall yield. Seasonal variations in weather conditions, prevalent in Northeast India, also pose a challenge as they can impact the timing and success of manual harvesting. The need for a more technologically advanced and mechanized approach becomes apparent in addressing these challenges, ensuring a more efficient, precise, and sustainable pineapple harvesting process that can withstand the region's unique environmental and labour constraints. As Northeast India strives to enhance its agricultural practices, identifying and mitigating these challenges in existing harvesting solutions is paramount for the growth and prosperity of the pineapple industry in the region.

5.2 Methodology

5.2.1 Product development process

The basic objective of ideation/concept generation is to examine as many concepts as possible to satisfy the end user's needs in a certain situation. To suit the needs of the user (in this case, pineapple growers), a concept must first be generated. Field research was conducted to assess the needs of the pineapple farmers. After conducting field research, the data was examined to develop design criteria and determine the needs of pineapple farmers in northeast India. At this stage, new ideas are explored that are novel, economically viable, and of value to the pineapple farmers. The design task is fragmented into sub-functions that can be easily understood and solved. For this purpose, Morphological Chart for ideas generation was employed to come up with as many as design concepts. With the aid of this tool, the main function was identified, and broken down into smaller functions, and ideas for achieving each smaller function were then generated. This exercise generated a tabular list of the deconstructed sub-functions of a design along with the methods by which each sub-function may be realised. The column on the left has a list of the sub-functions. The sub-functions were listed with the means to the right of them. Once the chart was populated, the possible means (solutions) were combined to form connected solutions as variants of possible solutions for pineapple harvesting. Then, Pugh Chart was used to compare and evaluate multiple options with respect to certain criteria. From the solutions (design concepts) generated earlier, the best concepts were selected as per the Pugh Chart and came up with a final design for pineapple harvesting.

5.2.2 Structure of pineapple plant

Most of the pineapple plants in their economic life (5-6 years) were growing upright or leaning slightly (Figure 5.1). But even for years, pineapple growers in northeast India continued to use their pineapple plants as ratoon crops. As a result, the old mother plants had numerous slips, air suckers, and ground suckers from which two to three suckers were kept with the mother plants for subsequent fruiting. To keep the plants healthy and prevent obstacles during intercultural operations and fruit harvesting, the suckers were periodically removed. Despite de-suckering (thinning out of excess suckers and slips), this old plantation was mostly fruited in leaning or lodged conditions. The pineapple plant heights at the measuring location were rather dispersed, with the highest being 950 mm. The majority of them were centered in the 630–850 mm range.

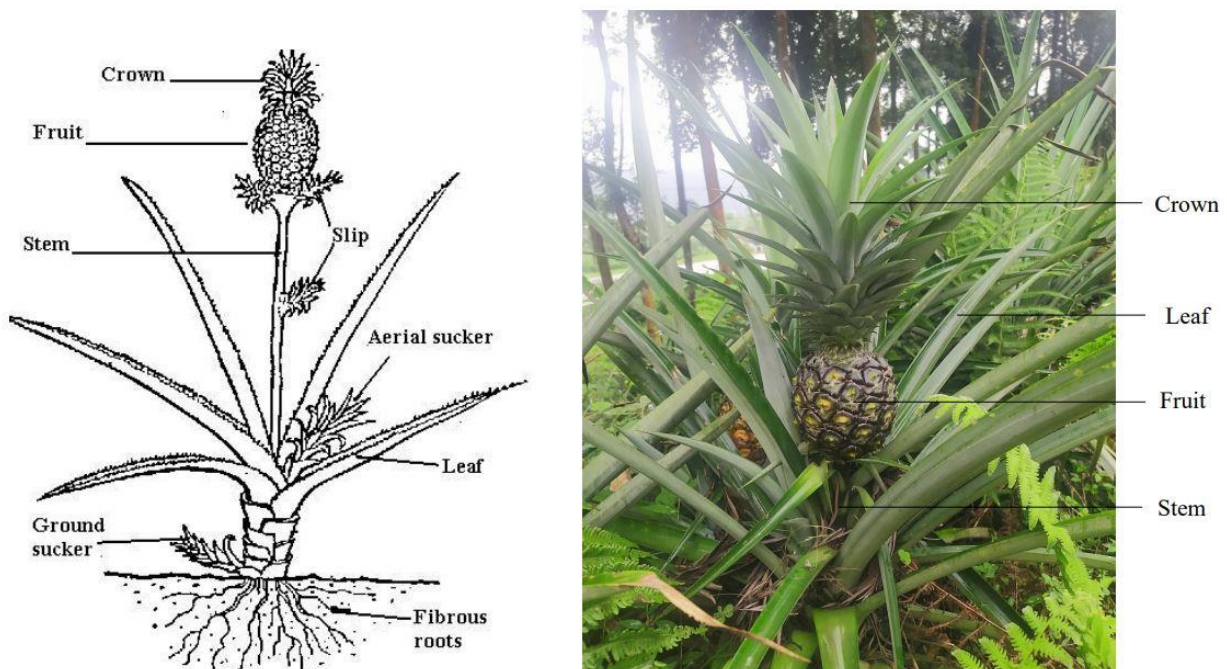


Figure 5.1. Structure of pineapple plant (Anon, 2024)

5.2.3 Physical properties of pineapple fruit

The detailed physical properties of pineapple fruit (Kew variety) are disclosed in Table 5.1. The weight of a single whole fruit for pineapple varies between 0.75 kg and 1.45 kg with an average value of 1.12 kg. Table 5.1 shows the diameters of pineapple fruits at three different sections of whole pineapple fruit. The diameter of the pineapple fruit was found at a maximum, in the middle section and less at both ends. The maximum and minimum observed diameters for the *kew* variety cultivated in northeast India were 10.4 cm and 8.4 cm, respectively at the middle diameter. The maximum and minimum observed fruit lengths were 15.1 cm and 10.2 cm, respectively. The maximum and minimum length of the crown was found to be 26.0 cm and 16.5 cm, with the average was 21.4 cm.

Table 5.1. Fruit length and diameter of pineapple

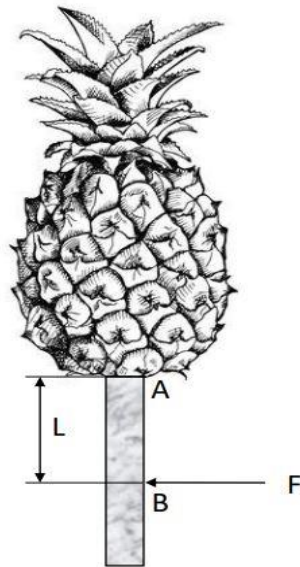
Parameters	Maximum	Minimum	Average	STD
Top diameter (D1), cm	8.5	6.5	7.51	0.53
Middle diameter (D2), cm	10.4	8.5	9.5	0.55
Bottom diameter (D3), cm	8.9	7.2	8.19	0.48
Fruit length, cm	15.1	10.2	13.45	1.42
Crown length, cm	26.0	16.5	21.41	2.03
Stalk diameter, cm	2.3	1.6	2.07	0.16
Fruit weight, kg	1.45	0.75	1.12	0.18



Figure 5.2. Measurement of physical properties of pineapple

5.2.4 Mechanical properties of pineapple fruit

The average and maximum bending moment when the fruit break at the calyx with maturity levels (stages) S1 (0–25% yellow) and S2 (25–50% yellow) were 3.67 N.m and 2.41 N.m; and 4.96 N.m and 3.03 N.m, respectively (Liu *et al.*, 2022). Between S1 and S2 maturity, pineapples are reported to be easier to transport and less prone to damage (Ikram *et al.*, 2021). At the calyx of the fruit, all fruit stems were broken from the abscission layer, and the length of the moment arm (L) multiplied by peak force (F) yielded the necessary bending moment M to break the fruit at this point (Figure 5.3).



A = fruit calyx abscission layer
 B = Position of fruit stem under pressure
 D = Length of moment arm
 F = Peak force

Loading rate = 0.33 m/s
 Transducer used: 250 N
 Machine used: Universal testing machine
 Accuracy: $\pm 0.5\%$
 Resolution: $\pm 1/500,000$

Moment, $M = F \times L$

Figure 5.3. Force diagram (simplified) of bending test (Lie *et al.*, 2022)

A study by Singh *et al.* (2022) shed light on the cutting forces associated with the *Kew* and *Queen* pineapple varieties, in addition to their respective maximum displacements. Notably, the results demonstrated that the *Kew* variety demanded a greater amount of stalk cutting energy compared to the *Queen* variety. Specifically, the peak cutting force for the *Queen* variety ranged from 155.36 to 183.49 N, with a mean value of 168.15 N. Conversely, the *Kew* variety exhibited a peak cutting force spanning from 167.89 to 210.35 N. This meant that the mean peak cutting force for the *Kew* variety exceeded that of the *Queen* variety by 11.97%. These findings have significant implications for understanding the power requirements necessary to detach pineapples from the plant. For the *Queen* variety, the cutting energy fell within the range of 0.99 J to 1.45 J, whereas the *Kew* variety displayed a broader range, from 1.82 J to 2.31 J. The mean cutting energy required for the *Kew* variety was 39% higher when compared to the *Queen* variety.

5.2.5 Design Considerations and Limits

The basic design criteria considered in the design of this device included:

- It should effectively grab and harvest the pineapple fruit.
- It should be easy to operate and portable (lightweight).
- It should be harvested safely with proper work posture.
- It should be low cost.
- It should be easy to maintain after use.
- It should be a simple design so that it can be fabricated locally.

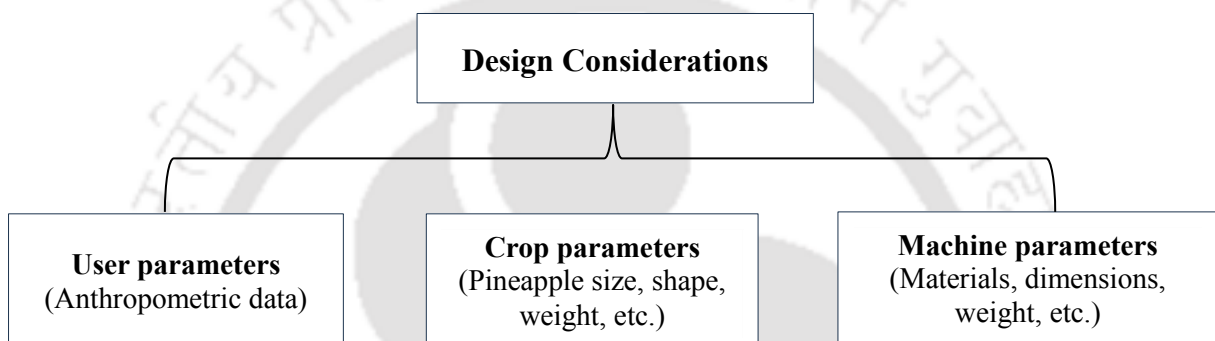


Figure 5.4. Design considerations for development of proposed harvester

Crop parameter

In the design and development process of farm tools for fruit harvesting, an in-depth comprehension of fruit crop parameters assumes paramount importance. Firstly, the tools must be tailored to the diverse characteristics of the targeted fruit (Pineapple), considering factors such as fruit size, shape, fruit length etc. This customization ensures that the tools can delicately handle fruits during the harvesting process, minimizing damage and preserving quality. By meticulously incorporating these fruit crop parameters into the design and development endeavours, hand tools for fruit harvesting can enhance efficiency, minimize wastage, and contribute to sustainable agricultural practices. From the study, it was found that the maximum diameter, fruit length, stalk diameter and fruit weight were 10.4 cm (middle diameter), 15.1 cm, 2.3 cm and 1.45 kg, respectively. The dimensions of the pineapple fruit harvesting device were selected based on the physical properties of pineapple fruit, i.e., fruit dimensions, maximum allowable compressive force, fruit weight etc. Therefore, the dimensions considered for the fruit grabber were 12 cm in diameter during closed

position and 16 cm in length of the fruit grabber, respectively.

Anthropometric characteristics of farmers (user parameter)

Another facet of agricultural tool development revolves around user parameters. A comprehensive understanding of user needs significantly influences tool efficacy and usability. Primarily, the ergonomic aspects come to the fore, necessitating tools that are comfortable to handle for extended periods, minimizing strain and fatigue for farmers who spend long hours in the field. Secondly, the tools must align with the diverse skill levels and physical capabilities of the users, catering to both seasoned agricultural veterans and newcomers alike. By thoughtfully integrating these user parameters, the design and development of farm tools can truly elevate efficiency, comfort, and sustainability within agricultural practices.

Grip dimensions

A study by Agrawal *et al.* (2010) centered on the anthropometric analysis of agricultural workers in Meghalaya, northeastern India, and its implications for the design of agricultural tools and equipment. He made comparisons and found that the values of several body measurements do not significantly differ amongst the states in the area. Therefore, workers throughout the region can efficiently use tools and equipment that were built based on the data that was obtained. Nonetheless, in comparison to other regions of the nation, the region's population has smaller bodies than those of India. To ensure effective force application when using manually operated farm tools, a proper grip is essential. The study conducted on agricultural workers in northeast India (Meghalaya) examined the grip diameters (inner measurements) for males and females at different percentiles. For males, the grip diameters were 3.7 cm (5th percentile), 4.2 cm (50th percentile), and 4.7 cm (95th percentile), while for females, the values were 3.3 cm, 3.6 cm, and 4.1 cm respectively. For a comfortable holding of the grip, the grip needs to be designed in such a way that a person with 5th percentile body dimensions can properly grip the handle. To ensure comfortable handling for individuals with smaller dimensions, the minimum grip diameter should be 3.7 cm for males and 3.3 cm for females. The length of the grip is determined by the width of the palm of the population. To allow for proper grip, the handle length should be designed based on the 95th percentile individual. For males, the minimum handle length should be 9.9 cm, and for females, it should be 9.5 cm. Since the same type of locally available tools was found to be used by both genders except

bamboo baskets. Therefore, the grip dimensions considered were 3.00 cm as grip diameter and 10 cm as handle length to accommodate both male and female farmers.

Handle Holding Height

The height at which the handle is held is determined by the elbow height of the users and the acceptable range of elbow angles. According to Grandjean (1981), the recommended range for the elbow angle is 100-110 degrees. For the agricultural workers in northeast India (Meghalaya), the standing elbow heights for different percentiles were measured (Agrawal *et al.*, 2010) (Table 5.2). For males, the heights were 94.7 cm (5th percentile), 101.6 cm (50th percentile), and 107.6 cm (95th percentile). For females, the corresponding values were 90.6 cm, 96.1 cm, and 101.2 cm respectively. At an elbow angle of 100 degrees, the handle height should be 89.5 cm for males and 85.7 cm for females at the 5th percentile. For individuals at the 95th percentile, the handle heights should be 95.6 cm and 101.2 cm for males and females respectively. To maintain an elbow angle of 110 degrees, the corresponding handle heights should be 81.0 cm and 84.6 cm for the 5th percentile individuals, and 89.0 cm and 95.6 cm for the 95th percentile males and females respectively.

Table 5.2. Anthropometric characteristics of farmers for northeastern states

Parameters	Male			Female		
	5 th	50 th	95 th	5 th	50 th	95 th
Grip diameter (Inside), cm	3.7	4.2	4.7	3.3	3.6	4.1
Grip Length, cm	-	-	9.9	-	-	9.5
Handle Holding height, cm	94.7	101.6	107.6	90.6	96.1	101.2

Source: Agrawal *et al.* 2010

Machine parameters

Incorporating machine parameters into the creation of fruit harvesting hand tools further may underscore their efficacy and impact. It is necessary to implement adaptable cutting or gripping mechanisms which is crucial to accommodate varying attachment strengths across different fruit types. Lightweight materials contribute to user-friendliness without compromising durability. Additionally, tools should facilitate minimal wastage through effective mechanisms to catch and collect harvested fruits. Portability and maneuverability are pivotal for navigating dense foliage and

reaching fruits in challenging positions. Lastly, ensuring maintenance convenience through easily accessible cleaning and parts replacement enhances the longevity and usability of these tools. By thoughtfully addressing these machine and hand tool parameters, the design and development of fruit harvesting hand tools can significantly enhance overall efficiency, product quality, and user satisfaction within agricultural practices.

5.3 Development of prototype and Trials

5.3.1 Concept Generation

From the data collected and analysis, numerous sub-functions of the pineapple harvesting device that are necessary to fulfil the device's overall functions were identified. The following sub-functions were identified based on the functional diagram. They were: 1. Easy grabbing of pineapple fruit, 2. harvest of fruit, and 3. Collection of harvested fruit. For each sub-function, various possible concepts were explored as many as possible. To accomplish the entire sub-functions, different options had to be accessible. Next, the choices made for every sub-function were identified as sub-components. The sub-components that comprised the sub-functions were arranged logically to accomplish the machine's primary overall function. Then, the sub-components needed for the developed sub-functions were identified and decided for easy grabbing, harvesting, holding, etc.

5.3.2 Construction of Morphological Chart

For preparing Morphological chart (Norris, 1963), the main function of the pineapple harvester was identified, split down into smaller functions, and concepts for achieving each smaller function were generated. The exercise produced a tabular list of the deconstructed sub-functions of a design along with the methods by which each sub-function may be achieved. The column on the left has a list of the sub-functions. The sub-functions were listed with the means to the right of them. Following the chart's filling, all of the options (solutions) were amalgamated to generate connected solutions, which were then versions of potential solutions for pineapple harvesting by various amalgamations, resulting in a wide range of product arrangements to fulfil the device's overall function.

Table 5.3 lists each unique sub-component that can result in the aforementioned sub-functions. For instance, several methods of grabbing (grab from one side, grab from the top, etc.) applying different mechanisms, such as brake type lever, finger type mechanism, link bar type mechanism, etc., might be utilized to achieve the sub-function "grabbing of fruit." To determine the overall function of the pineapple harvester, each sub-component could be combined with other sub-components under specific sub-functions. Thus, the morphological chart was used to generate ideas for numerous pineapple harvester designs.

Table 5.3. Morphological chart for concept generation of manual pineapple harvester

		SOLUTIONS →				
SUB-FUNCTIONS ↓	Grabbing of pineapple fruit	<i>Ways of grabbing</i>	Grab from one side	Grab from the top	-	-
		<i>Mechanisms</i>	Brake type lever mechanism	Finger type lever mechanism	Link-bar mechanism	-
	Harvest of fruit	<i>Ways of harvesting</i>	Breaking the stalk	Cutting the stalk	-	-
		<i>Mechanisms</i>	Bending	Shearing	Impact	-
	Collection of harvested fruit	<i>Manual collection</i>	-	-	-	-

The following is a list of the sub-components that were combined under various sub-functions in order to develop the new pineapple harvester:

- # **Design concept 1:** Grab from one side + Brake lever + Breaking the stalk by shearing
- # **Design concept 2:** Grab from one side + Brake lever + Breaking the stalk by bending
- # **Design concept 3:** Grab from one side + Brake lever + Cutting the stalk by impact
- # **Design concept 4:** Grab from one side + Brake lever + Breaking the stalk by shearing-cum-bending
- # **Design concept 5:** Grab from one side + Link-bar + Breaking the stalk by bending
- # **Design concept 6:** Grab from top + Brake lever + Breaking the stalk by bending
- # **Design concept 7:** Grab from top + Finger type lever + Breaking the stalk by bending

5.3.3 Concept generation through sketching

As seen in Figure 5.5, product designs were sketched in pencil on paper during the conceptual design stage. The first sketches depicted all of the possible solutions that may be found for the identified issue. Through drawing, as many potential answers as possible were produced for the given situation. Note that the amalgamation matrix does not have to indicate the logical sequence in which each sub-component is related to the other; rather, it simply refers to the sub-components chosen under a sub-function.

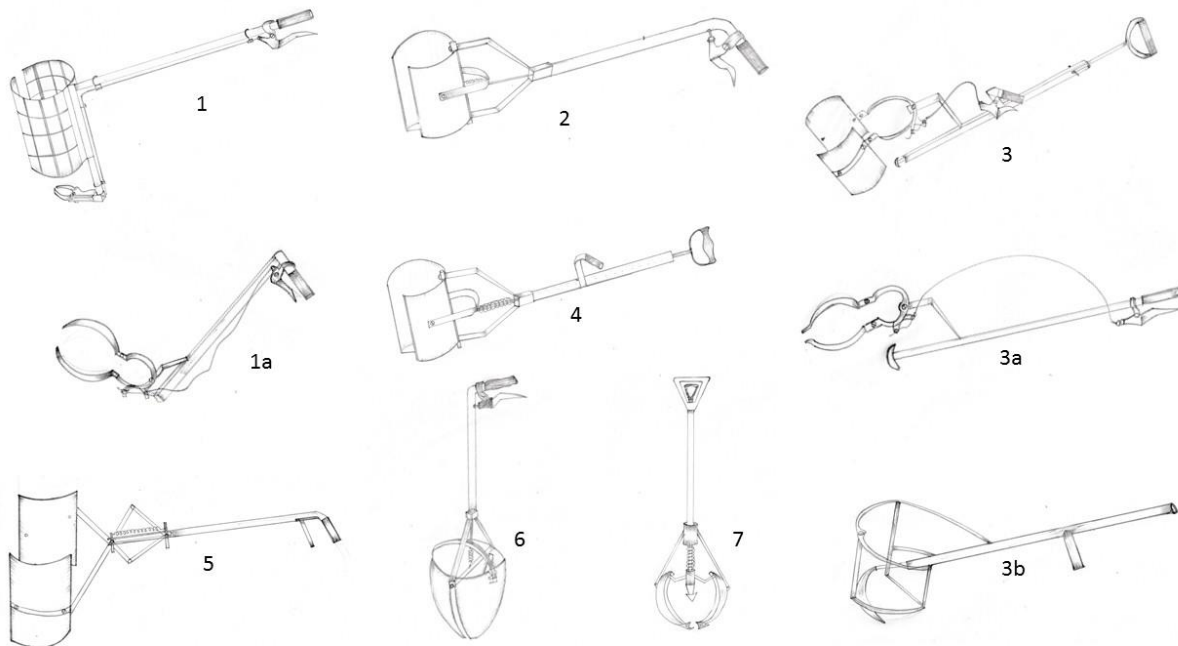


Figure 5.5. Sketches of seven concepts generated from amalgamation

5.3.4 Concept Evaluation and Selection

Following the creation of the many concepts, each one had to be examined to determine which one was the best. Establishing the evaluation criteria by which the concepts were to be selected was the first stage in the concept analysis process. These requirements varied from product to product and were mostly based on the kind of product that needed to be designed. Then Pugh Chart (Pugh, 1991) was employed to select the best design concepts.

Table 5.4 below displays the Pugh chart made for the pineapple harvester. The various concept solutions were examined by considering the existing traditional method as the datum. The concept solutions were analysed for each of the criteria. The various solutions were ranked using a scale consisting of the symbols "-", "0," and "+," where a negative symbol (-) denoted a lower-quality thought than a positive symbol (+). An individual design concept received a positive (+) rank if it outperformed the datum concept for that particular criterion. A negative (-) rank was given to the concept if it was substandard. A zero (0) rank was given if the datum's execution and a design concept matched a certain criterion. For every design concept, an estimated net score was obtained. The idea with the greatest score on the Pugh chart was chosen as the superior concept above the other concepts. Concept 4 received the highest score possible according to the Pugh chart in this exercise.

Table 5.4. Pugh chart for concept selection of manual pineapple harvester

Design Criteria	Weight	Design Concepts						
		1	2	3	4	5	6	7
Grabbing fruit	3	0	+	++	+	++	0	+
Pineapple harvest	3	0	---	---	++	---	++	---
Field capacity (Productivity)	3	0	+	++	++	++	0	+
Fruit damage	3	0	0	0	0	0	0	0
Working posture	3	0	0	0	0	0	0	0
Low cost	2	0	0	0	0	0	0	0
Light weight (Portability)	2	0	0	0	0	0	0	0
Safety	2	0	+	+	+	+	+	+
Ease of use	1	0	-	0	0	-	0	-
Comfort	2	0	0	+	++	+	+	0
Maintenance	1	0	+	0	0	+	0	+
	+	0	9	16	21	17	10	9
	0	0	0	0	0	0	0	0
	-	0	10	9	0	10	0	10
Total		0	-1	7	21	7	10	-1

Note: “+” Better than datum/baseline, “-” Worse than datum/baseline, and “0” Same as datum/baseline

5.3.5 Development of digital prototype

Following the concept generation process, the next step was to design and develop the prototype of a pineapple harvesting device. The CAD models of the selected design of pineapple harvesting devices were prepared using SolidWorks software (Figure 5.6). The mock-ups of four selected design concepts were also built and evaluated at the laboratory for their feasibilities (Figure 5.7) out of which two design concepts (concepts 3 and 4) were finalized for development and fabrication of full-scale prototypes for testing and evaluation at farmers' field.

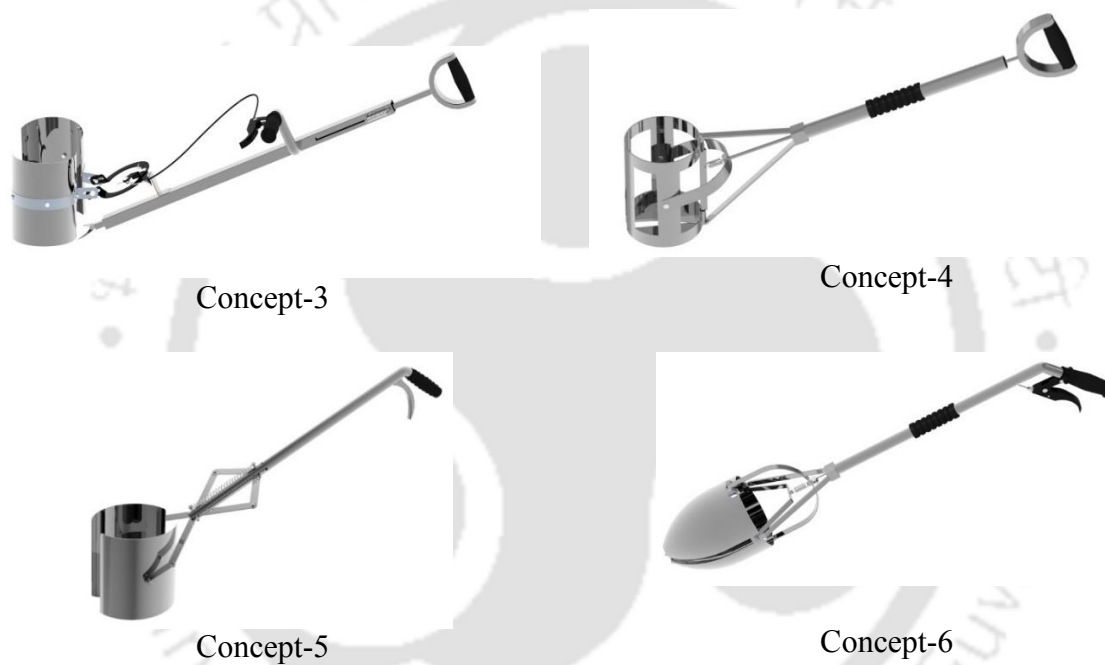


Figure 5.6. CAD models of four selected design concepts of manual pineapple harvester



Concept-3



Concept-4



Concept-5



Concept-6

Figure 5.7. Mock-ups of four selected design concepts of manual pineapple harvester

5.3.6 Fabrication Physical Prototype

The full-scale prototypes of Concept 3 and Concept 4 are shown in Figures 5.8 and 5.9. The prototype of concept 3 consists of three main sub-units: (i) a fruit grabber with a brake-lever mechanism to grab the fruit, (ii) a fruit cutting blade with a tension spring-assisted mechanism to cut the fruit after grabbing it, and (iii) a main frame where both the grabbing and cutting mechanism are attached. During the harvesting process, the pulling force exerted by the operator from the brake lever is transmitted via cable to the brake lever mechanism. Due to the exerted pulling force, the brake lever mechanism rotates towards each other about the axis of the nut and bolt to close the flaps of the fruit grabber thereby achieving fruit grabbing. After grabbing the fruit, the cutter blade cut off the fruit stalk by impact. The harvested fruit is then held between the flaps and supported by the base of the flaps. In this way, pineapple fruits don't fall under their own gravity to the ground after harvest.



Figure 5.8. Prototype of manual pineapple harvester (Concept 3)

In the case of concept 4, the pineapple picker consists of three main units – a fruit grabber with a cutting knife arrangement at one end, a tension spring mechanism to operate the grabber at another end, and a frame in between attaching both at its two ends. The main frame has a support grip at its centre and is attached with a handle to hold and operate the picker at one end. In the harvesting process, the pulling force exerted by the operator from the handle is transmitted via the connecting rod to the arc arm. Owing to a pulling force, the flaps of the fruit grabber open up by rotating about the axial pole to the extent that it can grab the fruit. At this point, the tension spring gets expanded due to the exerted pulling force. When the flaps are in open position, the operator reaches out to grab the fruit inside the flaps and simultaneously makes breaking marks on the pineapple stalk by the left and right sharp edges of the blades attached at the bases of the flaps. After grabbing the fruit and making the breaking marks on the fruit stalk, the device is rotated either side to break out the fruit from the stalk at the breaking marks.

Cutting blades are a critical component and are specifically designed to efficiently and safely cut the fruits from the plant without damaging the fruit or the plant itself. The harvesting blades need to be sharp and durable to withstand the tough and fibrous nature of the fruit stalk of the plant. Innovations in blade technology, such as self-sharpening edges or materials with anti-corrosion properties, can contribute to more sustainable and cost-effective in fruit harvesting practices. In this study, three different designs of blades were used for the pineapple harvesting task as shown in Figure 5.9.



Figure 5.9. Prototype of pineapple harvester (Concept 4) with three designs of blade (a, b and c)

5.3.7 Testing and Field Trials for Users' Feedback

The prototypes were then taken to the pineapple-growing villages in the Ri Bhoi district of Meghalaya and demonstrated to the farmers (users) for feedback and necessary modifications (Figure 5.10). Field trials of the prototypes were also conducted both at the research farm, ICAR Umiam, Meghalaya, and the farmer's field in Nongkhrah Village, Ri Bhoi district, Meghalaya as shown in Figure 5.11. The performance of the pineapple harvester (Concept 4) was satisfactory under the field conditions for standing fruits. The pineapple fruit stalk could easily be broken and harvest the fruit by bending the harvester on one side after properly grabbing the fruit between the two halves of the fruit grabber to avoid the fruit falling on the ground after harvest. Out of the three designs of blade, jaw type blade (Blade-c) could make breaking marks easily on fruit stalk and outperformed the two designs of blade. Therefore, the other two blades were rejected from this study.

However, due to the weight of the fruits in addition to the weight of the device, there was a need to modify the handle and incorporate a support system for the forearm after the fruit is harvested. This is because the average weight of the fruits is 1.5 kg. Altogether, a total weight of about 3 kg is to be supported by one forearm after harvest and during the collecting of the harvested fruit by one hand and placed inside the basket strapped on the back of the farmers. It was observed that the grabbers were self-locked by the fruit weight and there was no need for a spring mechanism provided to hold the fruit by the strength of the spring.



Figure 5.10. Demonstration of pineapple harvester and users' feedback



Figure 5.11. Field trials of developed prototypes

5.3.8 Modification of pineapple harvester

During field trial and testing, the performance of the pineapple harvester was satisfactory under the field conditions for standing fruits. However, due to the weight of the fruits in addition to the weight of the device, there was a need to modify the handle and incorporate a support system for the forearm after the fruit is harvested. Because the average weight of the fruits is 1.5 kg. Altogether, a total weight of about 3 kg is to be supported by one forearm after harvest and during the collection of the harvested fruit by one hand and placed inside the basket strapped on the back of the farmers. Another modification required was the tension spring mechanism to operate the grabber. During the trial, it was observed that the grabbers were self-locked by the fruit weight and there was no need for a spring mechanism to hold the fruit by the strength of the spring.

The details of the modified pineapple harvesting device are illustrated in Figures 5.12 and 5.13 below. The modified device comprises three units. They are (1) integrating main frame cum actuator assembly, (2) fruit grabber cum cutter assembly, and (3) handle with adjustable elbow crutch assembly.

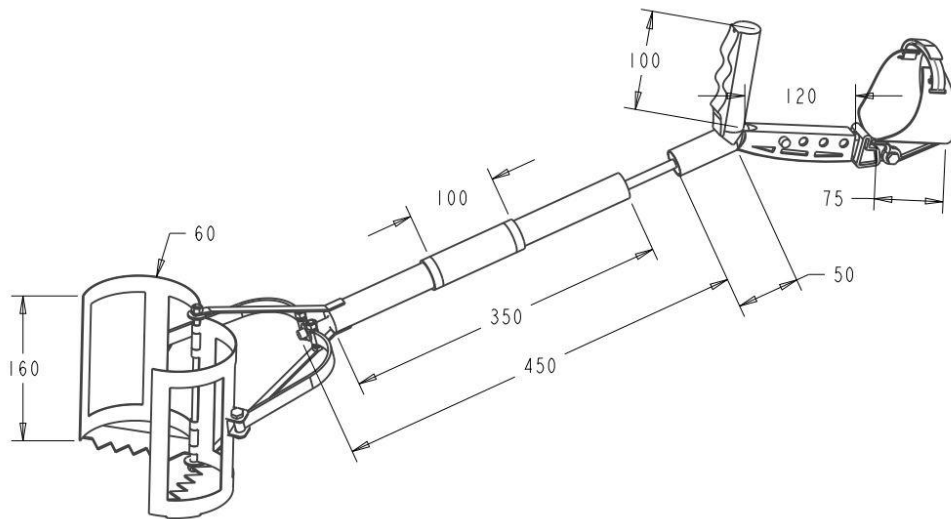
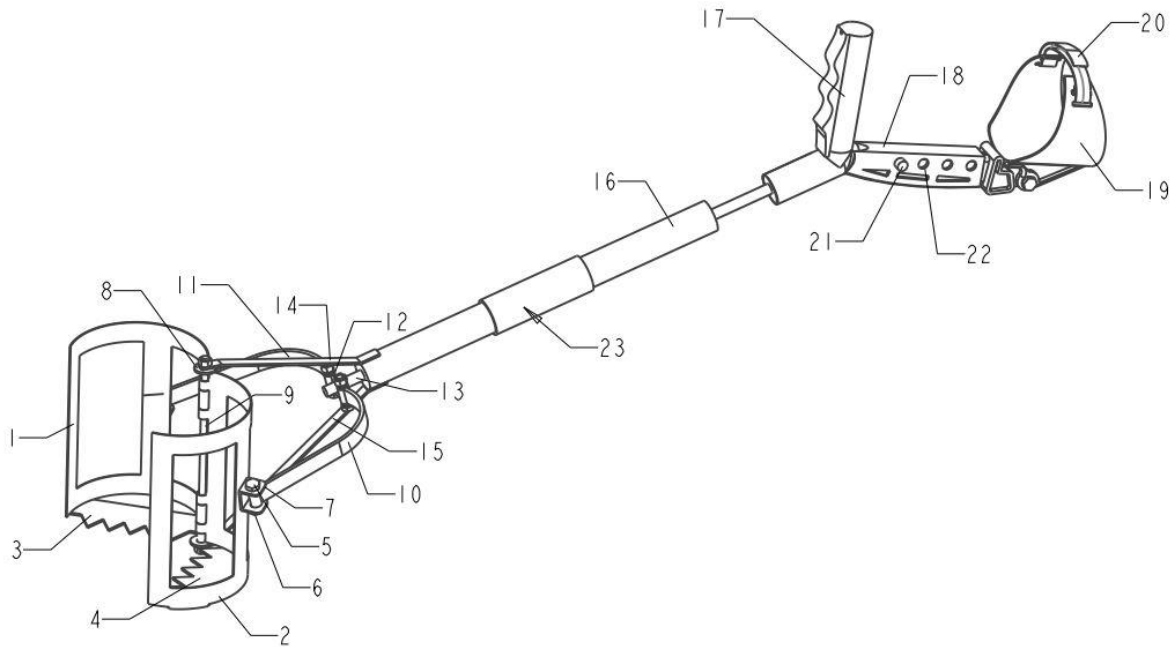


Figure 5.12. Modified pineapple harvester with dimensions



Components of pineapple harvester

- | | |
|--------------------------------|-------------------------------|
| 1. Grabber-right | 13. Connecting rod |
| 2. Grabber-left | 14. Main Frame Top Link |
| 3. Cutter-right | 15. Main Frame Bottom Link |
| 4. Cutter-left | 16. Main Frame Pipe |
| 5. Bolt | 17. Handgrip |
| 6. Nut | 18. Collar |
| 7. C-clamp | 19. Forearm Cuff |
| 8. Washer | 20. Strap for cuff adjustment |
| 9. Grabber axial rod | 21. Adjustment Pin |
| 10. Flexible C-clamp-Left | 22. Adjustment Hole |
| 11. Flexible C-clamp-Right | 23. Support grip |
| 12. Hinge for Flexible C-clamp | |

Figure 5.13. A schematic diagram of the newly developed pineapple harvester

In the harvesting process, the pulling force exerted by the operator from the hand (17) is transmitted via the connecting rod (13) to the flexible c-clamp ends (10 and 11). Owing to a pulling force, the flexible c-clamp moves backwards and rotates the two halves of the fruit grabber cum cutter about the axis of the radial rod (9) simultaneously to open up the fruit grabber cum cutter. Then, the device is brought forward in the open position to the target fruit for grabbing the fruit. After the fruit is targeted, pushing force is applied to grab and make breaking marks simultaneously on two sides of the fruit stalk by the two sharp edges of the cutting blades attached at the bases of the grabber. At this position, the breaking marks are made at a certain distance (up to 7 cm from the base of the fruit) to avoid breakage at the base of the fruit while bending it to harvest. Then, the device is rotated/bent at either side to break out the fruit at breaking marks from the fruit stalk. After the harvest, the harvested fruits are self-locked inside the grabber cum cutter and remain in a closed position due to fruit weight. In this way, pineapple fruits don't fall under their own gravity to the ground after harvest in this design. The harvested fruit is then collected by one hand in the basket strapped on the back of the farmer while holding the device in another hand.

This pineapple harvester is ergonomically designed to meet the requirements of small and marginal farmers in northeast India where pineapple is cultivated on hill slopes and foothills. This device enables the farmers to work in an upright standing position, thus eliminating the awkward postures being adopted (forward bending, stooping, etc.) during the harvesting task. It enables the farmers to work away from the sharp-edged and spiky leaves that cause cuts and injuries. It promotes safety in such pineapple harvesting tasks. The fine rubberized grips are provided at the gripping areas/ surfaces to minimize the pressure points to reduce damage to the fingers/ hands/palm, etc. A handle with an adjustable elbow crutch is incorporated using ergonomic design principles to ascertain handle width, circumference, actuating force, etc. This innovative harvester eliminates the need for a traditionally used sharp-edged tool like Dao with a strong force that often gives a sudden jerk to the hand and arm that causes nerve damage. Using this harvester, the cutting of pineapple fruit is achieved via the mechanical advantage provided by this innovative ergonomically designed pineapple harvester. All the parts of this ergonomic pineapple harvester are made up of stainless steel, and the handle grip is made up of soft plastic material having rubber grips. A field trial of the modified pineapple harvester was also conducted before its evaluation as shown in Figure 5.14.



Figure 5.14. Field trial of modified pineapple harvester

5.3.9 Constructional Details of Modified Device

The pineapple harvester consists of three main units – fruit grabber cum cutter arrangement at one end (A), handle with adjustable elbow crutch at another end (C), and main frame with flexible c-clamp actuating mechanism (B) in between attaching both at its two ends to operate the grabber cum cutter assembly (open/close) for pineapple harvesting (Figure 5.15). The materials used and their specifications for the fabrication of the newly developed pineapple harvesting device are given at *Appendix IX*.

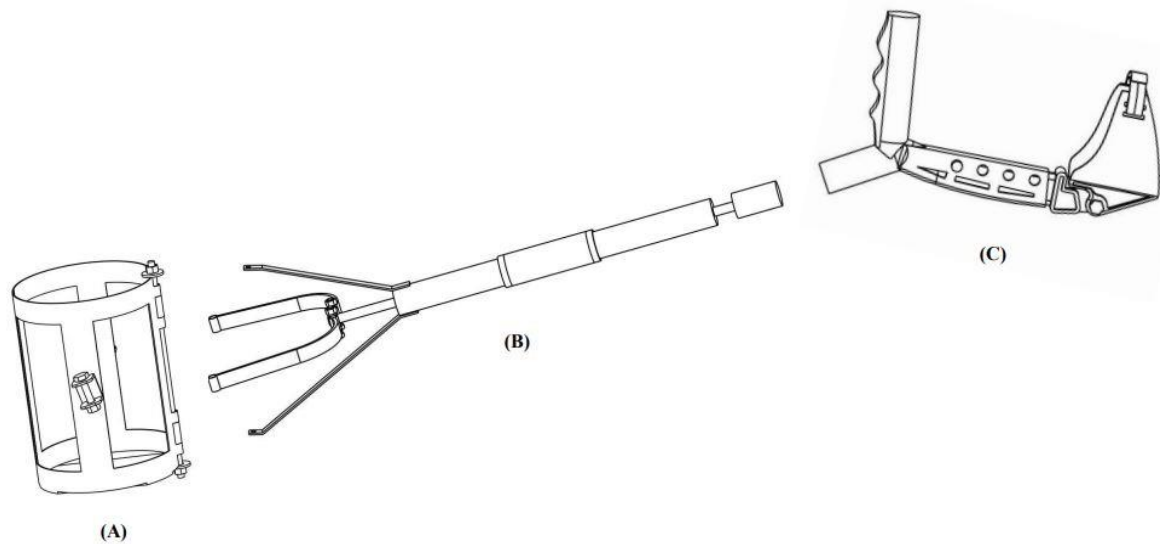
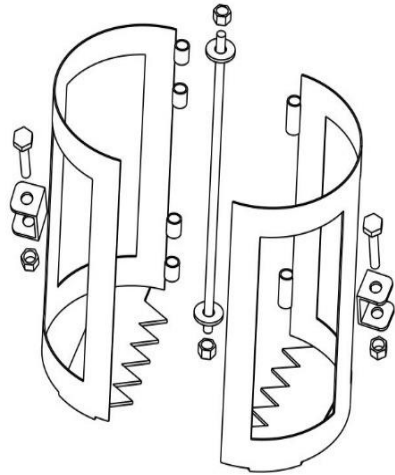


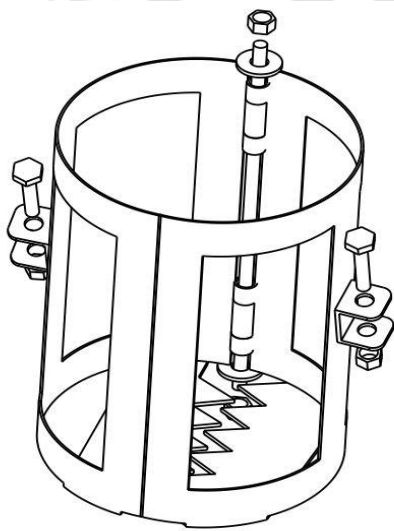
Figure 5.15. Three main units of the developed pineapple harvester

The fruit grabber cum cutter assembly (A)

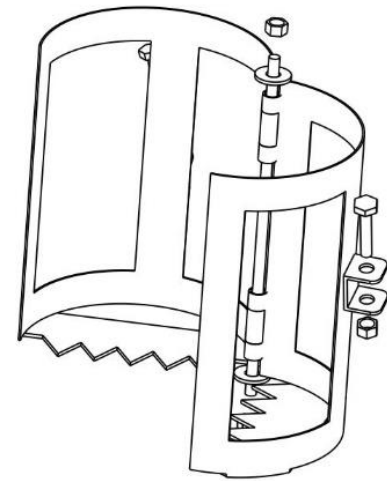
The fruit grabber cum cutting assembly (A) comprises two halves of the fruit grabbing flaps (12); upon these flaps, two sharp cutters (34) are welded at the lower ends of the flaps (Figure 5.16). The grabbing flaps are given cuts to reduce the weight of the fruit grabber cum cutter assembly and to provide fruit visibility of grabbed fruit during the harvesting task. These two halves of the fruit grabber cum cutter are hinged so that they can rotate about the axis of the axial rod (9) of the fruit grabber cum cutter. The two halves are also attached with C-clamps (7) to hinge the integrating main frame cum actuator assembly with nuts and bolts (56).



a. Exploded view of fruit grabber



b. Closed position



c. Open position

Figure 5.16. Fruit grabber cum cutter assembly (a, b and c)

An integrating main frame cum actuator assembly (B)

The integrating main frame cum actuator assembly (B) forms the linking part between the fruit grabber cum cutter assembly (A) and handle with adjustable elbow crutch assembly (C) and lies in the middle of both (Figure 5.17). The flexible C-clamps (10 11) of the mainframe cum actuator assembly are hinged with C-clamps (7) of the fruit grabber cum cutter using nuts and bolts (56) to enable backwards-forward movement. The top link (14) and bottom link (15) of the mainframe cum actuator assembly are fixed to the opposite ends of the axial rod (9) the grabber cum cutter assembly using washers (8) and nuts (6). The connecting rod (13) of the flexible c-clamp is attached to the handle through the main frame pipe (16). A support handgrip (23) is provided at the middle of the main frame pipe for holding the device and giving additional support during the harvesting task.

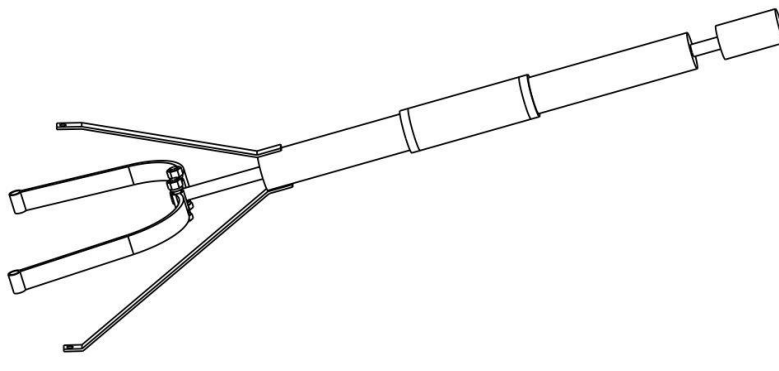


Figure 5.17. Integrating the main frame with actuator assembly

A handle with adjustable elbow crutch assembly (C)

The handle with adjustable elbow crutch consists of a handgrip (17), collar (18), forearm cuff (19) strap (20) along with an adjustment pin (21) and four adjustment holes (22) (Figure 5.18). The elbow crutch can be adjusted by changing the position of the adjusting pin at adjusting holes and it can rotate to adjust the forearm position. This assembly is fixed and linked to the connecting rod (13) of integrating main frame cum actuator assembly.

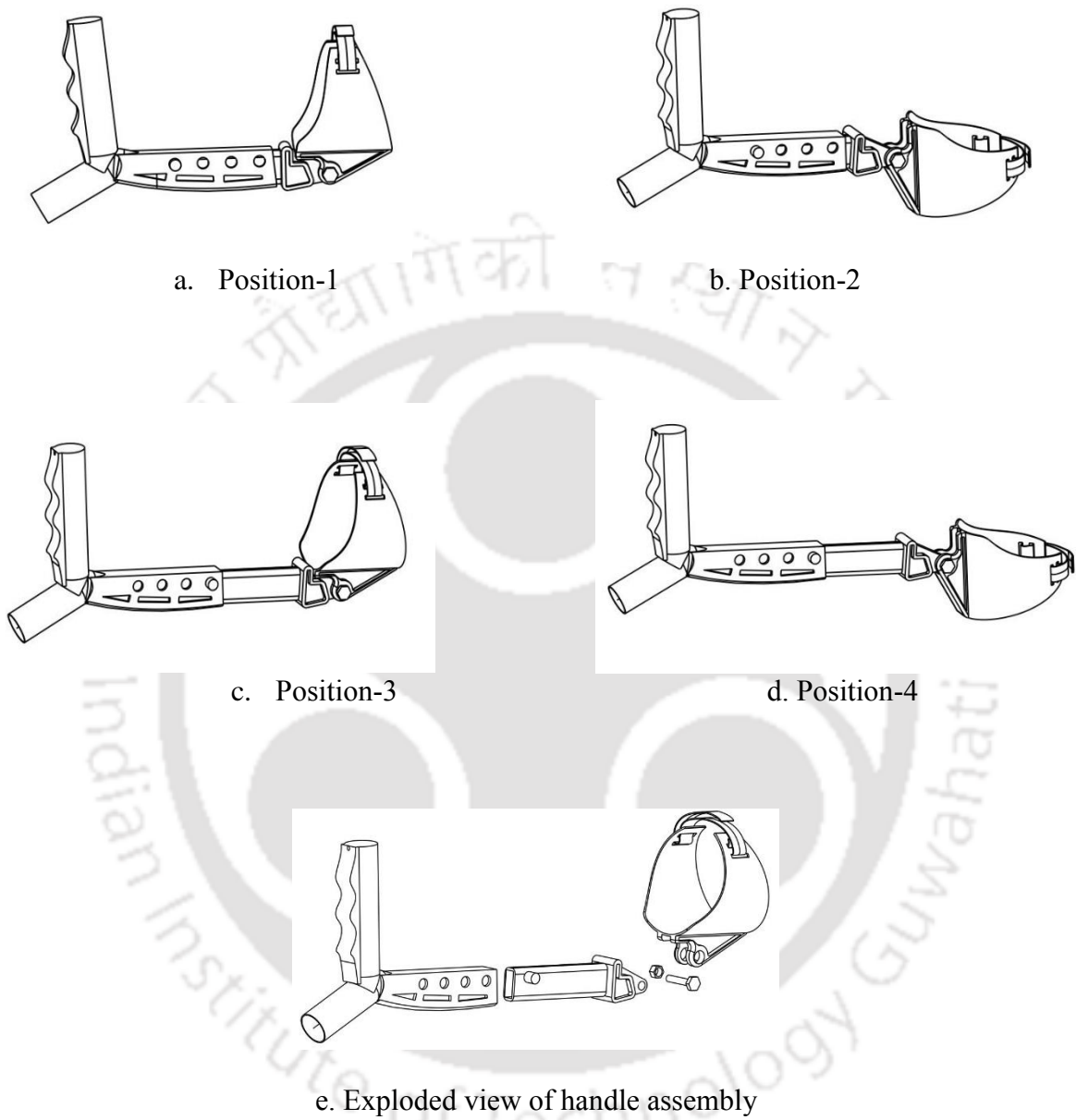


Figure 5.18. Handle with adjustable elbow crutch assembly (a, b, c, d and e)

5.4 Discussion

This research focuses on the variability in growth and physical properties of pineapple plants, specifically the *Kew* variety cultivated in northeast India. The study observes scattered heights of pineapple plants ranging from 630 mm to 950 mm, attributing this variation to soil conditions, climate, and individual plant characteristics. Detailed insights into the *Kew* variety's fruit characteristics reveal variations in weight (0.75 kg to 1.45 kg), diameter, length, and crown length.

The mechanical properties of pineapples are crucial for harvest and transportation feasibility. Investigations into bending moments required to break pineapples at different maturity levels emphasize the transportability of fruits at specific stages. Additionally, cutting forces for different pineapple varieties, such as *Kew* and *Queen*, shed light on the power requirements for detachment, impacting harvesting processes.

Considering the design and development of pineapple harvesting tools, the research emphasizes the importance of customization based on fruit parameters. Ergonomic considerations, including grip dimensions and handle lengths, are vital for tool usability. Machine parameters, such as adaptable cutting mechanisms and lightweight materials, contribute to the efficacy and user-friendliness of tools.

The research then transitions to the concept generation process for a pineapple harvesting device, involving systematic data collection and analysis. The study identifies sub-functions and sub-components critical for the device's functionality, ensuring a comprehensive exploration of potential concepts. Following concept generation, the research employs the Pugh Chart methodology for concept evaluation and selection. This systematic approach allows for a structured comparison of each concept against established criteria, leading to the identification of the optimal design for the pineapple harvesting device.

The full-scale prototypes of selected concepts demonstrate advancements in the development of the pineapple harvesting device. The chosen prototype features a coordinated fruit grabber and cutter blade mechanism, ensuring a controlled and efficient harvesting process. Practical demonstrations and field trials in pineapple-growing villages provide valuable insights into the

performance of the prototypes, particularly highlighting the need for modifications to enhance usability. Farmer feedback emphasizes the importance of user-centric design considerations, ensuring the device's technical effectiveness and ergonomic practicality in real-world conditions.

5.5 Conclusions

In conclusion, this research presents a holistic approach to pineapple harvesting tool design, considering crop parameters, user parameters, and machine parameters. The systematic concept generation and evaluation process, along with field trials and user feedback, contribute to the development of an effective and user-friendly pineapple harvesting device tailored to the needs of farmers in northeast India.



6 Evaluation of developed manual pineapple harvester

Chapter Abstract

This research explores the physical and physiological implications of a newly developed pineapple harvester on the well-being and productivity of pineapple farmers. The study, involving 20 participants, investigates baseline characteristics, ergonomic advantages, physiological impacts, and usability of the harvester. Comparative analysis revealed significant differences in physiological parameters between the new harvester and the existing method. The average working heart rate increased by 44.49% and 52.83%, categorizing the tasks as moderate and heavy work, respectively. Ergonomic assessment using the Rapid Entire Body Assessment method identified lower-risk postures with the new harvester, reducing the risk of musculoskeletal disorders. Body discomfort scores favoured the new harvester, especially in the lower back, showcasing its ergonomic benefits. Work-rest schedules indicated a significantly shorter rest period with the new harvester, enhancing user comfort and reducing stress and fatigue. Harvesting capacity assessment also demonstrated the satisfactory performance of the harvester, with 88 fruits per hour compared to 84 fruits with the existing method, without causing fruit damage. Lastly, the System Usability Scale scores categorized the harvester as acceptable, affirming its user-friendliness.

6.1 Introduction

The evaluation of the newly developed pineapple harvesting device for Northeast India marks a significant step forward in addressing the region's agricultural challenges. This research initiative emerges from the pressing need to enhance the efficiency and sustainability of pineapple harvesting practices in this unique geographical context. With the existing manual methods posing limitations in terms of labour availability, precision, and adaptability to local terrains, the development of a specialized harvesting device represents a promising solution. This evaluation aims to rigorously assess the performance, functionality, and feasibility of the designed device in real-world conditions prevalent in Northeast India. By undertaking this research, we aspire to contribute to the advancement of agricultural technology tailored to the specific requirements of the region, ultimately fostering increased productivity, economic growth, and resilience in the pineapple cul-

tivation sector. The findings of this evaluation hold the potential to inform future agricultural practices not only in Northeast India but also in other regions facing similar challenges, emphasizing the significance of localized and context-specific innovations in sustainable farming.

6.2 Methodology

The field evaluation of the modified pineapple harvester was conducted during July –September 2022 in Marangar village, Ribhoi District, Meghalaya. The temperature during the field evaluation was 27-31 °C. A total of 20 farmers from Borkhatsari village, Ri Bhoi District, Meghalaya participated in the field evaluation. The farmers were asked to harvest pineapple using two methods viz. by use of developed pineapple harvester existing traditional method. The subjects were asked to perform the task for 60 minutes. At the end of each task, the subjects were given to rest for 15 minutes to regain their physiological parameters at resting level. Observations recorded were body weight, stature, blood pressure and heart rate. The physiological parameters (heart rate) of the subject were recorded before starting the task, during the task, and after the task. Machine performance parameters such as field capacity (number of fruits harvested per hour), and fruit injury percentage. Postures adopted during the harvesting task were also analyzed using REBA and compared with the existing method.

6.2.1 Monitoring heart rate

Heart rate is a primary physiological parameter which varies with workload and energy demand. It is commonly and effectively employed for the indirect estimation of energy consumption and physical workload in the field. In this experiment, heart rate was monitored and recorded using a polar heart rate monitor (Polar H10) as shown in Figure 6.1. An elastic chest strap with an electrode sensor and a transducer to detect and transmit heart rate data to a receiver (a mobile phone via an app) makes up the heart rate monitor.



Figure 6.1. Polar Heart Rate Monitor

6.2.2 *Blood pressure and Body Weight*

Measuring blood pressure is a basic diagnostic technique that evaluates the force of blood against artery walls as the heart circulates blood throughout the body. The procedure entails utilizing a sphygmomanometer, or blood pressure cuff, which is an inflatable cuff attached to a pressure gauge. The most popular approach is called auscultatory method, in which blood flow is momentarily stopped by wrapping an inflatable cuff around the upper arm and inflating it to a pressure greater than the systolic blood pressure. Technological advancements have introduced automated digital blood pressure monitors, which provide quick and accurate readings without the need for manual auscultation. In this experiment, the blood pressures of participants were measured and monitored to check their fitness and health conditions before the experiment using Norton Blood Pressure Monitor as shown in Figure 6.2. A digital weighing machine was used to measure the body weight of the participants as shown in Figure 6.3.



Figure 6.2. Nuton Digital Blood Pressure Monitor



Figure 6.3. Digital weighing machine (Bodyweight)

6.2.3 Energy expenditure rate

The energy expenditure rate refers to the pace at which an individual's body consumes and utilizes energy to sustain its vital functions and activities. This includes the energy needed to sustain basic body functions at rest, or the basal metabolic rate (BMR), as well as the extra energy used for daily tasks and physical activity. Factors such as age, gender, body composition, genetics, and overall health contribute to variations in energy expenditure rates among individuals. The regression equation of Varghese *et al.* (1994) was used to estimate the energy expenditure rate (EER) from heart rate as given below.

$$\text{EER} = 0.159 \times \text{AWHR} - 8.72 \quad \text{----- (1)}$$

Where,

EER = Energy expenditure rate, kJ/min

AWHR = Average working heart rate, bpm

6.2.4 Oxygen consumption rate

One important physiological measure that indicates how much oxygen the body uses for different tasks is the oxygen consumption rate, also known as VO₂ (volume of oxygen consumed per minute). It functions as a direct indicator of energy consumption and metabolic activity. Techniques like indirect calorimetry, which examines the ratio of inhaled and exhaled gases, especially carbon dioxide and oxygen, are frequently used to measure VO₂. Due to the lack of a pulmonary gas analyzer device, direct assessment of energy expenditure was not possible during the field evaluation. Heart rate was therefore taken into consideration for an indirect measurement of OCR. For the estimation of oxygen consumption rate (OCR) from the heart rate, the following equation by Singh *et al.*, 2008 was used.

$$\text{OCR} = 0.0114 \times \text{AWHR} - 0.68 \quad \text{----- (2)}$$

Where,

OCR = Oxygen consumption rate, l/min

AWHR = Average working heart rate, bpm

According to Nag *et al.* (1980), 20.88 kJ of physiological energy is required to consume 1 litre of oxygen at NTP (Normal Temperature and Pressure).

6.2.5 Body part discomfort

The most widely used local discomfort scales were used to quantify body part discomfort, and they were based on the body part discomfort (BPD) rating method developed by Corlett and Bishop in 1976. A modified Bishop-Corlett body map and the Borg CR 10 scale were used to determine ratings (Borg, 1990). Each participating farmer rated discomfort for each 25 local body parts and their whole body after the completion of harvesting tasks. Before taking part, the individuals were well accustomed to the rating methods. The subjects rated the scale ranged from 0 to 10 (0 – no discomfort, 0.5 - extremely weak, 1 - very weak, 2 - weak, 3 – moderate, 4- somewhat strong, 5 – strong, 7 – very strong, 10 – extremely strong).

6.2.6 Work Rest Pause

Adequate rest is necessary for good work output during any demanding outdoor work. When the user is at ease, they are supposed to produce their best work. Consequently, to prevent stress, exhaustion, injuries, and discomfort during any field operation, a suitable rest break during the work period is required. The work rest schedule was calculated using the following Murrell (1965) formula:

$$R = T (O_{work} - O_{rec}) / (O_{work} - O_{rest}) \quad \text{-----(3)}$$

Where,

R = Rest time required, min

T = Total working time, min

O_{work} = Oxygen consumption during work

O_{rec} = Recommended oxygen consumption level (33% of VO₂ max)

O_{rest} = Oxygen consumption during rest

6.2.7 Fruit harvesting performance

To assess the performance of the newly developed pineapple harvesting device, two indicators were defined. The first indicator, the harvesting rate, was represented by equation (4). The total pineapple fruits collected in a given amount of time is known as the harvesting rate. The second indicator was the damage rate, which was given by equation (5). The total number of damaged pineapple fruits divided by the total number of harvested pineapple fruits is known as the damage rate.

$$\text{Harvesting rate} = \frac{\text{Total number of fruit harvested}}{\text{Time}} \text{-----(4)}$$

$$\text{Damage rate} = \frac{\text{Total number of damage fruit}}{\text{Total number of fruit harvested}} \text{----- (5)}$$

6.2.8 Handgrip Strength Measurement

Before agreeing to participate in the study, the subjects were told about the purpose of it and their involvement in it. Prior to the test, conditions that could have a substantial impact on handgrip strength, such as inflammatory joint illnesses, upper limb injuries, or neurological disorders, were taken into account. The Jamar handgrip dynamometer was used to assess handgrip strength. Maximum isometric muscle strength can be measured with handgrip dynamometry, which is a strong and possibly the most accurate method (Bohannon, 1986; Sullivan *et al.*, 1988). This dynamometer included 5 grip positions and a force-exerted dial that indicated strength. You can examine the strength reading in either pound (maximum 200 lb, to nearest 2.5 lb) or kilogram (maximum 90, to nearest 0.5 kg).

The handgrip strength of the preferred hand used in farm activities was measured in a standing position. To provide optimum grip strength, each patient stood straight, arms dangling downward, trunk and wrist in neutral postures. Three replications of the observation were made for every participant. To prevent muscle fatigue, there was a 3-minute rest period between each subject's two consecutive trials. Both before and after utilizing the pineapple harvesting apparatus, each participant underwent a grip test. Every participant was told to maintain a straight grip on the dynamometer handle while applying maximum isometric force and holding it for three to five seconds

without moving their other body parts significantly. Encouragements (a little more, you can do it more, finally relax!) were delivered as the patients started to squeeze.

6.2.9 System Usability Scale (SUS)

The System Usability Scale (SUS) (Brooke, 1995) is used as a reliable tool for measuring usability. It consists of 10-item questionnaires with five response options for respondents; from strongly agree to strongly disagree. It is typically used before a conversation but after the respondent has used the system under review. The answer needs to be noted right away. The response should be recorded as the centre point of the scale if a respondent is unable to respond to a specific item. The SUS score spans from 0 to 100. Following the use of the recently created pineapple harvesting device in actual operating conditions, 20 pineapple farmers were given the SUS questionnaire for this study. The respondents were given explanations for each issue and asked to indicate on the Likert scale as appropriate.

6.3 Results

6.3.1 Physical and physiological characteristic of subjects

A total of 20 pineapple farmers were engaged in the field evaluation and ergonomic assessment of the developed pineapple harvester and compared with the existing method of harvesting (Figure 6.4). Descriptive statistics viz. mean, SD, and range of various physical and physiological parameters were recorded as detailed in Table 6.1. The average (\pm SD) of age, body weight and height (stature) of the subjects are 42.70 (\pm 10.32) years, 53.13 (\pm 6.57) kg and 161 (\pm 7.32) cm, respectively. The average BMI was observed to be 20.04 (\pm 1.54) kg/m² which was within the normal range (18.5 – 24.9) specified by WHO (2014).

Table 6.2 also provides a comparison of the physiological parameters used during the harvesting task between the new approach (using a pineapple harvester) and the existing method. For the newly developed pineapple harvester, the average working heart rate (AWHR) increased by 28.39% over the resting heart rate and by 55.58% over the existing method (Figure 6.5). The Shapiro-Wilk test ($n < 50$) was used to assess the distribution of AWHR for normalcy. The test resulted in $p < 0.05$, ruling out the possibility of normality. As a result, the Mann-Whitney U test, a non-parametric test, was run. When utilizing the newly created pineapple harvester, the average working heart rate differed considerably from the conventional method ($Z = -3.250$, $p < 0.001$). In

accordance with Astrand and Rodahl's (1986) classification system (light work if <90 bpm, moderate work if 90 – 100 bpm, heavy work if 110-130 bpm, very heavy work if 130 – 150 bpm and extremely heavy work if 151 -170), the pineapple harvesting task using the developed pineapple harvester and existing method could be classified under moderate work and heavy work, respectively.



Figure 6.4. Evaluation of pineapple harvester at farmers' field

Table 6.1. Physical and physiological characteristics of the subjects (n=20)

Physical and physiological characteristics	Range	Mean (\pmSD)
Age, years	23 - 58	42.70 (\pm 10.32)
Weight, kg	41 - 71	53.13 (\pm 6.57)
Height, cm	146 – 170	161 (\pm 7.32)
BMI, kg/m ²	17.93 – 23.73	20.04 (\pm 1.54)
Experience, year	5 - 38	17.20 (\pm 9.61)
HRrest, beats/min	61 - 92	77.70 (\pm 9.35)
HRavg, beats/min	85– 128	110.33 (\pm 14.74)
HRmax, beats/min	120 - 165	140.15 (\pm 13.87)
Blood pressure (Sys/Dias, mm Hg/mm Hg)	98/60 – 130/85	117/78

BMI =Body weight divided by squared stature in m (kg/m²)

Table 6.2. Comparison of physiological parameters between existing method and improved method

Parameter	Existing Method	Pineapple harvester
	Mean (\pmSD)	Mean (\pmSD)
HRavg, beats/min	120.89 (\pm 8.51)	99.76 (\pm 11.16)
HRmax, beats/min	151.50 (\pm 9.57)	125.60 (\pm 5.31)
EER, kj/min	10.50 (\pm 1.35)	7.14 (\pm 1.77)
OCR, l/min	0.70 (\pm 0.10)	0.46 (\pm 0.13)

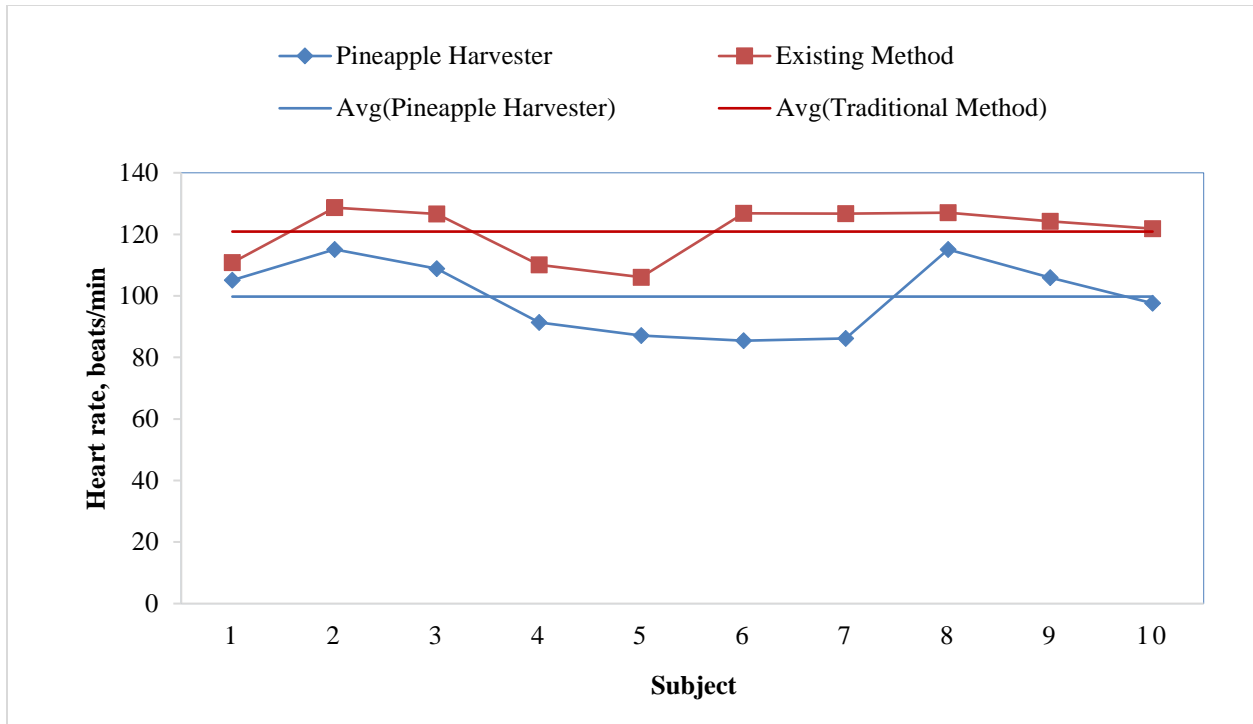


Figure 6.5. Response of heart rate while using pineapple harvester and existing method

Table 6.2 presents the physiological cost of employment as heart rate (HR), oxygen consumption rate (OCR), and energy expenditure rate (EER). With the aid of the previously mentioned formula the OCR and EER were determined based on the working and resting heart rates. Throughout the experiment, the average temperature and relative humidity were measured and found to be between 27°C and 31°C and 56 % and 65 %, respectively. For the created harvester and the existing method, the observed differences (Mean \pm SD) of HR, OCR, and EER were 23.466 \pm 11.78 bpm and 41.78 \pm 10.14 bpm; 0.27 \pm 0.13 and 0.48 \pm 0.12 l/min; and 3.73 \pm 1.87 and 6.65 \pm 1.61 kJ/min, respectively. The new pineapple harvester may have required less effort to harvest, as seen by the change in HR, OCR, and EER. The Shapiro-Wilk test was used to determine if the observed difference (mean) of HR, OCR, and EER was normally distributed. The results showed that $p > 0.05$. Consequently, the Student's *t*-test for independent samples was performed, and the results showed a significant variance in all of the physiological costs of employment ($t(18) = -3.73, p < 0.05$) (Figure 6.6).

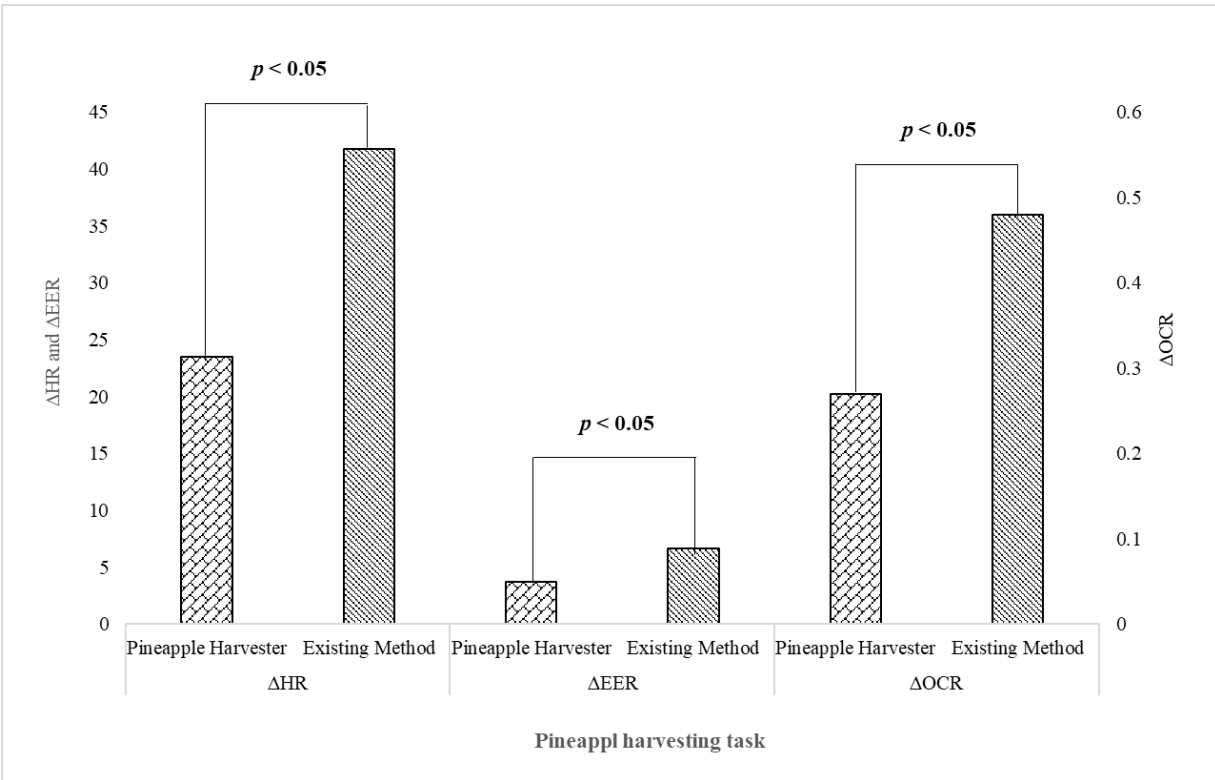


Figure 6.6. Change in HR, EER and OCR (ΔHR in bpm, ΔEER in kJ/min and ΔOCR in l/min) duration pineapple harvesting task

6.3.2 Muscular Fatigue

A handgrip dynamometer was used to assess the handgrip strength both before and after the task was completed (Figure 6.7). The percentage change in handgrip strength before and after the pineapple fruit harvesting process is shown in Table 6.3. At the end of the work, it was observed that the average handgrip strength for the existing method vs developed harvester was 27.12 (± 3.79) kg vs 32.75 (± 4.23) kg for female, 40.25 (± 6.97) kg vs 46.00 (± 7.60) kg for male and 35.00 (± 8.77) kg vs 40.70 (± 9.19) kg for overall (male and female), respectively. For the existing method vs. developed harvester, the percentage difference before and after completion of the pineapple harvesting task (indicating fatigue of the concerned muscle) was recorded as follows: 15.22% vs. 5.07% for females, 13.73% vs. 6.45% for males, and 14.32% vs. 6.00% for the overall (male and female), respectively. Farmwomen in the age range of 21 to 30 years old showed an 8.33% change in handgrip strength during weeding operations, according to Sharma and Sharma (1999).



Figure 6.7. Measurement of handgrip strength of pineapple farmers

Table 6.3. Percentage change in isometric muscle strength after using the developed harvester versus the existing method of pineapple harvesting

Particulars	Before work (at rest)	After completion of work		% change	
		Existing method	Developed harvester	Existing method	Developed harvester
Female	34.50 (±4.24)	30.25 (±3.99)	32.75 (± 4.23)	12.32	5.07
Male	49.17 (±8.19)	43.33 (±7.25)	46.00 (±7.60)	11.88	6.45
Overall (Female + male)	43.30 (±9.98)	38.10 (±8.92)	40.70 (±9.19)	12.01	6.00

Note: % change in handgrip strength = $(A-B/A) \times 100$
A is handgrip strength at rest and B is handgrip strength after work

The handgrip strength was checked with the Shapiro-Wilk test for normality, and it resulted in the statistics, $W=0.95$ and $p>0.05$. Therefore, a student's *t*-test was performed to compare between existing and developed pineapple harvester (Table 6.4). The muscles that are actively engaged in harvesting tasks may be fatigued, which would explain the decrease in muscle strength during

work. The force used to hold a cutting tool, the shearing action used to harvest pineapple fruit, and the hand movement with highly repetitive deviation and twisting of the wrist from a neutral position (> 20 times per minute) may have contributed to the significant decrease in handgrip strength during the harvesting task. This static constriction of the grip muscle caused further fatigue to the handgrip muscles.

Table 6.4. Student's *t*-test of handgrip strengths for developed harvester and existing method

Grip Strength	Mean ± SD	SDEM	CI		t-value	d.f.	Sig.
			Upper	Lower			
Female	2.5±0.53	0.19	2.05	2.95	13.23	7	<0.001
Male	2.67±1.23	0.35	1.88	3.45	7.51	11	<0.001
Overall (Female + Male)	2.60±0.99	0.22	2.13	3.07	11.69	19	<0.001

Note: SD = Std. deviation, SDEM = Std. error mean, CI = 95 % confidence interval

6.3.3 Posture Analysis

In this investigation, the REBA technique was employed to identify and analyze the main probable risk postures. While harvesting pineapple with the developed pineapple harvester and existing method, the REBA scores for various body sections and determined. The postures that were adopted with an action level 1 low-risk score of 2–3 and an action level 2 medium-risk score of 4–7 was determined to be approximately 40% and 60%, respectively. In contrast, the prior technique recorded approximately 30% and 70% of cases with high-risk scores of 8–10 (action level 3) and very high-risk scores of 11 or more (action level 4).

6.3.4 Body part discomfort

A modified Bishop-Corlett body map and the Borg CR 10 scale were used to rate the discomfort of each body component and the overall level of discomfort (Borg, 1990). Following each task, participating farmers rated body part discomfort and whole-body discomfort. The subjects rated the scale ranged from 0 to 10 (0 – no discomfort and 10 – extremely strong). The body part discomfort scores for the developed harvester and existing method were 23.60 (±6.45) and 30.50

(± 7.69) respectively, whereas the overall discomfort scores were 2.90 (± 0.88) and 4.30 (± 1.25), respectively (Table 6.5). Using the Shapiro-Wilk test, the distribution of the body parts' discomfort score and the total discomfort score were examined for normality; the results showed that both were normally distributed ($p > 0.05$). Consequently, the Student's *t*-test was used, and the results showed that the overall discomfort score was significantly different [$t(18) = 2.89, p < 0.01$]. As shown in Figure 6.8, the range of body part discomfort varied from 7.14 to 59.56 %.

Table 6.5. Discomfort scores in pineapple harvesting task

Particulars	Body parts discomfort score		Overall discomfort score	
	Existing Method	Pineapple Harvester	Existing Method	Pineapple Harvester
Minimal	23	16	3	2
Mean \pm SD	30.50 \pm 7.69	23.60 \pm 6.45	4.30 \pm 1.25	2.90 \pm 0.88
Maximal	48	34	7	4

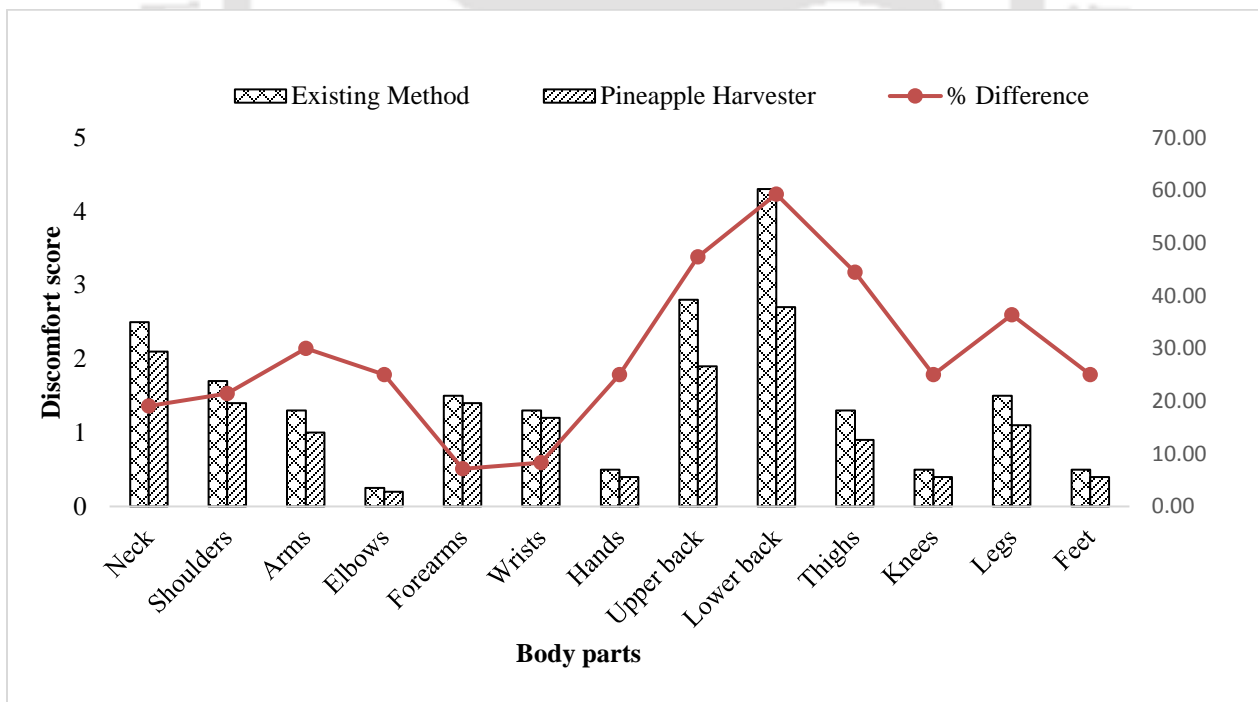


Figure 6.8. Discomfort score for pineapple harvesting task

6.3.4 Work-rest Pause

Adequate rest is necessary for good work output during any demanding outdoor work. When the user is at ease, they are supposed to produce their best work. Consequently, to prevent stress, exhaustion, injuries, and discomfort during any field operation, a proper rest break during the work period is required. Therefore, before beginning the next cycle of 60 minutes of work with the developed harvester and the existing approach, a farmer should, on average, take a break for 16.07 minutes and 30.34 minutes after working for 60 minutes, respectively as shown in Figure 6.9. The Shapiro-Wilk test was used to determine whether the recovery time distribution was normal ($W=0.91$ and $p>0.05$). According to the student's t-test, there was a significant difference in a work-rest cycle between the developed harvester and the existing approach ($t(18) = 5.88, p<0.001$).

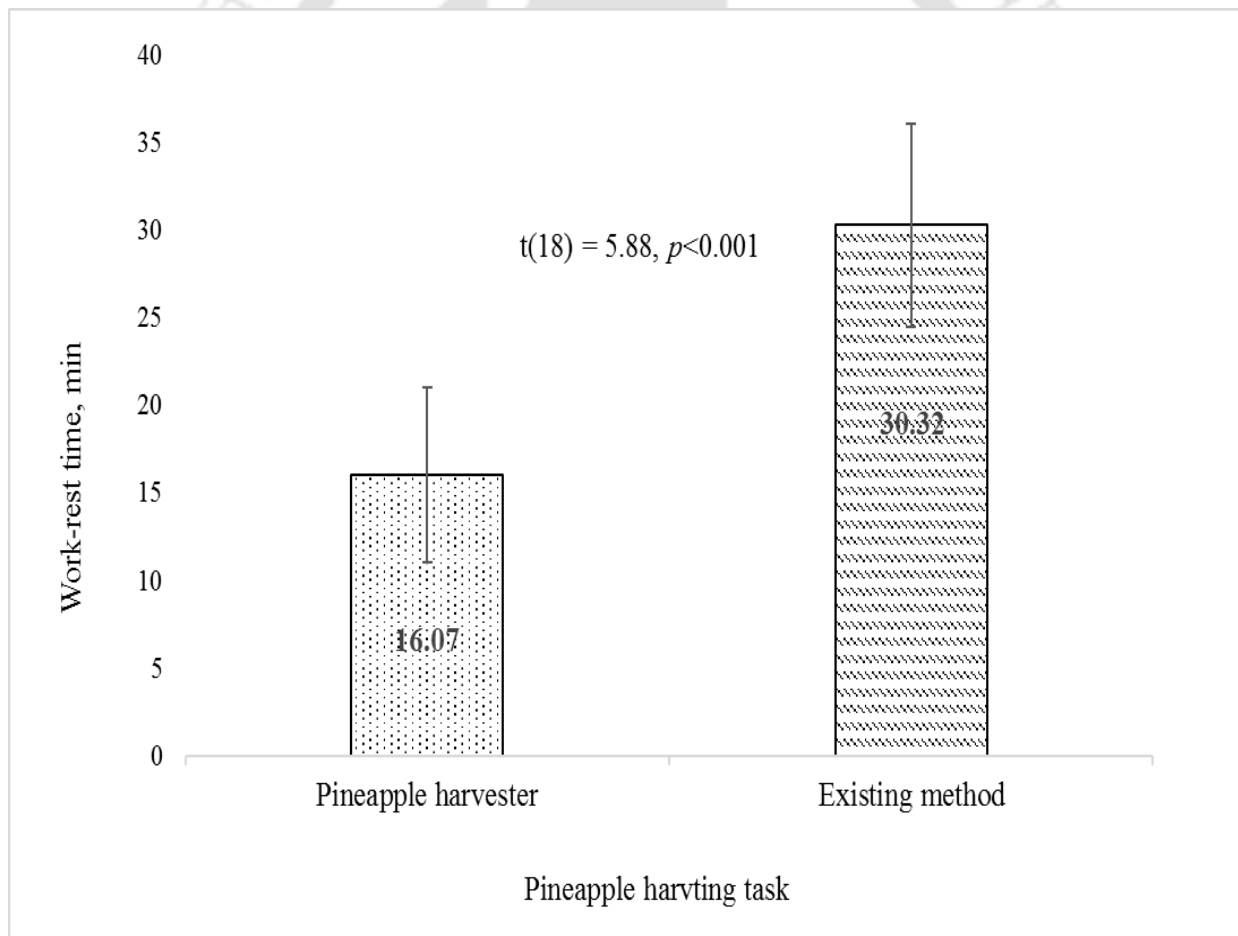


Figure 6.9. Recovery after 60 minutes of work

6.3.5 Fruit harvesting capacity

The performance of the pineapple harvester was found satisfactory under the prevailing field conditions. The pineapple fruit stalk could easily be broken and harvest the fruit by bending the harvester on one side after properly grabbing the fruit between the flaps of the fruit grabber to avoid fruit falling on the ground after harvest. The harvester could harvest 75 to 112 (average: 88) fruits per hour depending on fruit density and maturity as compared to the existing method (61 to 108, average 84) as shown in Figure 6.10. During the field evaluation, there was no any fruit damage while harvesting using the newly developed pineapple harvesting device. Further, an independent sample student's t-test was used to determine whether the difference was significant. The new pineapple harvester and the present technique did not significantly differ in their capacity to harvest pineapples, according to the results of the student's *t*-test [$t(18) = 0.830, P > 0.05$].

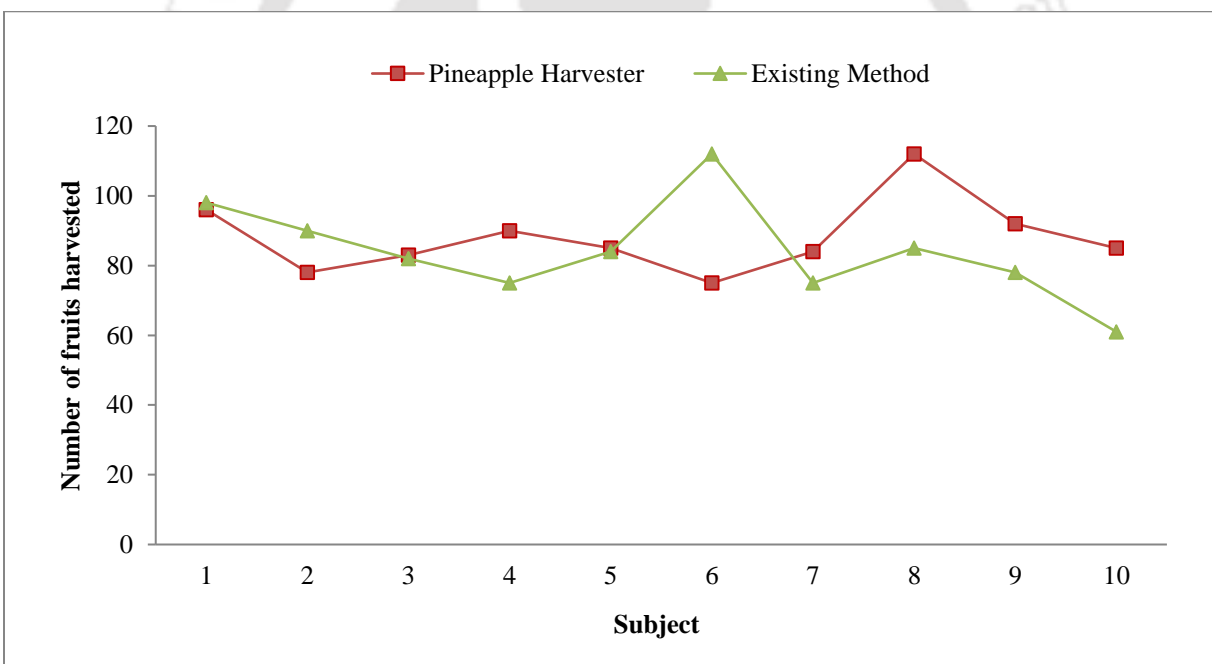


Figure 6.10. Performance of developed pineapple harvester and existing method

6.3.6 System Usability Scale

The SUS scores of the developed pineapple harvester were also evaluated after the completion of each harvesting task. The SUS score of the harvester ranged from 50 to 97.50 with an average SUS score of 85 (± 14). A system is considered acceptable if the SUS score is above 70, marginal if

between 70 to 50, and unacceptable if below 50 (Bangor *et al*, 2009). Therefore, the developed pineapple harvester may be categorised within the acceptable range.

6.4 Discussion

The investigation into the physical and physiological attributes of 20 pineapple farmers, focusing on the field evaluation and ergonomic assessment of a recently introduced pineapple harvester, provided valuable insights into the implications of this innovation on various parameters. A comparative analysis between the traditional harvesting method and the newly developed pineapple harvester reveals substantial differences in physiological parameters. Notably, the average working heart rate (AWHR) increased by 28.39% and 55.53% compared to the resting heart rate and the conventional method, respectively. Statistical analysis ($t(18) = -3.077, p < 0.05$) categorizes the harvesting task with the developed harvester as moderate work, while the conventional method is classified as heavy work following Astrand and Rodahl's classification. Utilizing the Rapid Entire Body Assessment (REBA) method for posture analysis unveiled potential risk postures. It was shown that the developed harvester resulted in lower percentages of high and very high-risk scores (30% and 70%, respectively) compared to the conventional method, emphasizing the ergonomic advantages in minimizing the risk of musculoskeletal disorders.

The assessment of body part discomfort and overall discomfort scores reinforces the ergonomic merits of the developed harvester. Discomfort scores for the new harvester were consistently lower than those associated with the conventional method, with the most significant disparity observed in the lower back (59.26%). These findings align with the expected ergonomic enhancements from a well-designed harvesting device. Work-rest cycle, also indicated that the developed harvester allows for a significantly shorter rest period (16.07 minutes) compared to the conventional method (30.34 minutes) after 60 minutes of work. This suggests that the innovative harvester enhances user comfort, and mitigates the risk of stress, fatigue, and discomfort during field operations.

The harvesting capacity assessment demonstrated that the developed harvester performed satisfactorily under field conditions, harvesting an average of 88 fruits per hour compared to 84 fruits per hour with the existing method. Notably, the absence of fruit damage during harvester use is a noteworthy positive outcome. Furthermore, System Usability Scale (SUS) scores ranging from 50

to 97.50, with an average of 85 (± 14), categorize the developed harvester as acceptable, following Bangor *et al.* (2009). This underscores the positive reception of the harvester by users in terms of usability.

For technology transfer, on-farm trials (OFTs) and frontline demonstrations (FLDs) may be conducted in different Krishi Vigyan Kendras (KVKs) in northeast India under the National Agricultural Research System (NARS) of the country for popularization among the farmers. This harvesting device should also be promoted through kisan *mela*, exhibition, agri-expo etc. organized at different levels by institutes/organizations in the region. Local artisans and manufacturers may also be encouraged to start manufacturing and supply at the local level to make the harvesting device/pineapple harvester available in the vicinity of the farmers for faster adoption among the farmers in the region. Moreover, rural unemployed youths/individual farmers should also be sensitized and trained for entrepreneurship development.

6.5 Conclusions

The comprehensive evaluation indicates that the developed pineapple harvester effectively improves harvesting processes, offering potential benefits to farmers' well-being and productivity. This research contributes valuable insights to agricultural technology, emphasizing the positive impact of ergonomic design on farming practices.

7 Summary and Conclusions

7.1 Key Findings

The present study provides a thorough and perceptive investigation of a wide range of subjects that together advance our knowledge of the pineapple production system in general and pineapple harvesting in particular in northeast India. Through meticulous investigation and rigorous analysis, this study inquires deeply and thoroughly into key areas such as socio-demography of pineapple farmers, working conditions and problems associated with pineapple harvesting task in northeast India. By synergistically examining these facets, the research uncovers novel perspectives and explores innovative design solutions for small and marginal pineapple farmers in northeast India. This study presents a synthesis of these pivotal discoveries, encapsulating the essence of the research's contribution to the greater body of knowledge in pineapple farming. The following salient findings were observed from this research work.

1. In northeast India, the majority of pineapple farmers (>95%) belonged to the small and marginal farmer categories, with the majority having low to medium annual income groups. The pineapple farmers had strong customs of mutual assistance and cooperation for all aspects of farming. These helpful hands were reciprocal and rotated amongst each other.
2. During the study, all of the respondents reported they had used locally evolved indigenous hand tools, including sickles, knives, spades, and multiple types of short and long handled machetes, for any kind of activity related to pineapple growing. It was discovered that in northeast India, the only source of farm power used for pineapple cultivation was human labor.
3. Symptoms of occupational health hazards were observed among the pineapple farmers working with traditional hand tools. The study's findings demonstrated how common musculo-skeletal disorders (MSDs) were across all age groups (79.61%) among pineapple growers in northeast India, with the low back being the most affected (76.32%).
4. The total REBA score revealed that the postures used in the pineapple harvesting task were around 30% and 70%, respectively, for high-risk scores of 8–10 (action level 3) and very high-risk scores of 11 or more (action level 4). Throughout the pineapple harvesting task in

northeast India, the farmers were also subjected to a number of ergonomic risk factors, including forceful exertions on their shoulders and fingers, highly repetitive deviation and twisting of their wrist from a neutral position (> 20 times per minute), excessive bending posture during harvest, prolonged stooping, heavy load carrying (40–50 kg uphill or downhill at a time and a total of 400–500 kg in a day), etc.

5. There was no improved tool/equipment suited to local conditions for the pineapple fruit harvesting task. Therefore, an innovative pineapple harvesting device was designed and developed from an ergonomic perspective to overcome the problems associated with harvesting pineapple fruit in northeast India and it was evaluated at the farmer's field.
6. For the developed pineapple harvester, the average working heart rate (AWHR) increased by 27.39% over the resting heart rate and by 55.58% over the existing traditional method. When utilizing the newly developed pineapple harvester, the working heart rate differed significantly from the existing method ($Z = -3.250$, $p < 0.001$).
7. As per Astrand and Rodahl's (1986) classification, which divides labour into five categories: light work (< 90 bpm), moderate work (90–100 bpm), hard work (110–130 bpm), very heavy work (130–150 bpm), and extremely heavy work (151–170 bpm), the pineapple harvesting task using the developed pineapple harvester and existing method (traditional method) could be classified under moderate work and heavy work, respectively.
8. For the newly developed harvester and the existing method, the observed differences (Mean \pm SD) of HR, OCR, and EER were 23.466 ± 11.78 bpm and 41.78 ± 10.14 bpm; 0.27 ± 0.13 and 0.48 ± 0.12 l/min; and 3.73 ± 1.87 and 6.65 ± 1.61 kJ/min, respectively. Significant variance ($t(18) = -3.73$, $p < 0.05$) was observed in the outcomes for all physiological costs of work.
9. Approximately 40% and 60% of the postures were adopted with a low-risk score of 2–3 (action level 1) and a medium-risk score of 4–7 (action level 2). In contrast, the prior technique recorded approximately 30% and 70% of cases with high-risk scores of 8–10 (action level 3) and very high-risk scores of 11 or more (action level 4).
10. The average handgrip strength for the existing method vs developed harvesting device was $27.12 (\pm 3.79)$ kg vs $32.75 (\pm 4.23)$ kg for females, $40.25 (\pm 6.97)$ kg vs $46.00 (\pm 7.60)$ kg for male and $35.00 (\pm 8.77)$ kg vs $40.70 (\pm 9.19)$ kg for overall (male and female), respectively. The % difference before and after completion of the pineapple harvesting task for the existing

- method vs developed harvesting device was recorded as 15.22 % vs 5.07 % for females, 13.73 % vs 6.45 % for males and 14.32 % vs 6.00 % for overall (male female), respectively.
11. The body part discomfort score for the developed harvester and existing method were 23.60 (± 6.45) and 30.50 (± 7.69) respectively, whereas the overall discomfort scores were 2.90 (± 0.88) and 4.30 (± 1.25), respectively. The difference in body part discomfort ranged from 7.14 to 59.26 %. The highest percentage difference in discomfort score in the developed harvester and existing method was lower back (59.26%) followed by upper back (47.37%), thighs (44.44%), legs (36.36%), arms (30%), and so on. There was a significant difference in the overall discomfort score [$t(18) = 2.89, p < 0.01$].
 12. The average values of the work-rest cycle for the developed harvester and existing technique were 16.07 (± 4.99) minutes and 30.34 (± 5.81) minutes, respectively. Consequently, after working for 60 minutes, a farmer should rest for 16.07 minutes and 30.34 (± 5.81) minutes, respectively, before beginning the next cycle of 60 minutes of work using the newly developed harvester and the present approach. According to the student's t-test, there was a significant difference in the work-rest cycle between the developed harvester and the present approach ($t(18) = 5.88, p < 0.001$).
 13. The performance of the pineapple harvester was found satisfactory under the prevailing field conditions. The harvester could harvest 75 to 112 (average: 88) fruits per hour depending on fruit density and maturity as compared to the existing method (61 to 108, average 84). There was no significant difference in harvesting capacity between the developed pineapple harvester and the existing method [$t(18) = 0.830, p > 0.05$].
 14. The pineapple farmers participated in field testing and their feedback was incorporated into the final and modified device. The modified device was evaluated at farmers' farms and its performance was satisfied in terms of capacity, posture, safety, etc. After the System Usability Scale (SUS) was used to evaluate usability, the SUS score of the harvester ranged from 50 to 97.50 with an average SUS score of 85 (± 14). Therefore, the developed pineapple harvester may be categorised within the acceptable range.

7.2 Key features of the newly developed device

1. The pineapple harvesting device comprises three sub-assemblies viz. (1) integrating main frame cum actuator assembly, (2) fruit grabber cum cutter assembly, and (3) handle with adjustable elbow crutch assembly.
2. This device could easily grab and make the breaking marks simultaneously on two sides of the fruit stalk by the two sharp edges of the cutting blades attached at the bases of the grabber. The breaking marks could be made at a certain distance (up to 7 cm from the base of the fruit) to avoid breakage at the base of the fruit while bending it to harvest. Then, the device is rotated/bent at either side to break out the fruit at breaking marks from the fruit stalk.
3. After the harvest, the harvested fruits are self-locked inside the grabber cum cutter and remain in a closed position due to fruit weight. In this way, pineapple fruits don't fall under their gravity to the ground after harvest in this design.
4. This pineapple harvester is ergonomically designed to meet the requirements of small and marginal farmers in northeast India where pineapple is cultivated on hill slopes and foothills. This device enables the farmers to work in an upright standing position, thus eliminating the awkward postures being adopted (forward bending, stooping, etc.) during the harvesting task.
5. This device enables the farmers to work away from the sharp-edged and spiky leaves that cause cuts and injuries. It promotes safety in pineapple harvesting tasks.
6. A handle with an adjustable elbow crutch is incorporated using ergonomic design principles to ascertain handle width, circumference, actuating force, etc. This innovative harvester eliminates the need for traditionally used sharp-edged tools like *Dao* with a strong force that often gives a sudden jerk to the hand and arm that causes nerve damage.
7. Using this harvester, the cutting of pineapple fruit is achieved via the mechanical advantage provided by this innovative and ergonomically designed pineapple harvester.
8. The fine rubberized grips are provided at the gripping areas/ surfaces to minimize the pressure points to reduce damage to the fingers/ hands/palm, etc.
9. All the parts of this ergonomic pineapple harvesting device are made up of steel, and the handle grip is made up of soft plastic material having rubber grips.

10. The weight of the harvester is 1.7 kg and its approximate cost is Rs. 1,500/- (~18 USD).

7.3 Testing of Hypothesis

The hypothesis that was formulated at the beginning of this research work has been tested by achieving several objectives.

H1: The equipment which facilitates easy holding of pineapple fruit and allowing cutting from a certain location to avoid awkward working posture and injury from leave tips and spines would significantly reduce drudgery thereby improving productivity and efficiency of pineapple harvesting.

For the newly developed pineapple harvester, the average working heart rate (AWHR) was increased by 28.39 % over the resting heart rate by 55.58 % as compared with the existing traditional approach. The working heart rate while harvesting pineapple using the developed pineapple harvester was significantly different from the existing method ($Z = -3.250, p < 0.001$). As per Astrand and Rodahl's (1986) classification, divides work into five categories: light work (< 90 bpm), moderate work (90–100 bpm), hard work (110–130 bpm), very heavy work (130–150 bpm), and extremely heavy work (151–170 bpm), the pineapple harvesting task using the developed pineapple harvester and existing method could be classified under moderate work and heavy work, respectively. For the newly developed harvester and the existing method, the observed differences (Mean \pm SD) of HR, OCR, and EER were 23.466 ± 11.78 bpm and 41.78 ± 10.14 bpm; 0.27 ± 0.13 and 0.48 ± 0.12 l/min; and 3.73 ± 1.87 and 6.65 ± 1.61 kJ/min, respectively. Significant variance ($t(18) = -3.73, p < 0.05$) was observed in the outcomes for all physiological costs of work.

Approximately 40% and 60% of the postures were adopted with a low-risk score of 2–3 (action level 1) and a medium-risk score of 4–7 (action level 2). In contrast, the prior technique recorded approximately 30% and 70% of cases with high-risk scores of 8–10 (action level 3) and very high-risk scores of 11 or more (action level 4). The body part discomfort scores for the developed harvester and existing method were $23.60 (\pm 6.45)$ and $30.50 (\pm 7.69)$ respectively, whereas the overall discomfort scores were $2.90 (\pm 0.88)$ and $4.30 (\pm 1.25)$, respectively. The difference in body part discomfort ranged from 7.14 to 59.26 %. The highest percentage difference in discomfort score in the developed harvester and existing method was lower back (59.26%) followed by upper back

(47.37%), thighs (44.44%), legs (36.36%), arms (30%), and so on. There was a significant difference in the overall discomfort score [$t(18) = 2.89, p < 0.01$].

The average values of the work-rest cycle for the developed harvester and existing technique were 16.07 (± 4.99) minutes and 30.34 (± 5.81) minutes, respectively. Consequently, after working for 60 minutes, a farmer should rest for 16.07 minutes and 30.34 (± 5.81) minutes, respectively, before beginning the next cycle of 60 minutes of work using the newly developed harvester and the present approach. According to the student's t-test, there was a significant difference in the work-rest cycle between the developed harvester and the present approach ($t(18) = 5.88, p < 0.001$). The pineapple harvester was evaluated at farmers' farms and its performance was satisfied in terms of capacity, posture, safety, etc. After the System Usability Scale (SUS) was used to evaluate usability, the SUS score of the harvester ranged from 50 to 97.50 with an average SUS score of 85 (± 14). Therefore, the developed pineapple harvester may be categorized within the acceptable range.

From the above-mentioned points, it is proved that the newly developed pineapple device is helpful for avoiding awkward working posture and injury from leave tips and spines and reduces drudgery significantly thereby improving productivity and efficiency of pineapple harvesting. Therefore, it can be argued that the research hypothesis H1 has been accepted.

7.4 Fulfilment of the objectives

Objective 1: To assess the socio-demography of pineapple farmers, working conditions and problems associated with pineapple harvesting task in northeast India

A comprehensive cross-sectional study was conducted during 2019 in seven districts from the top three pineapple-growing states of northeast India (Assam, Manipur, and Meghalaya). A detailed description of the methodology adopted has been presented in Chapters 3 and 4. A total of 152 pineapple farmers (92 males and 60 females) participated in the study. Data were collected using a pre-tested structured schedule and SNQ questionnaire through personal interviews followed by direct observation. The Rapid Entire Body Assessment (REBA) tool was also employed to assess the key working postures adopted during the entire pineapple harvesting task. Statistical techniques such as Chi-square (χ^2) analysis and multiple logistic regression were conducted using SPSS

software 16.0 to explore the association of various independent factors and their influences on musculoskeletal disorders (MSDs) scores. Detailed findings for the same have been disclosed in Chapters 3 and 4 of the thesis.

Objective 2: To explore innovative design solutions for ease and safe pineapple harvesting in the context of northeast India

During the field study, challenges related to the pineapple harvesting task under the hilly ecosystem of northeast India were identified. To address the challenges, there was no improved tool/equipment available suited to local conditions for the pineapple fruit harvesting task. Therefore, innovative and feasible design solutions were explored for ease and safe harvesting of pineapple fruit in the context of northeast India. Morphological chart and Pugh Chart were used for design-concept exploration and concept selection. Details of design exploration and selection for the development of a prototype pineapple harvesting device are included in Chapter 5.

Objective 3: To develop and evaluate the performance of the prototype pineapple harvester from an ergonomic perspective

In the present research, the prototypes of two selected concepts were fabricated for initial field trials and demonstrated to the pineapple farmers for their feedback. From the performance of field trials, a prototype was finalized and refined in due consideration of trials conducted and users' feedback. The modified harvesting device was evaluated at farmers' farms from an ergonomic perspective involving 20 participants. Evaluations were conducted at the farm level using standardized techniques and methods. Both machine performance parameters and physiological responses of the farmers operating the harvesting device were recorded and compared with the existing methods. A detailed description of the same is presented in chapters 5 and 6.

Objective 4: To study the effect of newly developed pineapple harvester on productivity, efficiency and manual labour

The comprehensive evaluation indicated that the developed pineapple harvester effectively improves harvesting processes, offering potential benefits to farmers' well-being (in terms of physiological factors, work postures, muscular fatigue, and discomfort scores) thereby enhancing the

productivity and efficiency of farm workers during pineapple harvesting task as presented in chapter 6. Moreover, there was no fruit damage while harvesting pineapple using the newly developed harvesting device.

7.5 Novelties of the research

- An innovative pineapple harvesting device was designed, developed, and evaluated at farmers' farms to assess the performance, usability, and acceptability of the targeted users with special reference to northeast India. The design is unique and facilitates the farmers to avoid awkward working posture, picking the fruit from a certain with the help of a telescopic handle, saving the farmers from injuries or cuts caused by thorny leaves, and eliminating the use of a knife (*dao*).
- Four (04) unique design concepts for manually operated mechanical pineapple harvester have been explored in the present research and the designs have been protected with Indian design registrations.
- This study also introduces the application of Design-thinking and user-centric design approach in the domain of horticulture under a hilly ecosystem aimed at alleviating the physical toll on resource-limited pineapple farmers in northeast India.
- For the first time, socio-demographic traits, orchard environment, working conditions, and prevalence of ergonomic risk factors in the pineapple production system (such as intense physical exertion, highly repetitive motion, excessive bending, prolonged stooping, and heavy load carrying) among pineapple farmers were thoroughly studied and presented in this research in the context of northeast India.

7.6 Key contributions of the present research

The present research introduces several novelties that would significantly advance our understanding and knowledge in the field of pineapple harvesting in northeast India. Through meticulous investigation and methodologies, this study unveils a series of key contributions that promise to reshape the existing paradigms. The research outputs have the potential to catalyse transformative changes in pineapple harvesting tasks across pineapple farmers in northeast India. The key contributions are highlighted hereunder.

▪ **Contribution to knowledge-base**

The literature provides evidence that the adoption and transmission of agricultural technology are greatly influenced by the working environment and socio-economic factors (Lestrelin *et al.*, 2012). Many of the socio-demographic traits of the farmers have an impact on their socioeconomic status. An individual's socioeconomic level is directly linked to any agricultural or non-farming activity they engage in (Ganesh *et al.*, 2007). A thorough analysis of the socio-demographic traits, working conditions, and related issues with integrating cutting-edge equipment and methods for pineapple farming and harvesting, however, was lacking. Therefore, a great deal of work in this field has been investigated in the present study.

Despite the fact that issues encountered during the pineapple harvesting process were rather obvious and offered a large amount of research potential, not much study had been done in this field. According to a few studies, picking pineapples is the task with the greatest risk of ergonomic hazards (Rani *et al.*, 2016). The two main risk factors are poor work posture and heavy lifting (Salleh and Sukadarin, 2018b). Other than this, however, very few research in this field and none specifically from India and northeast India, in particular, have been published. As a result, the thesis includes extensive work in this area, carefully examining the frequency of issues linked to occupational health, including musculoskeletal illnesses as well as evaluating ergonomic risk factors.

▪ **Contribution to methodological perspective**

The present study employs a systematic research methodology that begins with a review of the literature and a field survey to determine the research need and problem statement. This leads to the development of an innovative product design that addresses the problems identified through design, development, and field testing. Present research efforts have shown how to use questionnaires and direct/indirect (photography and videography) observations to identify ergonomic stressors during field surveys. Research approaches, both qualitative and quantitative, were implemented based on the needs of data gathering. To determine the need for proper ergonomic intervention, a pre-tested structured schedule and standard questionnaire were used to identify the problems associated with the pineapple harvesting task. Mapping of body parts discomfort was also done based on a procedure by Corlett and Bishop using Body map and Borg's

CR 10 scale. The REBA technique for postural load evaluation, quantification of energy requirement, and oxygen consumption rate based on heart rate were also included in the study.

The present study has illustrated how to develop an ergonomic design solution that is suitable for addressing a particular issue. This study has adhered to the detailed approach of product design innovation. Design thinking and a user-centric design approach were adopted in the development of agricultural tools/equipment. Selecting design limits entails user research; product concept production through brainstorming and the use of morphological charts; Pugh chart screening of the final concept; construction of mock-ups and prototypes; and user testing and feedback from actual field conditions. SUS for usability evaluation was also applied during pineapple harvesting activities by both the existing traditional method and the newly developed pineapple harvester to demonstrate the effectiveness of the newly developed pineapple harvesting device in comparison to the traditional method.

The complete process/methodology of identifying a problem and coming up with a suitable solution, as detailed in the current study, will assist engineers and designers in using a similar approach to develop novel product designs. As a result, future researchers may use the standardized approach that was outlined and used in this study as a guide for their research.

▪ **Perspective of Intervention strategies**

The present study has led to the development of a novel device for harvesting pineapples. The device is simple in design, making it easily producible by local artisans at a low cost. It operates manually, eliminating the need for a power source, and avoids the use of any fossil fuels, thereby preventing the release of smoke and zero air pollution. Moreover, it is user-friendly and requires minimal maintenance. Due to its light weight, the device is portable and can be transported effortlessly uphill or downhill, catering to the topography of hilly pineapple farms in northeast India. Further, the availability of locally manufactured products of this nature in the vicinity of farmers will likely garner significant acceptance within northeast India, ultimately benefiting the targeted community as a whole in a substantial way.

▪ **Contribution to the society**

The present research has focused on addressing practical challenges and ergonomic concerns related to the task of harvesting pineapples among farmers in northeast India. This region is characterized by hilly terrains where small and marginal farmers cultivate pineapples for their livelihoods. Pineapple production in India amounts to approximately 1.96 million tons, achieving a productivity of about 17.85 tons per hectare. Notably, more than half of the nation's pineapple yield comes from northeast India, with the six states in this region consistently ranking among the top ten pineapple-producing areas in the country. Unfortunately, pineapple farmers in the northeast are constrained by outdated traditional harvesting tools due to limited fabrication resources, insufficient research initiatives, and geographical barriers. Given this context, there arose a pressing need to create innovative tools tailored to the safety requirements of northeast India. These tools should ensure the well-being of farmers and mitigate ergonomic challenges.

This study introduces an appropriate ergonomic design intervention aimed at alleviating the physical toll on resource-limited pineapple farmers. A novel harvesting device was developed, and its usability and acceptance were assessed on farmers' fields in northeast India. The newly developed harvesting device is simple in design and low cost which would be affordable for resource-limited pineapple farmers in the region. Through enhanced consideration of design parameters, this intervention led to a marked improvement in working postures and a reduction in drudgery and ergonomic risks thereby attracting small and marginal farmers and rural youths to pineapple farming activities. It is anticipated that the large-scale production and deployment of such devices for pineapple harvesting will have a profound positive impact on the lives of disadvantaged pineapple farmers. It will enhance the productivity of farmworkers and will help in generating more income for the socio-economic upliftment of the poor farmers in the region as a whole.

7.7 Limitations and Future Research Directions

Despite every attempt has been made to ensure that the current study yields the best possible results, certain limitations are outside the purview of the researcher. These limitations/set-backs should be investigated further as potential future study areas.

- The main limitation was the time allotted for gathering field data. The requirement to properly fill out several interview schedules and interview-administered questionnaires may have hindered the respondents' ability to provide accurate and sufficient information for the study. Due to the requirement for several questions to describe prior incidents, recall bias affected the use of the self-reported prevalence of MSDs.
- Assam, Meghalaya, and Manipur are the only three northeastern Indian states where research was conducted to meet the study's goals and validate the hypothesis. Similar research could be conducted outside and in other northeastern Indian states to develop new tools and equipment that are appropriate for the local population.
- The design intervention of the present work is limited to issues and improvement in the harvesting task of pineapple only. Therefore, similar studies may be extended to other important issues related to plantation, weeding, and de-suckering operations in pineapple farming.
- This study is cross-sectional in nature. Therefore, it was not possible to evaluate the cause-and-effect relationship of MSDs. Longitudinal research in the field is also necessary for better outcomes.
- This study is also limited to a design solution that prioritizes portability, affordability, user-friendliness, and safety such that a person can operate it and collect the fruit at the same time. There could be many other alternative solutions that might emerge from different combinations of power sources (manual, motor-powered, etc.).

7.8 Conclusions

In northeast India, the pineapple crop plays an important role in the region's agriculture and economy. The unique challenges of northeast India require tailored solutions, possibly involving ergonomically designed tools to address the prevalent issues and improve harvesting efficiency. However, addressing the challenges in cultivation practices and manual harvesting methods through systematic research and interventions is vital to enhance productivity, reduce drudgery, and improve the overall well-being of pineapple farmers in the region. Therefore, the present research was conducted systematically following the principles of design thinking which included user needs identification, exploring diverse possible solutions, and finalization of most feasible solutions for prototype development and field trials. The developed manually operated, lightweight, low cost and locally fabricable pineapple harvesting device has been liked and accepted by the

farmers as evident from the SUS score. Through enhanced consideration of design parameters, this intervention led to a marked improvement in physiological factors, working postures and a reduction in ergonomic risks. The comprehensive evaluation also suggested that the developed pineapple harvester was effective in improving various aspects of the harvesting process, making it a valuable contribution to agricultural technology in northeast India. Thus, it is envisaged that the developed pineapple harvester if implemented by large-scale production at the local level, and deployment of such device for pineapple harvesting will surely lead to drudgery reduction and socio-economic upliftment of the farmers in northeast India.



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APPENDICES

Appendix-I Participant informed consent form of Pineapple Farmers

CONSENT FORM

Project/Study Title	Exploring Innovative Design Solution for Pineapple Harvesting in the Context of Northeast India
Name of PI of the project/study	Prof. Sougata Karmakar, Professor Head, Department of Design, IIT Guwahati
Purpose of the study	Ergonomic design interventions for mechanized pineapple harvesting process and towards reduction of drudgery involved in pineapple harvesting task.
Procedures	At farmer's pineapple farm/home, you will be interviewed to collect information on the followings: <ol style="list-style-type: none"> 1. General demographic data 2. Anthropometric data (Height weight) 3. Work history 4. Pineapple crop/orchard characteristics 5. Mechanization status and problems associated with existing pineapple harvesting practices 6. Improved tools/equipment required for pineapple harvesting task 7. Prevalence of musculoskeletal symptoms in pineapple harvesting task using SNQ questionnaire 8. Psycho-social characteristics 9. Body part discomfort after completion of pineapple harvesting task using body pain map Borg' CR 10 scale 10. Overall workload using NASA task Load Index Photography and videography of the interview, pineapple farm, farmer's activity at farm will be taken to support the study and for documentation.
Potential Risks and Discomforts	Neither any drug will be administered nor will any invasive procedure will be followed. One may experience mild temporary exhaustion post completion of this experiment
Confidentiality	We will plan to publish the results of this study, but will not include any information that would identify you.
Right to Withdraw and Questions	Your participation in this research is completely voluntary. You may choose not to take part at any time.
Statement of Consent	Your signature indicates that you are at least 18 years of age; you have read this consent form along with purpose and procedure of the experiment
Signature and Date	Name of the participant:
	Signature:
	Date:

Appendix-II Schedule used for Pineapple Farmers' Information

Part-A: General Information of Pineapple Farmers

I	I. Demographic Information	
	Name of village, district state	Gender (M/F):
	Age (year):	Marital status (Married/Unmarried):
	Family members:	Family members involved in farming:
	Ethnicity:	Education level:
	Hand dominance (Left/Right):	Smoking habit (Yes/No):
	Income (Low/Medium/High):	
II	II. Anthropometric Information	
	Weight	Height:
III	III. Work Related Information	
	Work experience (years)	Previous work
	Daily working hours:	Income Satisfaction (Low/Moderate/High)
	Hand tool satisfaction (Low/Moderate/High)	Perceived fatigue/discomfort (Low/Moderate/High)
	Frequency of rest pauses (Adequate/Inadequate)	
IV	IV. Orchard Related Information	
	Land holding (ha):	Owned/Leased(O/L):
	Topography of farm (Hill/Plain):	
	Pineapple variety being cultivated:	Plant-to-plant and row-to-row spacing (cm):
	Orientation of rows of crop:	Removal of suckers/slips developed (Y/N):

Part-B: Mechanization Status in Pineapple Harvesting Task

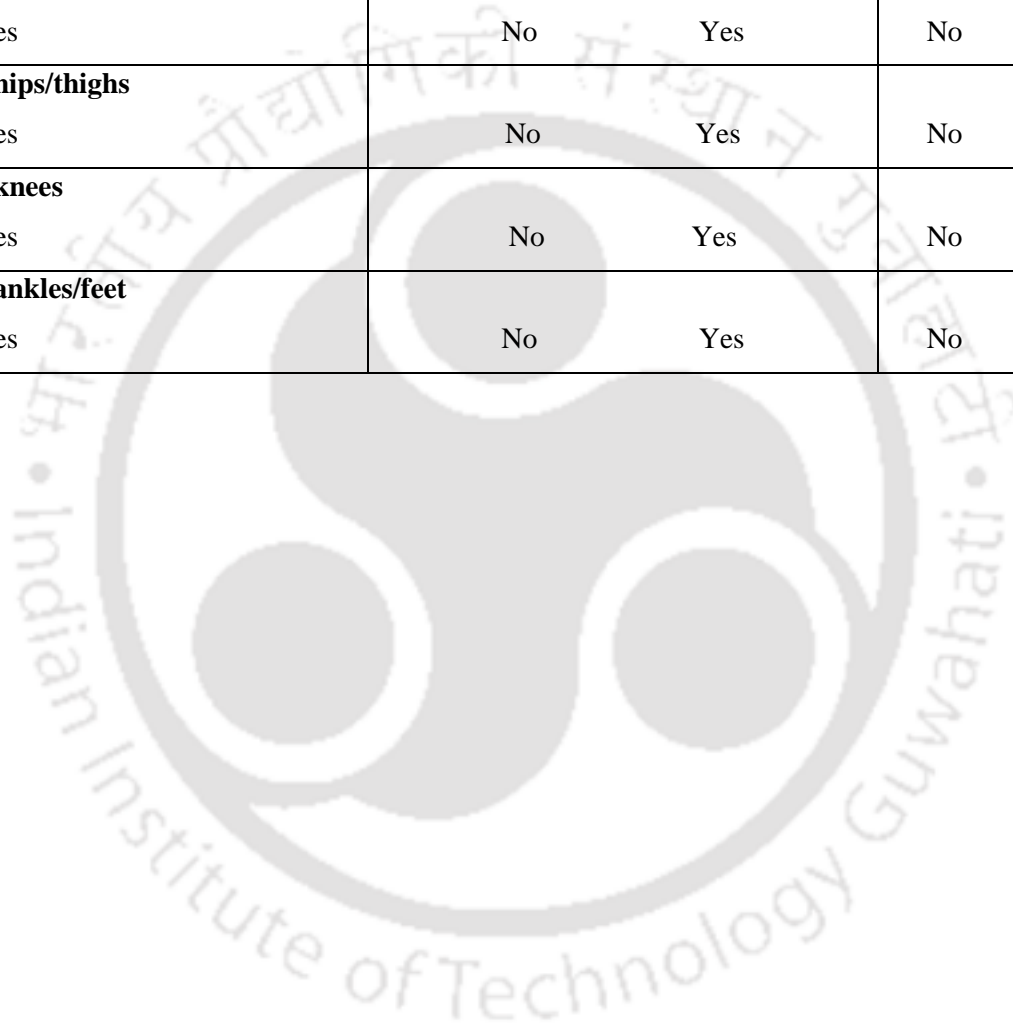
I	I. Pineapple Harvesting				
	Prevalent practices	Main Season	Man-hr/ha or Fruits /h		
II	II. Farm tools/equipment used				
	Tool/equipment in use	Owned/ leased	Power source	Cost (Rs.)	Field capacity, ha/h or Fruits/h
1					
2					

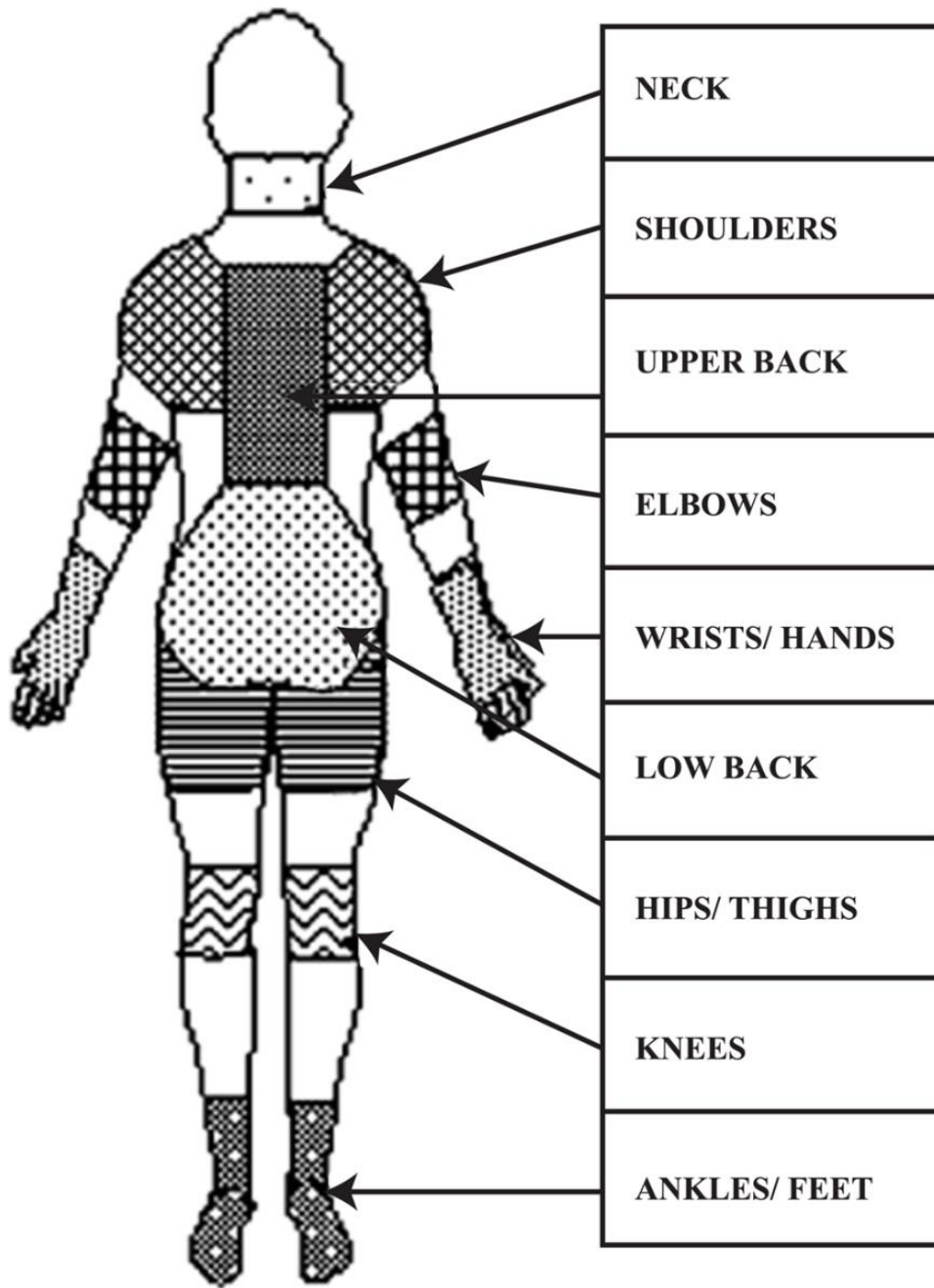
III	III. Socio- Economic Parameters			
III-A	III-A. Hiring Charges		Rate (Rs./day) (specify if unit is different)	
			Normal	Peak Season
1	Unskilled labour	Male		
		Female		
III-B	Economic Returns			
	Sale price, Rs./t or specify any unit		Expenditure (Rs.)	
	In-season	Off-season		
IV	Improved Tools/equipment Required			
	Tool/Equipment required	Specifications		
		Preferred power source, capacity, range of price (Rs.), individually owned or for custom hiring, expected annual use (h) etc.		
1.				
V	V. Any constraints (please specify)			
	Availability of improved tools and equipment			
	Working environment			
	Any safety issues			
	Any other			

Part-C: Standardized Nordic Questionnaire (Kuorinka *et al.*, 1987) for analysis of Musculo-skeletal symptoms in pineapple harvesting task

Have you at any time during the last 12 months had trouble (ache, pain, discomfort) in:	To be answered only by those who have had trouble			
	Have you at any time during the last 12 months been prevented from doing your normal work because of the trouble?		Have you had trouble at any time during the last 7 days?	
Neck	No	Yes	No	Yes
Shoulders	No	Yes, in the right shoulder Yes, in the left shoulder Yes, in both shoulders	No	Yes
Elbows	No	Yes, in the right elbow Yes, in the left elbow Yes, in both elbows	No	Yes

Wrists/hands No Yes, in the right wrist/hand Yes, in the left wrist/hand Yes, in both wrists/hands	No Yes	No Yes
Upper back No Yes	No Yes	No Yes
Low back No Yes	No Yes	No Yes
One or both hips/thighs No Yes	No Yes	No Yes
One or both knees No Yes	No Yes	No Yes
One or both ankles/feet No Yes	No Yes	No Yes





Body Map

Part-D: Mapping of Body Part Discomfort (Immediate after completion of task)

(Based on a procedure by Corlett and Bishop using Body map and Borg's CR 10 scale)

Sl. No	Body Parts	0 No discomfort 0.5 Extremely weak (Just noticeable) 1 Very Weak 2 Weak 3 Moderate 4 Somewhat strong 5 Strong 7 very strong 10 Extremely strong discomfort											
		0	0.5	1	2	3	4	5	6	7	8	9	10
		1.	Neck										
2.	Right shoulder												
3.	Left shoulder												
4.	Right arm												
5.	Left arm												
6.	Right elbow												
7.	Left elbow												
8.	Right forearm												
9.	Left forearm												
10.	Right wrist												
11.	Left wrist												
12.	Right hand												
13.	Left hand												
14.	Upper back												
15.	Lower back												
16.	Right buttock												
17.	Left buttock												
18.	Right thigh												
19.	Left thigh												
20.	Right knee												
21.	Left knee												
22.	Right leg												
23.	Left leg												
24.	Right foot												
25.	Left foot												
26.	Whole body												

Please rate the sense of discomfort using the Borg's CR 10 scale (0-10)

Place:

Date:

(Name, designation and signature)

Appendix-III Rapid Entire Body Assessment (REBA)

REBA Employee Assessment Worksheet

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

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

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

Step 2: Locate Trunk Position

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

Step 3: Legs

Adjust:
 30-60°: Add +1
 >60°: Add +2

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

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

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

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

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

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

Step 8: Locate Lower Arm Position:

Step 9: Locate Wrist Position:

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

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

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

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

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

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

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

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

Table C Score

+

Activity Score

Final REBA Score

Task name: _____ Reviewer: _____ Date: ____/____/____

provided by Practical Ergonomics
 rbarker@ergosmart.com (816) 444-1667

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA. © 2004 New Consulting, Inc.

Source: [https://www.physio-pedia.com/Rapid_Entire_Body_Assessment_\(REBA\)](https://www.physio-pedia.com/Rapid_Entire_Body_Assessment_(REBA))

Appendix-IV System Usability Scale used for evaluating pineapple harvesting device

System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
2. I found the system unnecessarily complex	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
3. I thought the system was easy to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
5. I found the various functions in this system were well integrated	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
6. I thought there was too much inconsistency in this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
8. I found the system very cumbersome to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
9. I felt very confident using the system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5

Appendix-V Specifications of Polar H10

Polar H10

The **Polar H10 Heart Rate Sensor** is an integrated chest strap and heart rate monitor designed to measure the user's heart rate. The H10 sends data wirelessly via either a Bluetooth data transmission to a compatible smartphone with supported heart rate service applications, or to compatible Polar devices using a coded transmission. The Polar H10 is fully waterproof and will function in the pool, and software updates are provided through Polar's Flow and Beat mobile apps. This sensor fits chests measuring 22 to 34".

Specifications:

Compatibility	iPhone 4s and later Android devices with Bluetooth 4.0 and OS version 4.3 or later
Bluetooth	Yes
Memory	One training session
Waterproof	Yes
Battery	CR2025
Battery Life	400 hours with BLE and 5 kHz transmission active
Material	Connector: ABS, ABS + GF, PC, stainless steel Strap: 38% polyamide, 29% polyurethane, 20% elastane, 13% polyester, silicone prints
Operating Temperature	14 to 122°F / -10 to 50°C
Sizing	Fits chests measuring 22 to 34" / 55.9 to 86.3 cm
Dimensions	Connector: 1.3 x 2.6 x 0.4" / 34 x 65 x 10 mm
Weight	Connector: 0.74 oz / 21 g Strap: 1.38 oz / 39 g



Polar H10

Appendix-VI Specifications of Nuton Blood Pressure Monitor

Brand	NUTON
Model Number	HOMECHECK BP01
Accuracy	0.03 pressure
Cuff Type	ARM TYPE
Measurement Range (Pressure)	0-280 mmHg
Usage/Application	Personal
Cuff Circumference	28-32 cm



Appendix-VII Specifications of Digital Weighing Machine

Weighing Machine (Measurement of respondent body weight)

Model Name	Wooden weight machine
Model Number	0001
Color	Camel wood
Display	LCD
Display Size	6 inch
Powered By	AAA BATTERY
Battery Type	AAA battery (2numbers)
Dimensions	260x260x20 cm
Maximum Weighing Capacity	180 kg



Weighing Machine (Measurement of fruit)

Capacity	20 Kg
Material	Stainless Steel
Type	Table Top
Display Type	LCD Display, LED Display
Accuracy	5 gm
Automation Grade	Automatic
Power Supply	240 V, 50 Hz





भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Section. R&D Section

Date: 04.07.2019

NOTE SHEET

AR(R&D)

Sub: Ethical approval for proposal submitted by Dr. Sougata Karmakar, Dept. of Design

A project proposal entitled "Ergonomic design intervention towards improving mechanization level of pineapple harvesting in north east India" has been received for approval/clearance from IHEC.

Placed for your kind perusal and advice, please.

Placed for consideration please.

Sushjit Choudhary
4/7/2019

Approved in principle.

Alor
JA(R&D)

→ Dean (R&D) L.D. 5/7/19

Appendix-VIII Details of Vernier Calliper

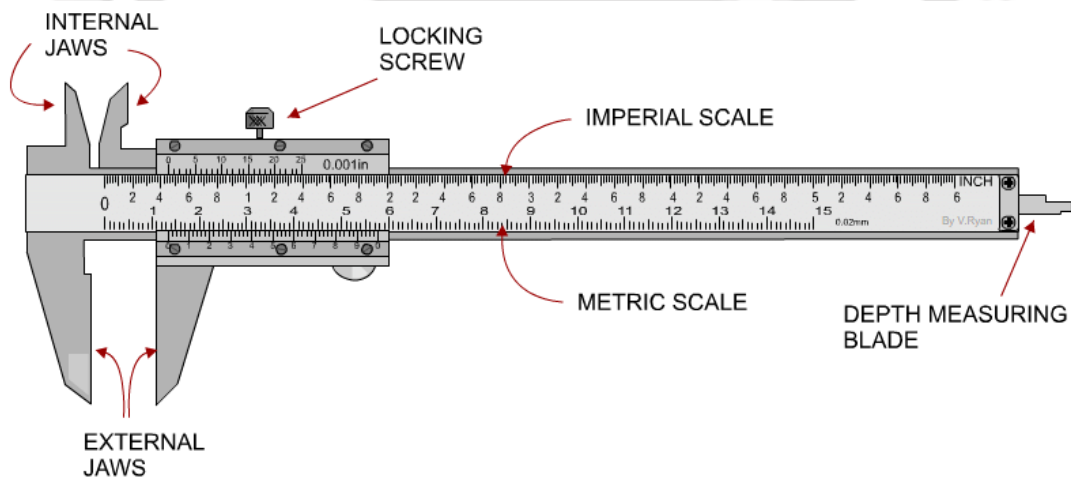
Vernier Calliper (0-100 mm, 0.05 mm, Metric)

This is a standard type of Vernier caliper that offers you the following benefits:

- Main scale and Vernier scale satin chrome finish give you high readability.
- Raised sliding surfaces

Features

With upper locking screw:	Yes
Range:	0 - 100 mm
Depth bar:	Ø 1.9 mm
Max. Permissible Error E MPE:	±0.05 mm
Max. Permissible Error S MPE:	±0.07 mm
Mass:	128 g



Vernier Calliper

Appendix IX Names and specifications of the items used for fabrications of developed pineapple harvesting device

Sl. No.	Item used	Specifications	Quantity
1	MS Sheet	180x210mm (16 Gauge)	2 nos.
2	MS Pipe	25.4 mm (1 inch)	36 cm
3	MS Flat	18 mm	25 cm (2 nos.)
4	MS rod	8 mm	45 cm (1 no.)
5	Steel saw blade	130x55x1 mm	2 nos.
6	Hinge	50 mm	3 nos.
7	Nut bolt	6 mm	4 nos.
8	Washer	12.7 mm (1/2 inch)	5 nos.
9	Elbow Cutch (Plastic)	Adjustable, universal size	1 no.
10	Handgrip (Rubber)	-	1 no.

Appendix X Fabrication of developed pineapple harvesting device



Fabrication of fruit grabber



Joining cutter at base of fruit grabber



Adjustment of Flexible clamp attached with fruit grabber and handle



Fabricated prototypes in workshop

List of publications

Journal Papers

- Singh, H. J., Singh, H.D., Chauhan, J.S. and Karmakar, S. 2020. Progress on Research and Development in Pineapple Harvesting: Special Emphasis on Indian Scenario. *Science and Culture*, 86(5-6): 178-187. ([Web of Science indexed](#))
- Singh, H.J. and Karmakar, S. 2022. Socio-demography, working conditions and musculoskeletal ailments among the pineapple farmers in northeast India. *Journal of Agromedicine*, 27 (2): 245-257. <https://doi.org/10.1080/1059924X.2021.1920529>. ([SCIE indexed](#)).
- Design and development of a pineapple harvesting device for small and marginal farmers of Northeast India: A systematic design process (in preparation).
- Ergonomic evaluation of pineapple harvesting device for small and marginal pineapple farmers of Northeast India (in preparation).

Conference Proceedings

- Singh, H.J., Chauhan, J.S., Karmakar, S. 2022. Ergonomic Risk Factors Associated with Pineapple Harvesting Task in Northeast India. In: Chakrabarti, D., Karmakar, S., Salve, U.R. (eds) *Ergonomics for Design and Innovation. HWWE 2021. Lecture Notes in Networks and*

Systems, vol 391. Springer, Cham. https://doi.org/10.1007/978-3-030-94277-9_65. (Indexed by SCOPUS indexed)

- Singh, H.J., Singh, H.D., Karmakar, S. 2019. Progress in Research and Development on Pineapple Harvesting: Special Emphasis on Indian Scenario. In: Abstract Book of Research Conclave 2019. Available at: <https://event.iitg.ac.in/researchconclave/rc19/>.

Patents

▪ Design Registration:

1. IIT Guwahati, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. 2021. Hand-held pineapple fruit harvester. Design No: 343374-001. **[Granted]**
2. IIT Guwahati, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. Hand-held pineapple harvester. Design No.345481-001. **[Granted]**
3. IIT Guwahati, Singh, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. 2021. Ergonomic pineapple harvester. Design No.346195-001. **[Granted]**
4. IIT Guwahati, Hijam Jiten Singh, Sougata Karmakar and Gurdeep Singh. 2021. Hand-operated pineapple harvester. Design No: 346209-001. **[Granted]**

▪ Utility Patent:

1. Ergonomic pineapple harvesting device for small and marginal farmers (in preparation)