Ergonomic Design Intervention for Pineapple Peeling Task in Small Fruit Processing Units

A thesis submitted
in partial fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

by

Prakash Kumar

Department of Design
Indian Institute of Technology Guwahati
Assam, India 781039

July 2014

Ergonomic Design Intervention for Pineapple Peeling Task in Small Fruit Processing Units

A thesis submitted
in partial fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

by

Prakash Kumar
(Roll No. 09610503)

Under the supervision of

Prof. Debkumar Chakrabarti

Department of Design
Indian Institute of Technology Guwahati
Assam, India 781039

July 2014

DECLARATION

It is certified that the work contained in this thesis entitled "Ergonomic Design Intervention for Pineapple Peeling Task in Small Fruit Processing Units" has been carried out by me, a student in the Department of Design, Indian Institute of Technology Guwahati under the guidance of Prof. Debkumar Chakrabarti for the award of Doctor of Philosophy and that this work has not been submitted elsewhere for a degree.

Date:

Prakash kumar
Department of Design
Indian Institute of Technology Guwahati
Guwahati 781 039
Assam, India

CERTIFICATE

The research work presented in this thesis entitled "Ergonomic design intervention for pineapple peeling task in small fruit processing units" has been carried out under my supervision and is a bonafide work of Mr. Prakash Kumar. This work submitted for the degree of Doctor of Philosophy is original and has not been submitted for any other degree or diploma to this institute or to any other institute or university. He has also fulfilled all the requirements including mandatory coursework as per the rules and regulations for the award of the degree of Doctor of Philosophy of Indian Institute of Technology Guwahati.

Dr. Debkumar Chakrabarti, PhD
Professor
Department of Design
Indian Institute of Technology Guwahati
Guwahati 781 039
Assam, India

ACKNOWLEDGEMENT

First and foremost, I would like to express my earnest gratitude to my doctoral committee members, Prof. Pinakeswar Mahanta, Prof. A. K Das and Dr. Utpal Barua, for their cooperation and valuable guidance during the research.

I would specially like to thank Mr. Bidyut Kumar Barua, Regional Manager, Guwahati Regional Office, Agricultural and Processed Food Products Export Development Authority (*APEDA*) and Dr. Bidyut Chandra Deka, Joint Director, ICAR Research Complex for North Eastern Hill Region, Nagaland Centre for their suggestions and inputs regarding scope of intervention in the field of horticulture and, specifically, in the area of pineapple peeling. I also wish to thank Pradeep Bhuyan, Asst. Manager-Marketing, North Eastern Regional Agricultural Marketing Corporation Limited (NERAMAC), for providing vital information regarding the small fruit processing units of North East region.

I would be ever indebted to the people who have helped in many ways; having volunteered to be a part of the study representing the target user group in government as well as non-government fruit processing units across the region. I am especially thankful to Mr. Pranav Mahanta from Rity Food Processing Pvt Ltd, Boko, Mrs Phikaralin Wangsang from Kara's Food Preservation Factory, shillong, Mr. L. Doulo from Exodelicia Pvt. Ltd, Dimapur and Mr Pijush from Pijush Agro Tech Food Products, Tripura for their cooperation and support during the study in their premises.

I also take this opportunity to express my sincere gratitude to all the faculty members and students of Department of Design, Indian Institute of Technology Guwahati who helped me in my endeavour at some point of time. I am especially grateful to my colleagues and friends, Mr Vikash Kumar, Mr T. Ravi and Mr K.K Balakrishnan for their moral support, encouragement and valuable suggestions. I also owe gratitude to my parents for their love, trust, patience and support. I am thankful to my little niece for her innocent tickling voice that gave me a reason to smile even during the toughest stretch of my work.

Last but not the least, I would like to convey my reverence to my supervisor Prof. Debkumar Chakrabarti for guiding me, giving me freedom to choose my path and above all, believing in me.

ABSTRACT

North east India is one of the largest producers of pineapples in the country and there are many small fruit processing units across the region that process pineapples during the harvest season. These units being labour intensive are a significant source of employment for the local population. But, the wellbeing of the pineapple processing workers as well as their productivity is highly compromised due to use of old traditional tools and techniques. Pineapple processing activities starts with the manual peeling task that is quite repetitive, time taking and laborious in nature. In spite of the various peeling related issues, the units adhere to these traditional peeling methods as they don't find any solution appropriate to their context of use. If the workers are provided with a comfortable and effective peeling aid with the consideration of prevailing conditions of the small processing units, the solution would not only improve occupational health and efficiency of the workers; and productivity of the units but also encourage many other small and marginalised entrepreneurs to get into this business. The thesis looks into existing work process related to pineapple processing and associated physical and occupational issues including risk factors influencing productivity. This provides the basis for evolving a holistic process for design intervention to develop work methods, tools and equipment for pineapple peeling.

The thesis is broadly divided into three parts. The first part discusses the assessment of the issues related to pineapple peeling task through observation and interaction with workers. During the visits, general working of the small scale units was observed and peeling related problems and hazards were found to be quite apparent. Since not much of work had been reported in the area from the perspective of occupational health issues, an effort was made to establish the prevalence of ergonomic risks using specific evaluation tools like body pain map, analog Borg's pain rating scale, Quick Exposure Checklist (QEC), Rapid Upper Limb Assessment (RULA). More than three fourth of the workers reported of pain in at least one of their body parts. Higher QEC and RULA scores for a large number of workers indicated further investigations and changes in work method soon. Different risk factors like repetitive task, prolonged work period, insufficient rest breaks, awkward posture adoption, repetitive force application, etc. associated with pineapple peeling task, were also identified. Thus, various ways of reducing these risk factors were thought of and eventually, the issues were decided to be addressed through an intervention, mechanically, by designing a pineapple

peeling equipment that reduced drudgery and improved the peeling task capability of the workers.

The second part elaborates upon the process adopted for conceptualisation and realisation of the intervention which would not only solve the ergonomics issues but also addresses other issue which hinders the implementation and adoption of new interventions. The ergonomic issues related to peeling had been addressed from engineering perspective (better operation and output) as well as considering a holistic systemic perspective (considering social, economic, infrastructure related factors, etc.). The issues related to the system, its stakeholders and interlink between the key stakeholders was studied to identify the key requirements along with study of peeling solutions available in the market which could be broadly segregated into different categories. With an intent to provide a more acceptable solution to the target users, a support tool, based on Quality Function Deployment (QFD) approach, was used to decide upon the most appropriate category of pineapple peeling solutions for given context. While attempting the design of peeling aid, the structure and fundamental properties of the fruit was also considered. Eventually, the final specifications were formulate followed by concept generation. The concepts were screened on the preliminary criteria like effort requirement, peeling effectiveness, peeling rate and constructional simplicity. Through iterative process, the final design solution was reached at which conceived peeling the pineapple slices instead of peeling the whole pineapple in one go. 3-D modelling and design detailing was carried out and final proof of concept was generated to demonstrate the working in principle. An effort was made to ascertain if the solution addressed the issues and requirements of workers and entrepreneurs, the two main stakeholders of the system in consideration. The strategies of the development were significantly influenced by the limitations of investment capability, skills and knowledge of local workers to adopt to the sophisticated high end equipment. Thus, a simple mechanical device, which was easy to manufacture and maintain with local expertise and could be used by local work force, was considered.

The third and concluding part reports evaluation of the ergonomic design intervention against key requirements of the workers and entrepreneurs which also validated the design process undertaken for the new intervention. Virtually simulated RULA assessment of the 3D model was done using Digital Human Modelling (DHM). The improved proof of concept was evaluated for its performance by the workers on NASA Task load Index (TLX) as well as Task Completion Time (TCT) of the workers was also determine to find the rate of peeling using the equipment. To get the feedback of the entrepreneurs, to assess the effectiveness of the solution, the working of the equipment in principle was demonstrated to them and all the relevant details i.e. price, dimensions, accessories details, material details, weight, etc. were provided to them. The entrepreneurs were then asked to rate the new intervention and their old peeling solution on the same key requirements which had been identified, initially, as the basis of the design specifications. Similarly, an effort was also made to validate the findings of the support tool proposed for deciding the most appropriate peeling solution category. The findings of these assessments and the future scope of work have been discussed in the final phase of the thesis.

CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION:

NEED AND APPROACH OF

ERGONOMIC DESIGN INTERVENTION

Chapter 1

INTRODUCTION: NEED AND APPROACH FOR ERGONOMIC DESIGN INTERVENTION

1.1 Overview of the research area

The thesis focuses on addressing ergonomic issues related to the manual pineapple peeling workers in small fruit processing units of north east India (comprising of states namely Assam, Meghalaya, Arunachal Pradesh, Manipur, Mizoram, Tripura and Nagaland; also referred to as North East). It delineates process for designing intervention that, along with the ergonomic issues, addresses the crucial requirements of various stakeholders, as well as, considers various constraints and conditions pertaining to the system in context. It also leads to design intervention in form of a mechanical peeling aid. North East is one of the largest producers of pineapple in the country (B. Kumar, 2011) and there are many small fruit processing units across the region that process pineapple during the harvest season (Figure 1.01). These units often lack in basic facilities i.e. regular power supply, sufficient space, efficient tools, etc. leading to poor working conditions. The adverse working conditions often result in different occupational health related problems including Work related Musculoskeletal disorders (WMSDs) which significantly affect the occupational health as well as productivity of the workers in industries, in advanced as well as, industrially developing countries (IDCs) (A. Nag, Vyas, & Nag, 2010). Hence, there have been significant efforts to address occupational health related problems prevalent in different industries and many remedies have also been suggested for specific problems. But, as far as the small industries in IDCs are concerned, there is much to be done yet. Small Pineapple processing industry in North East is one such industry that requires proper attention. Owing to its large impact and promising future potential, the issues related to pineapple processing industry are required to be looked into and addressed.

Figure 1.01 Pineapple processing in North east region; a-Pineapple during peak harvest season transported from field to units, b- Pineapple peeling using *Baithi*, c- Pineapple peeling using traditional knife, d- general posture adopted during peeling, e- General work at processing unit and f- Male workers at peeling task

There is a good scope of research but very little work had been reported in the area. The present work is an effort to fill this research gap in the field.

1.2 Statement of the problem

The main problem addressed through the thesis concerns establishing work related health problem among the manual pineapple peeling workers in the small fruit processing units and evolving a design process to come up with a peeling solution which is more appropriate to the system, in context, with respect to better productivity. Thus, thesis first tries to establish the prevalence of WMSDs among the workers engaged in manual pineapple peeling task through the assessment of ergonomic risk level using QEC (Quick Exposure Check) and

RULA (Rapid Upper Limb Assessment) as well as identification of various risk factors associated with the pain occurrence in difference body parts. This was followed by laying down a holistic process for designing a pineapple peeling solution. Finally, evaluation of the outcome was done to establish the efficacy of the design process adopted against the key requirement of the stakeholders.

1.3 Justification: Importance of pineapple processing for the region

Fruit processing is an important agro-based industry in North East, the region is abundant in different seasonal fruits. Being the largest producer of pineapples in India, it has many small fruit processing units which process pineapple during the season. Low levels of investment, labour intensive processes and minimum initial infrastructural requirement are the characteristics of these units. Since fruit processing industry uses fruit as main raw material which is organic and renewable natural resource, it has less impact on environment. Today every industry is seen from sustainability perspective i.e. considering society, economy and environment (P. Kumar & Chakrabarti, 2011b); fruit processing industry provides a viable and sustainable business proposition as compared to the big heavy industries that ask for greater infrastructure, huge investment and also have adverse effect on environment (Figure 1.02).

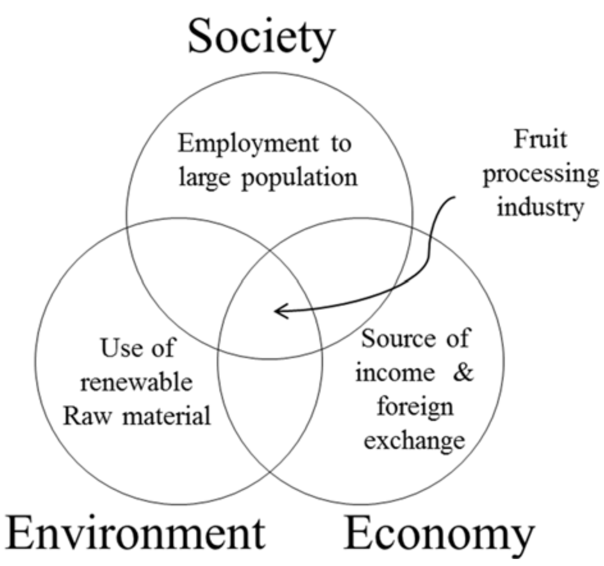


Figure 1.02 Fruit processing Industry from Sustainability perspective

Understanding need of the hour and realizing scope and potential of fruit processing industry in North East, Government has also been giving impetus on improvement of this sector and had launched 'Horticulture Technology Mission' in 2001 (Sema & Maiti 2011). Also, with the government proposal to connect India to the south east Asian countries through North East, this part of country is destined to become an important commercial hub for the whole of South East Asia in future (Sikri, 2009). Thus horticulture products from the region including processed pineapple products would have direct access to the whole of Asian market making it a consistent source of income as well a good source of foreign exchange. Hence, pineapple processing industry has a good scope and future market and has been seen as one of the biggest strength for the region.

1.4 Motivation for choosing pineapple processing industry

Since, these small labour intensive processing units, engaged in pineapple processing, are spread across the region; a large number of people are directly or indirectly associated and benefitted from it. It employs a large population of local workers providing them with an important source of income. Any improvement in the sector is supposed to impact a larger section of the local population. This thought of larger change that is possible with an improvement was the motivation to choose this area of research.

1.5 Rationale for focus on pineapple peeling task

Pineapple processing occurs for a shorter period of time during the year as peak harvest season is only for a few months i.e. from November to February and from July to September. To make decent profits, a large quantity of pineapple is required to be processed by the units within this stipulated time. But the productivity of these units is highly compromised due to slow pineapple peeling task owing to the use of generic, traditional tools like knives, *Baithi* (Figure 3.5), etc. To make up for this sluggish rate of peeling task, more workers are to be employed which is difficult to find during the peak season making the employed labourers work for long hours. Since pineapple peeling is tough and highly repetitive task, the prolonged exposure to such task often results in different health related problems. On the contrary, if the material lot is not cleared fast, spoilage starts which would be shear loss to the entrepreneurs. Hence, addressing the issues to remove this major bottleneck in pineapple processing, it was identified as highly critical. This is the main rationale for present work in the area.

1.6 Definitions as used in the thesis

In the thesis, different terms have been used with a particular intention. Therefore we define the meaning of important terms as it is intended in the present context of work, to remove any ambiguity. These definitions are as following:

A. Ergonomic intervention:

It is the process of intervening or modifying a particular situation through some aide or remedy to address the prevalent ergonomic issues (Norman & Wells, 1998). Ergonomic interventions are categorised into different class i.e. engineering, administrative and behavioural/ personal (Figure 1.03). It also a means of establishing optimum usage of human resources for maximizing productivity.

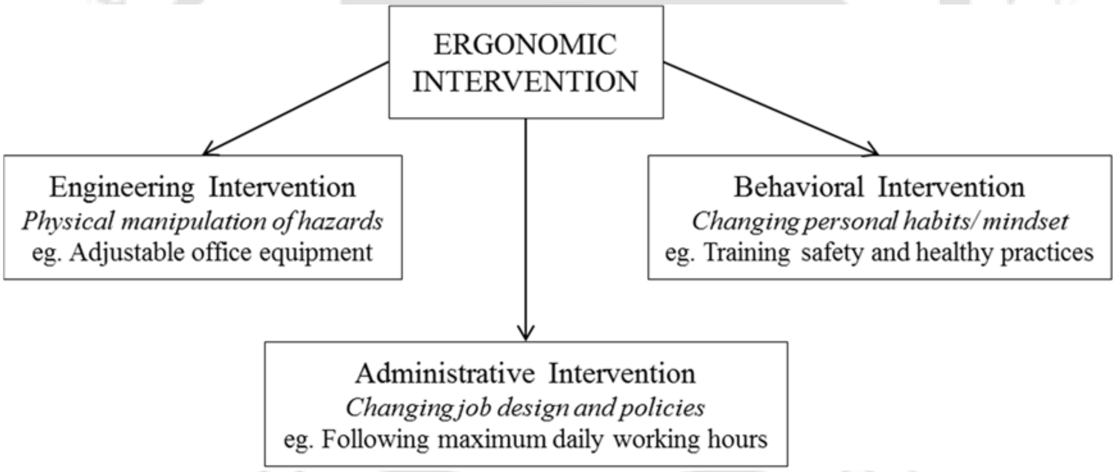


Figure 1.03 Classifications of ergonomic intervention

B. Ergonomic design intervention:

The process of intervening or modifying a particular situation to address the prevalent ergonomic issues, through a design approach, is termed as Ergonomic Design Intervention. This might not be just a small change or modification. The solution is generated with a holistic approach considering the system in context from different perspectives.

C. Proof of concept:

Proof of concept (POC) is realization of a certain method or idea to demonstrate its feasibility or working in principle. Proof of concept is usually small and might or might not be complete. In the present research work, the assumption that through ergonomic design intervention, workers' occupational wellbeing and productivity is possible to be achieved, is tried to be demonstrated through the proof of concept.

D. Pineapple peeling equipment

Important items or aide like tools, devices, machinery, etc., needed particularly for pineapple peeling purpose or activity, are termed as pineapple peeling equipment.

E. Small Units

Small units, as used in the thesis, stand for micro and small enterprise in the region. Micro enterprises are those where investment in plant and machinery does not exceed 25,00,000/- whereas small enterprise are those whose investment is more than 25,00,000/- but less than 5 crore rupees (Sircar, 2006).

1.7 Research Questions

Having defined and explained the research context, a set of research questions thus arose which this thesis tries to answer. In spite of benefit to a large number of small units in the region, there is a lack of research and initiatives for intervention in the area of pineapple processing particularly related to peeling activity that appears to be a bottle neck issue in the processing work flow, though a significant amount of research had been reported in other similar domains (Rai, Gandhi, Kumar, Sharma, & Garg, 2012). This poses several questions that need to be looked into:

1. Can one ascertain if the ergonomic risks related to pineapple peeling tasks are significant enough to be addressed?
2. Can one determine how prevalent the occupational health problems are among the workers in small processing units, associated with pineapple peeling task?
3. How are various factors affecting the solutions related to manual pineapple peeling task in the units?

4. What would be strategy for designing the intervention which addresses the ergonomic risk factors and is readily and largely adapted by the local entrepreneurs?

With an aim to find the answers to these research questions, following research objectives were framed.

1.8 Aim and objectives

The study aims at establishing ergonomic issues prevalent among manual pineapple peeling workers and develop a design intervention that builds upon the occupational wellbeing, performance and other related contextual issues.

To achieve this aim, following objectives were laid down:

1. To assess how prevalent are the risk related to manual pineapple peeling task using ergonomic tools, in terms of musculoskeletal symptoms and existing health hazards
2. To identify the problems related to existing pineapple peeling solutions and hence, scope of interventions in the area of pineapple peeling specifically for small processing units
3. Design development in tune to thus identified targeted task components
4. Evaluation of how better the design intervention is, as compared to the existing solutions, with respect to performance related issues concerning the workers and sustainability issues in small processing units.

1.9 Research Hypothesis

During the visits to pineapple processing units in Assam, Meghalaya, Tripura and Nagaland it was found that there were certain issues regarding the workers' occupational health and productivity i.e. pain occurrence among the manual pineapple peeling workers, hand itching and bleeding (in some cases), the slow pace of peeling task, reduction in peeling output of the workers with time, etc. Literature hardly reported any in-depth study addressing the above issues and, moreover, majority of the units were found using individual work skill based methods and traditional tools, despite the difficulties in performing the task.

Thus, two specific issues were considered to be addressed. At first, attempt was made to establish the prevalence and seriousness of the occupational health related issues among the manual pineapple peeling workers working in small processing units that might provide clues to development requirement focus and secondly, effort was made to lay down a strategy that would help in developing an appropriate peeling solution towards improved performance of the workers. Hence, two hypotheses were framed, as mentioned below, to work upon.

H1: Occupational health related problems are prevalent among the manual pineapple peeling workers in small processing units of North East India with high level of ergonomic risks.

H2: A strategic design intervention through a holistic approach can improve the occupational wellness and productivity of the workers engaged in pineapple peeling as well as suit the local entrepreneurs.

1.10 Research methodology and Research design

As the research aimed at finding solution for an immediate problem faced by some fruit processing units along with evolving process for design of a fruit processing equipment; the research was partially applied and partially fundamental in approach (Kothari, 2004) **.** The methodology adopted to accomplish the research goal for the thesis is shown is Figure 1.04.

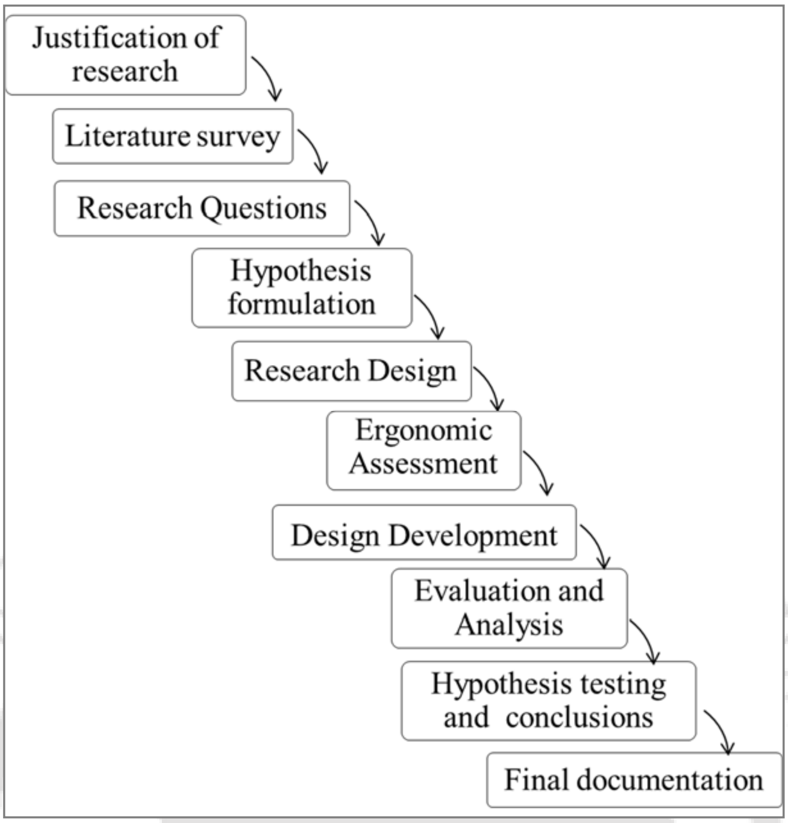


Figure 1.04 Research methodology adopted

In addition to following this broader research methodology, there was a need to lay down the research design which was a blue print of how the data would be gathered and analysed to draw inferences in the present research. Since not much of study was presently reported in the area, ergonomic evaluation of the manual pineapple peeling operations was carried out to establish the need for design intervention. Purposive random sampling was done to collect the data from different parts of North East for better representation of the region and was analysed using descriptive and inferential statistics. Secondly, requirement of the different stakeholders i.e. entrepreneurs and workers were gathered through purposive random sampling and analysed using descriptive and inferential statistics. A systematic assessment of the outcome was carried out through the stakeholders' feedback and the result was analysed and accordingly, inferences were drawn. Thus, the research design was divided into three phase i.e. ergonomic assessment of the existing work system, design intervention for development of work methods and equipment followed by evaluation and confirmation based on the trial of the proposed solution. Fig1.05 depicts the summary of the research design.

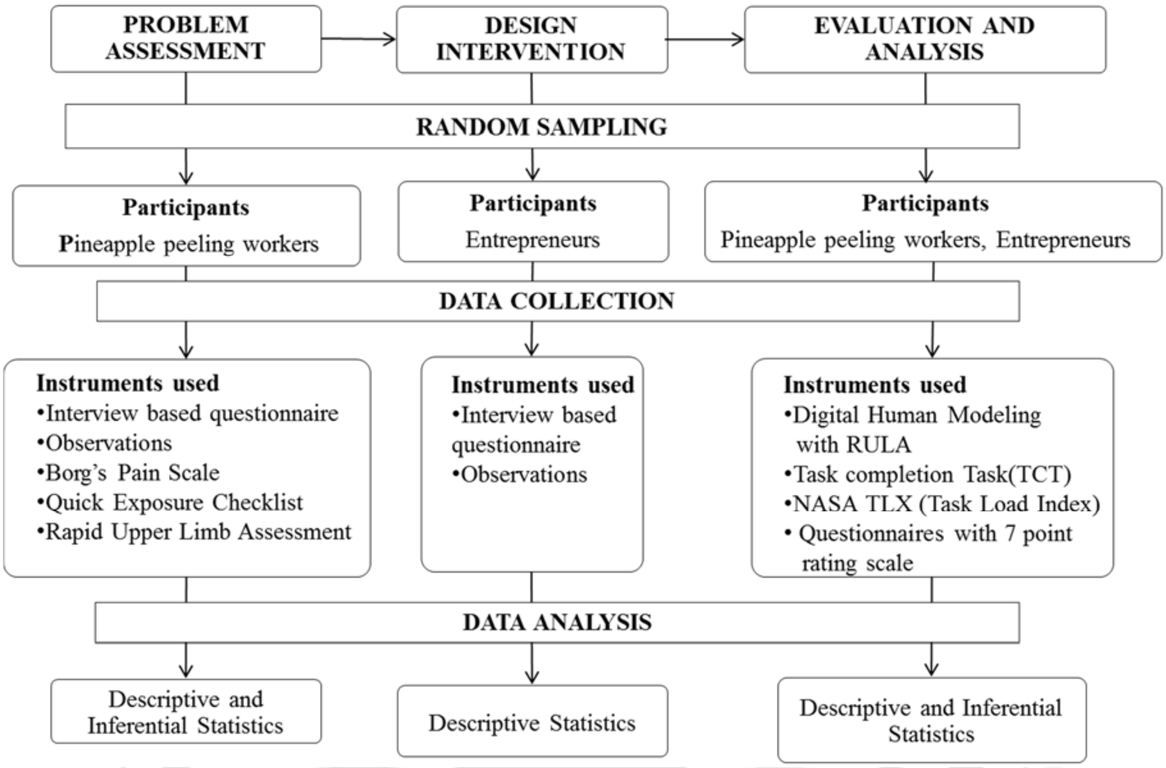


Figure 1.05 Summary of the research design

In problem assessment phase, full work process and individual task components were observed in different field locations. Relevant information was collected through interviews with workers and the management of the units, direct observations and recording of photographic evidences of working at the factory premises, contributed data for further analysis. The prevalence of pain in various body parts of the workers were determined using Body Pain Map and Borg's pain scale and the level of risk was determined using the Quick exposure checklist (QEC) as well as RULA (Rapid Upper Limb Assessment). The units were selected using random sampling and the sample consisted of male as well as the female worker participants. In design intervention phase, data regarding design specifications were collected from key stake holders like workers, fabricators, entrepreneurs, servicing person, etc. Purposive random sampling was done to collect data from the entrepreneurs regarding their requirements and priorities. In the evaluation, the outcome of the design process was evaluated by the key stakeholder i.e. workers and entrepreneurs against the same requirements which have been identified earlier as the basis of the design specifications. All the data were analysed statistically using IBM SPSS statistics 20.

1.11 Thesis contribution

In the present scenario, pineapple peeling workers face different health related problems in small fruit processing units especially, during the peak season, due to lack of effective tool for peeling, their productivity was highly compromised. In literature, a limited work had been reported regarding in-depth study of pineapple peeling problem. Hardly any design intervention had been reported for addressing the issue. This research offers the first time reports on an in-depth study on the subject and also lays down a systematic process for design intervention which had been realised and evaluated. Some Salient contributions of this thesis work are as following:

A. Ergonomic investigation into the manual pineapple peeling task

Though problems faced in pineapple peeling task were found quite apparent and presented a significant scope for investigation, there was hardly much of work reported in the area. A few works in literature did identify pineapple peeling as repetitive work along with tea plucking task; but other than this, there were limited studies reported in the area (Bhattacharyya & Chakrabarti, 2012). The thesis presents extensive work in this area, elaborately studying the prevalence of occupational health related problems in terms of musculoskeletal disorders and other health hazards, assessing the ergonomic risk using QEC and RULA methods, identifying various risk factors. It also determines their association with the risk of pain occurrence in order to find out specific design development scope to address these issues along with performance enhancement.

B. Process for designing intervention addressing ergonomic problems and other contextual issues

While reviewing literature regarding studies and interventions in other similar fields, it was found that application of technologies in industries in developing countries are different from that in developed countries. Literature also presented a method for designing such technological applications, specifically for designing food processing equipment for developing countries. But, this method of designing food processing equipment for developing countries was still very generic and hence based on this method; an elaborate process was evolved for developing pineapple peeling solution. This process can well be used for designing other fruit processing equipment.

C. Tool for predicting most suitable solution category for a given context

During the study of presently available tools and equipment for pineapple peeling task, it was found that they could be broadly put into 4 categories i.e. hand tool like solutions, human powered solution, semi- automated solution and fully automated solution. It is difficult to predict, which type of solution would be most suitable for the larger section of population. Hence a tool based on Quality Function Deployment (QFD) approach was developed where on the basis of weight age assigned to various key requirements by the users, the most suitable category of solution for the given user context was generated.

D. Effective design intervention for pineapple peeling

The outcome, in form of a novel intervention (an effective pineapple peeling equipment), is also one of the contributions of this research. This machine is capable of peeling different shapes and size of pineapples fast and effectively with lesser human effort. The trials confirm its suitability to be adopted by local workers with present level of skills and to be effectively implemented by entrepreneurs in the present industrial scenario.

1.12 Thesis Structure

As per the content of the work and chronological order of the various activities during the research, the thesis is divided into six chapters which are as following:

Chapter 1. Introduction: Need and approach for ergonomic design intervention

Chapter 2. Literature Review

Chapter 3. Ergonomic study: Risk assessment determining the scope of development

Chapter 4. Ergonomic Design intervention towards developing a suitable peeling solution

Chapter 5. Evaluation and results

Chapter 6. Discussion and Conclusion

Chapter 1 briefly highlights the background, motivation and rationale of research. The chapter further lays down the research methodology and research design along with mentioning the fundamental definitions. It then talks about the salient contributions of the thesis work and ends with summary of thesis chapters.

Chapter 2 highlights the literature findings of the earlier carried out work in similar intention. Various research gaps thus had been identified during the survey which posed specific research questions leading to the proposed hypothesis for thesis work.

Chapter 3 describes the detailed observation of the various issues associated with pineapple processing from ergonomic perspective. Peeling task was identified as the most repetitive work in the pineapple processing, indicating high risks. The prevalence of pain in different body parts was determined using Borg's pain rating scale. The level of involved risk was assessed using the QEC and RULA. Binomial logistic regression was used to determine if the association between different risk factors and the Pain prevalence were significant.

Chapter 4 lays down a systematic process for design intervention and reports in details various aspects of designing process and development of proof of concept. This includes defining the system, identifying the stakeholders, their key requirements, deciding upon the most appropriate type of solution for the given context, framing design specification, development of 3-D models, determining strength of critical parts of the machines using machine design approach and finally fabricating the proof of concept.

Chapter 5 states about the evaluation of the new design of peeling aid by the stakeholders on the same key requirements as identified earlier. Objective as well as subjective assessments were carried out for establishing efficacy of solution and the design approach.

Chapter 6 puts forward the discussion on the salient findings, outlining the limitations and future scope of work.

Chapter 2

LITERATURE REVIEW

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The chapter delineates the findings of literature survey concerning the different areas related to pineapple peeling and similar processing activities and tries to establish the research gap in the area through literature which paves path to further in the direction. From the initial inputs from higher authorities of organisations like North Eastern Regional Agricultural Marketing Corporation Ltd. (NERAMAC), Indian Council for agricultural research (ICAR) and Agricultural & Processed Food Products Export Development Authority (APEDA) and interaction with some entrepreneurs, it was inferred that pineapple processing is an important employment generating industry in the region. With this lead, an effort was made to find out in literature if something had been done in the area from the work related problems perspective. It was seen that not much had been reported in literature in this regards. Thus, an effort was made to see if some work has been reported in the areas similar to pineapple peeling. Peeling task is a part of pineapple processing (Figure 2.01) which is subset of fruit processing activities and considered to be a repetitive, time consuming and difficult task. Whereas fruit processing is a section of broader food processing domain. Therefore, an effort was made to find out relevant literature from all the related domains. To start with, ergonomic studies and investigation in other areas similar to pineapple peeling and processing, reported in literature, were reviewed. Then, the interventions in the similar field along with were studied. Here an effort was also made to understand what considerations are made for developing and implementing an intervention.

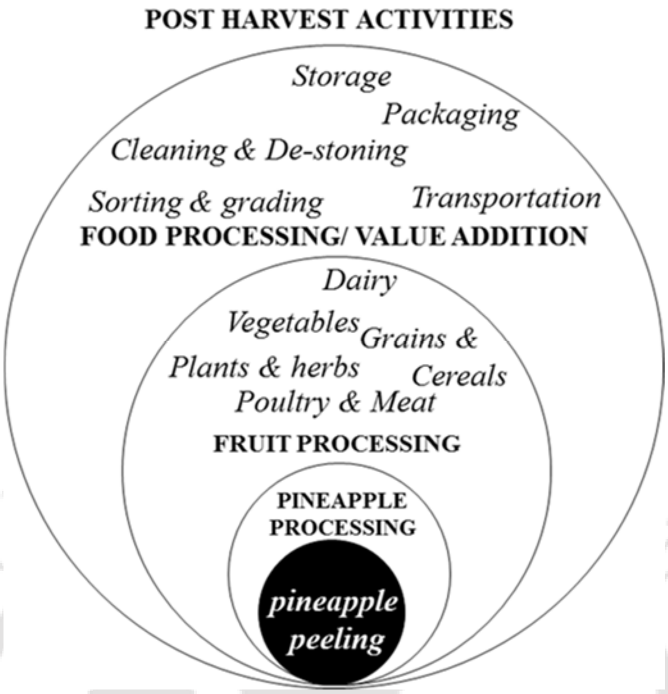


Figure 2.01 Broader domains related to pineapple peeling activity

2.2 Works related to pineapple related areas

While exploring the work done in the area of pineapple peeling, a few studies were found reported a preliminary study which identifies pineapple peeling and tea plucking as highly repetitive jobs. Though the main focus of the research was on tea plucking activity (Bhattacharyya & Chakrabarti 2012). Also need for design development of work tool specifically for small fruit processing units of north east India had been asserted in one of the reported works (Chakrabarti & Bhattacharyya, 2012). Some work had also been reported regarding effective packaging of pineapple after harvest (B. Deka, Sharma, Choudhury, & Pal, 2008). Some work had also been reported regarding development of an aid for pineapple eye removing (P. Kumar & Chakrabarti, 2011a). There have been efforts to study the physio-chemical properties of some pineapple varieties regarding the sucrose content in various parts like peel, core, flesh at different stages of maturity (Roha, 2013). Also study of physical and chemical properties of pineapple had been carried out (Montero-Calderón, Rojas-Graü, & Martín-Belloso, 2009). Other than these works, there were hardly much found in literature directly on pineapple or pineapple processing related work.

2.3 Ergonomic investigations in similar Food processing industries

Ergonomic issues among the workers is common phenomenon among the industrially advanced as well as developing countries (Bhattacharya, 2014; A. Nag et al., 2010) and it is specially critical in case of small and unorganised sectors in developing countries as referred in case of weaving industries. Fruit processing one such industry with high risk of occupational health issues related to its different tasks/ activities and thus has good scope of improvement through ergonomic investigation and intervention. An ergonomic investigation helps in finding occupational health related problems which workers might be having due to typical nature and requirement of job he is into.

Awkward posture, task repetitiveness and higher force are among the critical factors affecting the occurrence of MSDs. The ergonomic assessment of pricking task in *Aonla* (Indian gooseberries) processing industry using RULA and OWAS revealed that the task is having high levels of ergonomic risk. The traditional processing practices were found to very time taking, injury prone and less productive (Rai et al., 2012).

Safe and comfortable operation is key factors for well-being and productivity of the workers. Efforts had made to study certain fruit processing activities for identifying the drudgery involved in the works, safety and productivity of the palm nut fibre separation task by the workers. This eventually leads to design interventions towards developing work equipment (Adzimah & Seckley, 2009). A similar ergonomic study was done to evaluate the work performance and drudgery involved in pedal operated cashew nut Shelling task (Swain, Gupta, Mohanty, & Sahoo, 2009). A study has also been reported regarding the problems faced by the workers in traditional extraction process of Bambara Groundnut, an indigenous crop in Africa (Hammock, 2010). The situation of pineapple processing also faces the similar problems that need to be addressed considering the economic relevance in the north east region of India.

Fruit processing falls under the ambit of food processing which is an important sector with high growth potential especially in developing countries (Wilkinson 2004; McCullough et al. 2008; Díaz-Bonilla & Reca 2000; Sidhu 2005; Hui 2008) and this sector is also reported to have high risk of musculoskeletal disorders. Literature also showed emphasis on the need for boosting productivity and innovation in the area (Zjenane & Mattbieu Tockert, 2006). Several works also emphasize on the mechanisation in value addition process of agricultural product (Alam, 2002; Dorward, 2013; Nin-Pratt & McBride, 2014) .

Working environment and type of processing tools have significant effect on the occupational health of the workers in food processing. An ergonomic study in fish processing industry reported (P. K. Nag & Nag, 2007) prevalence of work related stresses due to hazards such as cold, wet, greasy and slippery work premises, congested work area, lack of personal protective wears, irregular work hours, the unsafe hand tools along with awkward sitting and prolonged standing postures. Whereas an investigation into problems of the meat processing and packaging industry showed working in extreme cold temperature as one of the major reason for occurrence of musculoskeletal symptoms section (Sormunen, Oksa, Pienimäki, Rissanen, & Rintamäki, 2006; Sormunen, Remes, & Hassi, 2009)(Marras & Karwowski, 2006). Study of traditional method of *Gari* (cassava) processing mentions smoke generation during the process adversely affect the work (Ajayi & Olukunle, 2008). Triangle of ergonomic risks might be looked into the working situations; force application, frequency of operation and posture adoption to do the task are the main contribution to the ergonomic risk triangle. If the efforts are made to address anyone or combination of these factors, the risk diminishes and overall performance improves. Hence, related factors need to be critically assessed. Physical risk factors such as high force exertions, high repetitiveness, awkward postures and prolonged vibration have consistently been linked to the development of musculoskeletal and this evident during investigation of cheese processing activities using OCRA method (Chiasson, Imbeau, Aubry, & Delisle, 2012; Murgia, Rosecrance, Gallu, & Paulsen, 2012).

Tool and accessories used for task is also an important factor leading to different work related health problems in poultry processing industry, Ergonomic investigation into new poultry cutting knives had been done against the tradition straight poultry knives and it was found that new design was helpful in reducing the injuries due to cumulative trauma disorders in poultry industries (Foglemen, Freivalds, & Goldberg, 1993). Similarly, meat cutting process using the present knife was compared against the other using more mechanised electric saw to establish the efficacy of better tools (Arvidsson et al., 2012). Introduction of an intervention for tea plucking had been observed to reduce tea plucking effort drastically (N. Bhattacharyya & Chakrabarti, 2012; VeerAiyan, Thangavelu, Alakiyamanavalan, & Lakshmi, 2014).

The physiological and psychological workload of the workers also plays a very important role in assessing the prevalence of work related problems. So in some investigation, the ergonomic assessment taken consideration of these loads. This had been evident in the investigation into rice pounding (Borah & Kalita, 2012) and *Aonla* processing task where the perceived fatigue was seen to affect the pain occurrences. A study had also been reported on studying prospects of efficient and economic processing of fruits and spices in Rajasthan (D. Singh, Wangshu, & Prahlad, 2008).

2.4 Interventions for fruit processing industry and other related areas

Ergonomic investigations often lay the base for the interventions. Reducing drudgery, improving the performance and efficiency of workers are the main objectives of interventions. Getting better quality of output along with quantity and reducing the wastage are also the motive for such efforts. Appropriate science and technology intervention especially in the field of processed fruit products with good domestic as well as global market can help in development of the socio-economic backward region (Foundation, 2009). There are different ways in which interventions can be made. It might be administrative, engineering or behavioural intervention. Administrative intervention might be in form of job design (Faucett, Meyers, Miles, Janowitz, & Fathallah, 2007) and the behavioural intervention might be in form of inculcating safety habits. But a large number of these are engineering interventions like physical manipulations to avert health risks.

Since, hardly any work is reported in literature regarding ergonomic intervention for the pineapple peeling task or even any aspect of pineapple processing, an endeavour was made to look into other similar areas to find strategy for intervention regarding pineapple processing. Several design interventions for specific fruits or vegetables had been tried to improve the occupation health and productivity and competitiveness of the small processing units (Batchelar, Willets, Mauley, & Greening, 2013; Owolarafe & Shotonde, 2004). In Malawi, a Low cost intervention for juice extraction technology for from mangos, papaya, melon, guava, etc. was developed and tested on parameter such as extraction capacity, effort requirements, efficiency and cost. The intervention, helped reducing the losses significantly and shelf life of juice was also extend due to hygienic extraction towards improving rural livelihood (Phiri & Wycliff, 2005). Similar interventional approach might be taken in the context of pineapple processing units considering the prevailing conditions.

In fruit processing, mechanised solutions is not always found to be the best intervention and whether the solution should be manual or hand powered, the approach is highly dependent on context of use. Literature reports development of manually operated fruit juice extractor which can be used for extracting juice from large variety of fruits like lemon, orange, tangelo, water melon and also pineapple, specifically for the small fruit processors and tested for its performance in terms of improvement in extraction rate (Samaila, Olotu, & Obiakor, 2008); workers' task comfort would be an added concern. There had also been several efforts made to design interventions which can be operated with motor as well as manually (Raji & Olofin, 2011). The processing units in North east uses manual systems, though some motorised installation for some specific extraction purpose had been found. But they were limited only to a few units at some of the units and peeling is carried out manually, irrespective of their capacity. Hence, proper strategy is required to be conceived to develop intervention that has larger applications.

In India, Efforts were made to study the feasibility a technological intervention for economic processing of various *Aonla* based product and some solution had also been developed in form of solutions for *Aonla* pricking (P. Singh, Singh, & Chopra, 2003). Owing to different physical properties and shapes it difficult to remove the outer cover of many fruits and there had been several design intervention in this field. Development of table mounted *Dika* nut (African fruit) cracking machine (Koya & Adeosun, 2008) , palm nut fibre separator (Adzimah & Seckley, 2009) , Bambara groundnut extractor (Hammock, 2010) are the examples of such interventions. There are different value added materials obtained from fruits like perfume and essence extracted from bergamot oranges which has been reported to had improved its extraction productivity with help of a new intervention (Giametta, 2013). Similarly, in the area of tomato pulping task in processing industry, intervention in form of modifications in present equipment had yielded positive results (Husain, Sabir, & Iqbal, 2010). The pineapple peeling task can also be improved using intervention suitable to the context.

In addition to the fruit and vegetable processing industry (B. C. Deka, Sharma, & Choudhury, 2008), there had been interventions reported in other similar fields. In fish and meat processing, preventive measures had been suggested in the form of incorporation of safety gears and improved cutting aide (Arvidsson et al., 2012; P. K. Nag & Nag, 2007; Sormunen et al., 2006;

Stellman, 1998).Considering the labour intensive works, some studies had been reported and consequently followed by development of large number of equipment like hand ridger, improved sickle, tubular and rotary maize sheller, sitting type ground nut decorticators, sorghum thresher, etc. to reduce injury, drudgery and increase productivity (Londhe, Pawar, & Bhosale, 2013; Shirahatti, Badiger, & Prakash, 2010; Simonya & Imokheme, 2008; S. P. Singh, 2006). In Rice processing, de-stoning of rice directly affects the quality of rice and hence its market value. Since manually inspection and destining a very time taking and highly laborious job, a rice de-stoning machine was locally developed using the principle of reciprocating and vibrating sieves (Simonyan, A, & J C Adama, 2008).

During initial visits to the fruit processing units in the region , it was observed that the units' pineapple processing hardly used any specific work tool for peeling rather depend on the old and locally available traditional hand tools and on enquiry, the entrepreneurs opined that they felt the new solutions like electro mechanised aid won't be much effective. Hence, there were apprehensions regarding the possibilities of solutions that match the skill requirements for operations as well as suit the financial and local reparability issues faced by the small entrepreneurs. Small entrepreneurs play a major role in pineapple processing industry of North East India. Hence, even if a small development is done to enhance their processing capability, it would had a large impact. Hence while reviewing the literature, an effort was also made to find out such determining factors for development of interventions for higher effectiveness within local capacity. Since pineapple processing units of north east India are similar to any small labour intensive industry in developing countries, special emphasis was given to ascertain the factors considered during developing interventions for them specially while selecting appropriate technology.

2.5 Design considerations for interventions in similar industries

Pineapple processing units of north east India are similar to any small labour intensive industry in developing countries so effort had been made to understand the factors considered for designing intervention for similar industries. It was apparent that the interventions made for solving issues in context of industrially advanced countries might not be equally relevant for the context of industrially developing (Gangopadhyay, 2012). In IDCs, there are many small scale industries and methods developed specifically for technology of large capital intensive industries might be transferred to smaller industries (Champoux & Brun, 2003) but even the application of ergonomic principles varies in case of industrially developed and developing countries. On one hand its effect is limited by the cultural and tradition diversity in practices and on the other, by the availability of infrastructure to support ergonomics applications and interventions (Neill, 2000). In other words, the reasons why intervention in form of new technology is not adopted are imperfect knowledge of technology, the skill requirements, improper provisions for workers' occupational health and safety, time and money required for training and mastering the tacit knowledge (Lall, 2010; McCullough, Pingali, & Stamoulis, 2008b).

There are several other challenges and which had to be considered while designing as well as an intervention especially its implementation in developing country. Cost is a critical factors to be considered influencing the adoption of intervention with new technology whether it is cost of equipment, installation cost or processing cost (Sinha, 2005). Provision for supporting technologies and troubleshooting in case of new technology is another major reason (Onwualu et al., 2009). Repair and maintenance is also a factor reported in literature that had to be considered while the designing any intervention (Bationo, Marouze, Boujut, A, & Giroux, 2009; Raji & Olofin, 2011).

Social factors are also found very important that is required to be considered while choosing the technology for interventions. According to FAO published document, the purpose for choosing a processing technology for developing countries ought to be to combine labour, material resources and capital so that not only the type and quantity of output produced are taken into account, but also the distribution of their benefits and the prospects of overall growth (Diouf, 1997). Some other studies also suggest that technological changes should be explored within the social fabric in which the innovations are actually developed and used (Daniele Archibugi, 1997). The other constraints in addition to cost that requires to be considered might be inadequate and inappropriate infrastructure i.e. transportation, power, storage, etc., low technology, cost for processing, packaging, long and fragmented supply chain, uncertain market and risk aversion (Sinha, 2005). Hence, development strategy for pineapple processing units of North east was required is context specific.

While conceptualising an intervention for a specific fruit processing, there are many inputs that must be taken into account. In addition to consideration of workers, entrepreneur, prevailing conditions, the properties of concerned fruit and nature of desired output also hold great importance. Several studies had been reported regarding study of fruit before designing and developing an appropriate intervention. physical Study of *dika* nut, date fruit (Jahromi et al., 2008), apricot (Naderiboldaji, Jannatizadeh, Tabatabaeefar, & Fatahi, 2008), *Jamun* (Shahnawaz & Sheikh, 2011) and *okro* fruit (Owolarafe & Shotonde, 2004) had also been reported in literature in this regards. The review of literature mentioned above led the thesis find the below mentioned research gap that is required to be addressed in a context specific way.

2.6 Research Gap

The literature review highlights the knowledge gap as far as peeling task is concerned. Figure 2.02 illustrates the literature reported regarding ergonomic investigation carried out in industries and various interventions that had been developed for their corresponding contextual requirements.

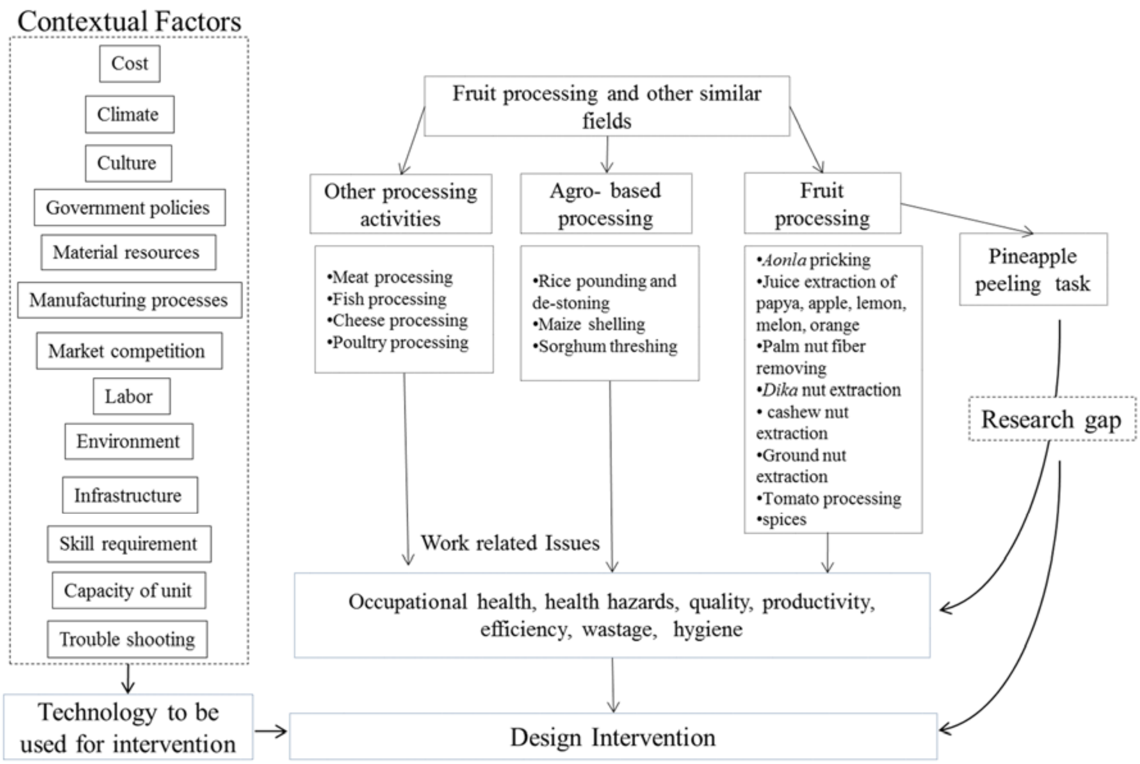


Figure 2.02 Summary of the literature review

On one hand, issues and requirements as well as interventions for processing tasks of different fruits and similar nature produces in processing industry had been reported and on the others, various factors and aspects considered for an intervention mainly from technological point of view had been presented as attempted by different interest groups. It was observed that not much of work is reported specifically related to pineapple peeling or pineapple related sectors. This gap in literature between research work done in other similar fields and unaddressed need with respect to pineapple processing scenario in North East, had been identified which required to be bridged. The prevailing pineapple processing scenario in North east requires a focussed work into the sector to improve the productivity without increase in wastage. Hence, thorough an in-depth ergonomic study of the working conditions, this gap was tried to be addressed in this thesis work. This was followed by an effort to see if the present conditions improve through design intervention in form of work tool/ equipment. Designing an appropriate intervention takes into account many contextual factors other than just the ergonomic issues of working. We also need to develop and evaluate the intervention with respect to all key contextual factors to ensure its appropriateness to the context. Hence, the research work here in thus focuses on two aspects:

1. Ergonomic study of pineapple processing with major bottle neck issues of peeling task; and occupational wellbeing and work efficiency
2. Design intervention to address the occupational, wellbeing and efficiency related issues holistically by exploring possibilities of work equipment/ tool that can be developed to meet the specific context of North East.

These two aspects are also reflected in the research questions on which the hypothesis is based.

2.7 Conclusion

During the review of literature, it was found that research work in terms of ergonomic studies and technological interventions had been reported in the similar areas like in some other food processing industries as well as other agricultural and agro-based industries. An intensive work was reported in the area related to tea leaf plucking and even some interventions had also been undertaken towards appropriate design and work method development and efficiency in terms of the specific requirements were also evaluated. But as far as pineapple processing related activities and specifically peeling is concerned there is not much of reported work being found in literature either be it in form of in depth studies or work methods as some design intervention. Though some studies based on North eastern states identified the tea plucking and pineapple peeling as highly repetitive and risk involving jobs emphasizing further work requirement in the area. Review also highlights various factors to be considered during design intervention in order to reduce the challenges faced in implementing it emphasizing on need for development strategy to improve the employability of local population as well as productivity of units rather than imposing new technology solutions. The thesis identifies this research gap and tries to fill it through specific study of pineapple peeling task in the North East context. It first tries to assess the condition of the pineapple processing unit with reference to manual pineapple peeling task followed by improvement of the prevailing conditions through designing suitable work tool/ equipment.

Chapter 3

ERGONOMIC STUDY: RISK ASSESSMENT DETERMINING THE SCOPE OF DEVELOPMENT

Chapter 3

ERGONOMIC STUDY: RISK ASSESSMENT DETERMINING THE SCOPE OF DEVELOPMENT

3.1 Introduction

Literature survey clarifies the knowledge gap in the area of pineapple processing with specific reference o peeling and laid down two important research objectives i.e. requirement of ergonomic study of pineapple peeling task and design intervention to address the related issues holistically towards developing work tool/ equipment. Out of the two, at first, the whole pineapple processing operation as the general working was studied to establish the ergonomic issues prevalent among the worker related to pineapple peeling task in small fruit processing units of north east India. An empirical study was conducted to establish the prevalence of MSDs in different body parts of concerned workers engaged in pineapple peeling using traditional methods and assessed the level of involved ergonomic risks in the task and also identified the potential factors having significantly higher risks of pain occurrence, thus, adversely affecting the work performance. This chapter presents the personal, physical and psychosocial characteristics of participants involved in pineapple peeling; body pain map followed by 0-10 Borg's pain scale rating to establish the pain prevalence associated with the task. Ergonomic methods and tools like Quick Exposure Checklist (QEC) and Rapid Upper Limb Assessment (RULA) were used for assessing ergonomic risk. This was followed by determining association between key risk factors and chances of pain occurrence in different body parts. The study was quantitative in nature mainly using descriptive and inferential statistics to draw conclusions for establishing the prevalence of ergonomics issues on the basis of the findings.

3.2 Survey population

The study was conducted across units in the major pineapple growing regions of north eastern states of India. During the study, 17 units across 4 states i.e. Assam, Meghalaya, Nagaland and Tripura were visited and the workers and entrepreneurs were interacted with. These workers are engaged in a wide range of activities that starts from unloading the pineapples from the vehicle, sorting of pineapples, peeling, slicing, pulping, juice extracting, packaging, storing, etc. Out of these tasks, the study focussed on the issues related to peeling of fruit which was considered to be the physically tough and most time consuming of all tasks. A cross sectional study was conducted using interviews and direct observations of the peeling process. The study was conducted on 151 participants included 63 men and 88 women worker participants and all the participant workers reported to be of right dexterity. All subjects having any pain history due to diseases, accidents or any kind of pain injuries were excluded so that common general information is obtained. The observation was made on combined work force irrespective of the gender as both male and female were seen to be engaged in peeling process. With this, participants were selected for specific study, as per suitability for the study followed by response analysis.

3.3 Job Description

The routine job of the workers at these units consists of multiple tasks including material downloading, primary and secondary processing and packaging as described in Figure 3.01. Though the workers were found to be multi-skilled and can perform all task as required; there were a few workers, fully dedicated for peeling purpose for the whole time and there were some which are partially engaged in peeling mostly during initial work hours. Worker engaged in other tasks are also involved in peeling task especially during the peak season, when a large amount of raw material was required to be peeled.

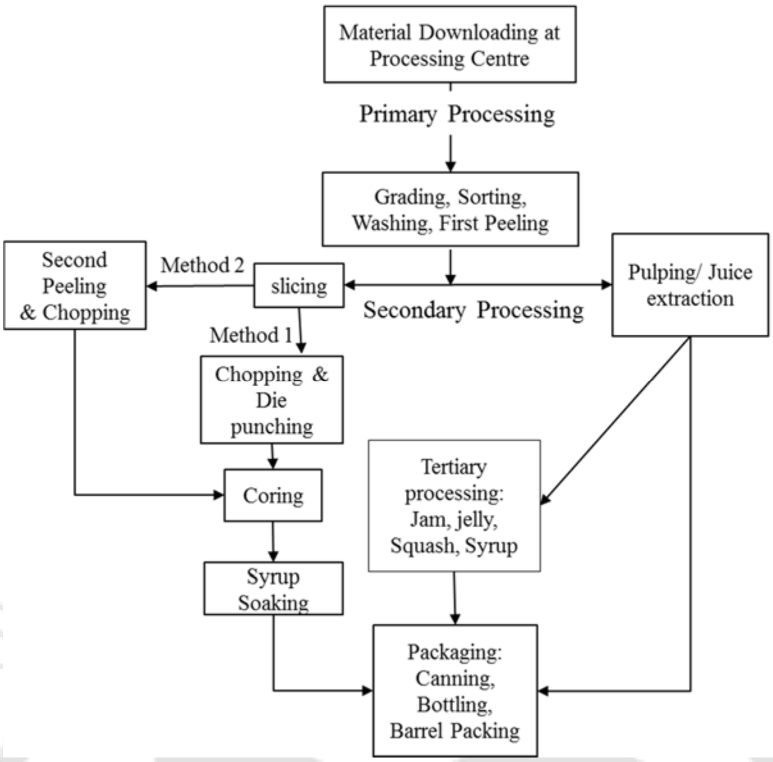


Figure 3.01 Flowchart of the work process at small processing units

There are two different types of peeling depending upon the type of item to be prepared. When only juice related items like jelly, juice and was to be made, rough peeling was enough as the fruit was then pulped and then pressed and filtered to get clear juice (Figure 3.02).

Figure 3.02 Preparation of juice and related materials: a- Rough peeling, b- Chopping and c- Juice extraction

On the other hand, if pineapple slices are to be canned. Then, after first peeling, the pineapples go for second peeling where all the traces of peels and eye on the surface are removed completely (Figure 3.03).

Figure 3.03 Pineapples after first peeling and second peeling

The leftover material with some peels and eye trace, after the second peel, can be used for juice extraction.

There are mainly four techniques observed to be used for peeling the fruits and these are as following:

- Technique 1- Peeling the pineapple using knife supporting it on a rest (Figure 3.04 a)
- Technique 2- Peeling using *Baithi* (Figure 3.04 b)
- Technique 3- Peeling using knife by holding pineapple in one hand (Figure 3.04 c)
- Other Techniques- slicing followed by punch peeling (Figure 3.04 d)

These four peeling techniques had been demonstrated below.

Figure 3.04 Techniques, tools used for pineapple peeling task; a- Peeling the pineapple supporting it on a base, b - Peeling using *Baithi*, c- Peeling using knife by holding pineapple in one hand, d- others like using punch cutter

The tools used for the purpose of peeling are variations of a normal household knife, traditional cutting device called *Baithi* or a punch cutter used in some units (Figure 3.05).

Figure 3.05 Different peeling tools: a- variety of knives, b- *Baithi*, c- punch cutter

The description of all the four techniques along with their advantages and disadvantages had been summarised in Table 3.01.

Table 3.01 Detailed analysis of the Peeling Techniques

Technique description	Physical analysis	Advantage	Disadvantage
Technique1 Peeling the pineapple supporting it on a base (Figure 3.04a) • Worker sits on a stool or bench, 250 mm to 400 mm in height. • Holding the knife in one hand, bends forward or sidewise, picks the fruit from the other hand. • Place the fruit horizontally on the platform or plank in front • Holding and rotating with one hand, cuts of both the end of the fruit • Places it vertically on the plank with one of the flat cut end • The fruit was then held tight with one hand and using other, a strip of peel, along the curved shape was removed by moving the knife from top to bottom with to and fro horizontal motion. • The process was repeated for 8 -10 times to remove the peel completely. The fruit was examined to remove any leftover peel. • The peeled fruit was placed in a separate container.	In this technique, the trunk was generally bent forward at a small angle accompanied by forward/ side bending of neck. To remove the peel along the curved fruit surface, the wrist angle gradually changes from pronation to neutral to supination. Simultaneous reciprocating horizontal and vertical force was applied through knife. The trunk was twisted or stretched to place the peeled fruit in the container depending on where the container was placed.	Peeling the fruit along the curve ensures lesser loss during peeling.	• The process was slow as each fruit had to be peeled in around 7-10 repetitions. • The cutting force was generally applied by one hand there by making it more prone to risk and injuries. • The slipperiness of the fruit makes it difficult to hold the fruit.

Technique2 Peeling using *Baithi* (Figure 3.04b) • The worker sits on ground over a very low height (50- 60 mm) seat. • The worker presses the device under one foot and picks a fruit by bending forward or sidewise. • The worker holds fruit in both the hands and removes the peel in strips using *baithi* by rubbing it against its sharp edge of the device with slight reciprocating motion. • Some vertical body force was also applied bending forward while peeling. • The above step was repeated for 7 – 10 times peel the fruit completely. • The peeled fruit was put in the container	In this technique, the worker adopts a posture similar to squatting posture. Both the foot though properly resting are at slightly different levels as one foot was resting over the base of *baithi.* The trunk was bent forward for almost all the time and frequent forward and backward movement of trunk was also observed which was to enhance the cutting force. The extension/ abduct -ion of arm was also observed while placing the peeled fruit in the container.	In this technique, the peeling was done by holding the fruit with both the hand, hence, the force required to cut the fruit was distributed on both the hands.	• The process was slow • Due to significant bending and stretching of the trunk, there was a risk of back pain.
Technique 3 Peeling using knife by holding pineapple in one hand (Figure 3.04c) • Worker sits on a stool or bench, 250- 400 mm high. • Holding the knife in one hand, bends forward or sidewise, picks the fruit with other hand. • Holding the fruit in one hand, moves the knife through the fruit peel towards the own body, thereby removing a strip of peel. • After removing one peel strip, the fruit was given a slight toss, bringing the unpeeled part towards the knife edge. • The process was repeated for 6- 8 times to peel the complete fruit. After peeling, the fruit was dropped in a container	Since one hand was always at some abduction angle continuously engaged in holding the fruit without any support The other hand was used repetitively for peeling off the fruit cover; the risks of injuries are high for both the hands. During peeling, the trunk was bent forward for most of the time. The arms are working across the midline of the body.	The peeling was fast as compared to the other methods.	The wastage was more as the fruit was not peeled along its curve. Since the fruit was held in hand without any support, the risks of injuries are more as well as the chance of slipping was more which might lead to accidents.

Other techniques Slicing followed by punch peeling (Figure 3.04 d) • The pineapple was cut into round slices either by knife or by the available slicing machine • The slices are placed on table (about 1 meter high) and each slice taken one by one. • On each slice the circular die was placed and a vertical force was applied on the die there by separating the outer cover in form of a ring. • The operation was generally done in standing position which helps in applying a firm cutting force on the fruit slices placed over the table.	The operation was generally done in standing posture and the vertical force was applied on the die in an extended arm position. The neck was bent to ensure the die was placed properly. The trunk was repetitively bent forward to enhance the cutting force.	The slice was peeled in one go. The peeling was uniform.	Wastage was more since the diameter of the die was fixed. The process had to be applied for 6- 7 times to peel one sliced pineapple.

3.4 Data Collection

Data was collected through direct observation, interviews with the workers based on questionnaire and assessment checklist. The interviews were used to get the personal information like age, sex, work experience and the occupational information like the daily work routine, the tasks handled, the technique used, the number of working hours, the general working condition, job satisfaction, perceived work fatigue, etc.

In addition, the body discomfort chart and analog pain rating scale (Borg's scale) was used to determine the occurrence and intensity of pain in the various body parts of the workers during last three months (Meksawi, Tangtrakulwanich, & Chongsuvivatwong, 2012). Since in all the peeling techniques, the upper limbs mainly involved in the task, to ascertain the level of ergonomic risk involved and urgency of an intervention, QEC and RULA was used (McAtamney & Corlett, 1993). The ergonomic risk factors were ascertained through observations and contextual inquiry. Videos and photographs of workers while performing task, were also taken along with the direct observation to support the observations and further analysis.

3.5 Ergonomic tools and methods used

The tools and methods used for studying from ergonomic perspective are as discussed below.

3.5.1 Pain Map and analog Borg's pain scale rating Method

In this method, the workers were shown the map illustrating important body parts and asked if they had pain in any of the body parts (Figure 3.06).

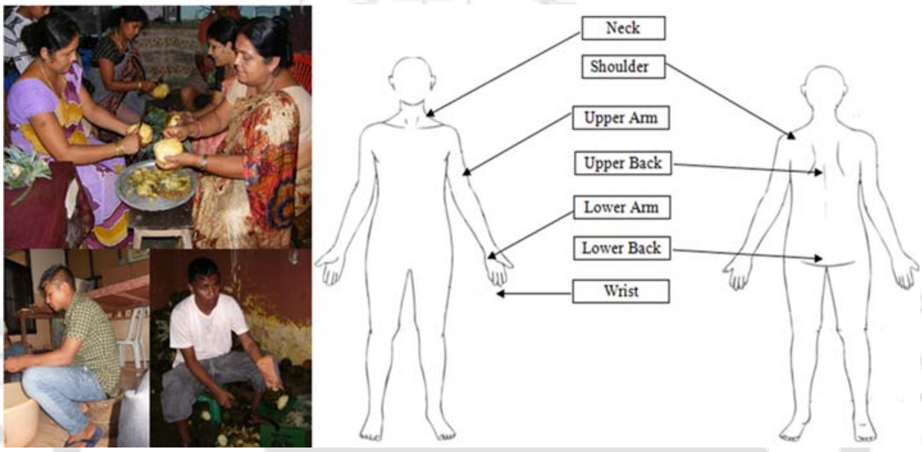


Figure 3.06 Body pain Map used to determine pain in different body parts of the manual pineapple peeling

When they indicated pain in any of the body parts, they were asked to rate their pain intensity on 0-10 rating scale. Nature of pain with different scores was shown in Table 3.02.

Table3.02 Scale based on Borg's pain ratings scale

Rating scale	Pain intensity
0	No Pain
1	Negligible pain
2	Very slight pain
3	Moderate pain
4	Somewhat severe pain
5	severe pain
6	-
7	Very severe pain
8	-
9	-
10	Extremely severe pain

This rating of pain greater than or equal to 3 had been considered as "pain". The assessment of pain prevalence was followed by determining the postural risk involved in peeling task. Whereas, extremely severe pain rating of 10 relates a state a state when compulsory rest and medical treatment was required.

3.5.2 Quick Exposure Checklist (QEC) method

To establish the level of postural risk involved in peeling, QEC method was used at first. Depending upon the posture adopted by different body parts, magnitude and frequency force application and duration of work, etc. The assessment was carried out on 35 workers involved in pineapple peeling. As per worker responses regarding posture, frequency of movement, force requirements for the job and other information, QEC scores were obtained for various body part (*Appendix 1*). There is range of scores for different body parts that suggests if the priority level is low, moderate, high or very high (Table 3.03).

Table 3.03 Priority level for different QEC scores

Priority level for QEC scores				
Body area	**Low**	**Moderate**	**High**	**Very High**
Back (static))	8-14	16-22	24-28	30-40
Shoulder/arm	10–20	22-30	32-40	42-56
Wrist/hand	10-20	22-30	32-40	42-56
Neck	4-6	8-10	12-14	16-18

The percentage of total score obtained (adding up all the individual body part scores) against the maximum possible total score gives the action level required and decides if any investigation and intervention is required (Table 3.04). Maximum possible score for individual body parts were 42 for back, 56 for shoulder, 46 for hand and 18 for neck.

Table 3.04 Level of action based on percentage QEC score

QEC % score	**Action level**	**Recommendation**
< 40%	Acceptable risk	Acceptable posture
40-49%	Moderate risk	Further investigation needed; changes might be required
50-69%	High risk	Investigation and changes needed soon
>70%	Very high risk	Investigation and changes needed immediately

Since the task mainly involved use of upper limb, Rapid Upper Limb Assessment (RULA) was also used to evaluate the level of risk involved in peeling.

3.5.3 Rapid Upper Limb assessment (RULA)

RULA is an effective tool used to assess the postures and muscle use involving the upper limbs i.e. arms, wrists, Neck, trunk, etc. and assess the risk involved in peeling operation by observing postures and activities during peeling process (N=151). A score is assigned to each body part as per the posture of the workers during the task for several work cycles (*Appendix 2*). The score for individual parts are clubbed in two groups and muscle score and load score added to both the groups as applicable in case of the given task. The two scores eventually lead to final grand score. Different values of grand scores had different implications (Table 3.05).

Table 3.05 RULA Scores and respective action level

Action level	RULA score	Risk Level
1	1-2	Acceptable
2	3-4	Investigation further
3	5-6	Investigation further and changes soon
4	7	Investigation and changes immediately

3.5.4 Statistical Analysis

The statistical analysis was performed using IBM SPSS Statistics Version 20.0.Descriptive statistical analysis was used to represent the personal data, physical and psychosocial characteristics, distribution of MSDs and RULA scores for individual body parts as well as overall RULA score. Multivariate analysis was done using Binary Logistic regression with Wald test to predict the influence of various ergonomic factors on occurrence of pain in different body parts. Hosmer-Lemeshow goodness of fit test was used for testing predictive capacity of the model. The outcomes with p value < 0.05 were considered statistically significant.

3.6 Results

The data gathered through observations, interactions and by using different ergonomic tools were then analysed and the final results based on the data were tabulated to draw conclusions.

3.6.1 Description of participants

For the study, 151 participants engaged in pineapple peeling activity at the small fruit processing units from north eastern states of India were purposefully and randomly selected. More than half (58.3%) of them were female workers. The mean age of the workers was found to be 30.95 years and it ranged between 18 years to 55 years. More than two- third (71.5%) of the workers did not have formal secondary education but all of them had primary literacy. The mean work experience was 3.49 years and ranged from 1-15 years. More than one third of the participants adopted "technique 1" (46.4%) and "technique 3" (38.4%) whereas 3.3% of the participants used other techniques (Table 3.06).

Table 3.06 Personal Characteristics of Participants (N = 151)

Characteristics	n (%) Respondents
Age	
Mean ± SD (Range)	30.95± 9.032 (18- 55) yrs.
18- 30 yrs.	89 (58.94)
31- 42 yrs.	43 (28.41)
43- 55 yrs.	19 (12.58)
Experience	
Mean ± SD (Range)	3.49±3.02 (1-15) yrs.
Gender	
Female	88 (58.3)
Male	63 (41.7)
Marital Status	
Married	122 (80.8)
Non –married	29 (19.2)
Education	
Primary level	108 (71.5)
Secondary level	43 (28.5)
Peeling Technique Used	
Technique 1	70 (46.4)
Technique 2	18 (11.9)
Technique 3	58 (38.4)
others	5 (3.3)

3.6.2 Physical and psychosocial characteristics

Around half (46.4%) of workers were observed to be engaged in the peeling activity for more than 4 hours. Long continuous and repetitive work without proper breaks increases MSDs chances (de Looze et al., 2006) and small but adequate rest break was found to effective in reducing the exertion (Faucett et al., 2007) . In the study, over half (69.5%) of the participants hardly had adequate rest breaks other than lunch break and even that was reduced or delayed when the quantity of raw material to be processed was more. The fruit is acidic in nature, handling the fruit bare handed for long, might lead to itching corrosion and even bleeding. Hence, it was hazardous to peel the fruit without gloves (Figure 3.07).

Figure 3.07 Skin corrosion due to peeling without gloves

Due to highly repetitive nature of force requirement for the peeling activity and discomfort experienced in handling the fruit with wet slippery gloves, a large number of participants reported of moderate (41.7%) to high (27.2%) level of perceived fatigue (Table 3.07).

Table 3.07 Physical and Physiological characteristics (N= 151)

Characteristics	n (%) Respondents
Perceived work stress	
Low	47(31.1)
Moderate	63(41.7)
High	41(27.2)
Frequency of rest pauses	
Inadequate	46(30.5)
Adequate	105(69.5)
Job satisfaction	
Low	72(47.7)
High	79(52.3)
Peeling work in hours	
Less than 2 Hrs.	70(46.4)
2-4 Hrs.	40(26.5)
More than 4 Hrs.	41(27.2)

3.6.3 MSDs reported in various body parts

Table 3.08 shows prevalence of MSDs in various body parts of the workers. The ratings of participants were analysed and it was found that 77.48% had pain in at least one of the body parts. A higher percentage of participants reported pain in shoulder (49%), upper arm (43%) and lower back (52.32%). While some percentage of participants also reported of pain in neck (13.2%), lower arm (15.9%), wrist (12.6%) and palm (6%). It was observed that most of the workers did not report of very high pain in the body parts but, moderate pain prevalence was found among workers.

Table 3.08 Distribution of MSDs in various body parts (N= 117) Pain Score ≥3

Body Parts	Mean(± SD)	Min	Max	Prevalence (95% CI)
Neck	3.1(.308)	3	4	13.2% (8.74 - 19.58)
Shoulder	3.76(.824)	3	6	41.06% (33.53- 49.03)
Upper Arm	3.25(.513)	3	5	37.09% (29.8- 45.03)
Lower Arm	3.08(.282)	3	4	15.89% (10.92- 22.56)
Upper Back	3.06(.239)	3	4	22.52% (16.59- 29.82)
Lower Back	3.49(.633)	3	6	45.7% (37.96- 53.65)
Wrist	3.21(.419)	3	4	12.6% (8.2- 18.81)
Palm	3.33(.500)	3	4	6% (3.17- 10.94)

3.6.4 QEC assessment results

QEC scores obtained were moderate to high for most of the individual body parts. The overall score was also found to be high for more than half of participants (Table 3.09).

Table 3.09 QEC Scores (N=35)

QEC Risk Level	Body Part n (%) Respondents				
	Neck	Hand	Shoulder	Back	Grand Score
Low (< 40%)	-	-	5 (14.3)	-	-
Moderate (40- 49%)	-	-	13 (37.1)	10 (28)	14 (40)
High (50-69%)	12 (34.3)	30 (85.7)	17 (48.6)	25 (72)	21 (60)
Very High (>70%)	23 (65.7)	5 (14.3)	-	-	-

In the QEC assessment, maximum score against which the percentages were drawn were 42 for back, 56 for shoulder, 46 for hand and 18 for neck. It was found that 60% percent of the participants had the grand score at high risk level. The neck score was found to be high to very high which was in contradiction with the prevalence of neck pain. This was the reason of using more widely acceptable upper limb assessment tool RULA was used for evaluation.

3.6.5 Assessment of ergonomic risk level using RULA

Table 3.10 shows the distribution of RULA score for different body parts of the participants. The mean score for upper arm region was found to be 2.8 as the extension was generally more than 20° and many a times it was also accompanied by abduction of the arm. The score for lower arm was normally 1 but in case of "technique 3", the mid line was often crossed during peeling activity, hence enhancing the mean score to 1.38. The mean wrist score was found to be 1.58 as the wrist was normally found to be bending from the neutral axis. The mean RULA score for neck was found to be 1.81 as the neck generally bent forward as well as sidewise during the peeling activity. The mean score for trunk was 2.39 as the trunk bends forward as well also bends sidewise during the operation. It was found that grand score for all the participants were found to be more than 2 with 15.2% of participants getting a high grand score of 6 followed by 45.7% of workers obtaining a grand score of 5, which can be interpreted as immediate risk of injury and need for prompt investigation and changes.

Table 3.10 RULA Scores (N=151)

RULA Score	**Upper Arm n (%)**	**Lower Arm n (%)**	**Wrist n (%)**	**Neck n (%)**	**Trunk n (%)**	**Leg n (%)**	**Final wrist & Arms**	**Final neck Trunk & Leg**	**Grand Score n (%)**
1	39(25.8)	93(61.6)	-	29(19.2)	-	113(74.8)	-	-	-
2	71(47.0)	58(38.4)	151(100)	122(80.8)	92(60.9)	38(25.2)	-	-	-
3	41(27.2)	-	-	-	59(39.1)	-	-	-	-
4	-	-	-	-	-	-	39(25.8)	86(57)	16(10.6)
5	-	-	-	-	-	-	71(47)	6(4)	35(23.2)
6	-	-	-	-	-	-	41(27.2)	37(24.4)	59(39.1)
7	-	-	-	-	-	-	-	22(14.6)	41(27.2)
Mean (SD)	2.1(.73)	1.38(.49)	2(.00)	1.81(.39)	2.39(.49)	1.26(.44)	5.01 (.73)	4.97(1.19)	5.83(.95)

For "technique 2" and "technique 3", trunk bending of more than 20° was also observed. Since the posture is generally repeated for more than 4 times a minute and repetitive force of more than 2 kg is required to peel the fruit, the muscle use score and force score was 1 and 2 respectively (Figure 3.6).

Figure 3.08 Force required for peeling the pineapple

3.6.6 Regression Models

Table 5 to 9 shows the results of binary logistic regression models for pain in shoulder, upper arm, upper back, lower back and wrist region of participants. The predictors which were included in the models were age, gender, experience, hours of peeling, frequency of rest breaks, technique of peeling, perceived fatigue, job satisfaction and education level of participants. The result showed that older workers were at higher risk of shoulder pain (odd ratio (OR) = 1.059; $p<0.05$) as compared to younger workers and workers with inadequate frequency of rest breaks are at higher risk of shoulder pain (odd ratio (OR) = 0.338; $p<0.05$) as compared to the male workers. The risk of pain is also higher in case of workers who perceived higher fatigue during work (odd ratio (OR) = 3.989; $p<0.05$) as compared to those who perceived moderate or low work fatigue. The occurrence of shoulder pain was not significantly associated with other independent factors (Table 3.11).

Table 3.11 Factors associated with shoulder pain among workers (n= 151)

Independent factors	**OR(95% CI)**	***p*- value**
Age	1.06 (1.00 -1.12)	0.043
Frequency of rest breaks (ref: Inadequate)	0.34 (0.12 – 0.98)	0.046
Perceived fatigue High (ref: Low)	3.99(1.17- 13.65)	0.027

Risk of upper arm pain was found to be more in case of workers with inadequate rest breaks (odd ratio (OR) = 0.056; $p<0.01$) as compared to those with adequate rest breaks (Table 3.12). Also worker engaged in peeling for more than 4 hours had greater risk of pain as compared to peeling time less than 4 hours (odd risk (OR) = 5.082; $p<0.05$).The association with other factors were found to be insignificant.

Table 3.12 Factors associated with upper arm pain among workers (n= 151)

Independent factors	**OR(95% CI)**	***p*- value**
Frequency of rest breaks (ref: Inadequate)	0.06 (0.01 -0.28)	< 0.000
Hours of peeling Greater than 4 hours (ref: Less than 2 hours)	5.08 (1.29- 20.08)	0.02

Risk of upper back pain is more in case of workers engaged in peeling for more than 4 hrs (odd ratio (OR) = 7.618; $p<0.05$) as compared to workers with peeling hours less than 2 hours. Even worker carrying out for more than 2 hours also show higher risk of upper back pain (odd ratio (OR) = 6.383; $p<0.05$). Also the risk of upper back pain is higher in case of workers who perceived higher fatigue during work (odd ratio (OR) = 6.383; $p<0.05$) as compared to those who perceived moderate or low work fatigue. The occurrence of pain was not significantly associated with other factors (Table 3.13).

Table 3.13 Factor associated with upper back pain among the workers

Independent factors	**OR(95% CI)**	***p*- value**
Perceived fatigue High (ref: Low)	6.26(1.41- 27.81)	0.027
Hours of peeling Greater than 4 hours (ref: Less than 2 hours)	7.62(1.46 – 39.84)	0.016
Between 2- 4 hours (ref: Less than 2 hours)	6.38(1.35- 30.19)	0.019

As far as lower back pain is concerned, older workers were at higher risk (odd ratio (OR) = 1.098; $p<0.05$) as compared to younger workers and female workers are at higher risk (odd ratio (OR) = 6.899; $p<0.05$) as compared to the male workers. The risk of pain is also higher in case of workers who perceived higher work fatigue (odd ratio (OR) = 12.171; $p<0.05$) as compared to those who perceived moderate or low work fatigue. The risk of pain is also higher for peeling hour more than 4 hours (odd ratio (OR) = 27.247; $p<0.01$) and even for peeling hours between 2-4 hours (odd ratio (OR) = 21.446; $p<0.05$). The risk of pain also increased in case of inadequate rest breaks (odd ratio (OR) = 0.119; $p<0.01$). The occurrence of pain was not significantly associated with experience, frequency of rest breaks, technique of peeling, and job satisfaction and education level of participants (Table 3. 14).

Table 3.14 Factors associated with lower back pain among workers (n= 151)

Independent factors	**OR(95% CI)**	***p*- value**
Age	1.1 (1.01- 1.19)	0.026
Gender	6.9 (1.80- 26.44)	0.005
Frequency of rest breaks (ref: Inadequate)	0.12 (0.025- 0.58)	0.008
Perceived fatigue High(ref: Low)	12.17 (2.18- 67.90)	0.004
Hours of peeling Greater than 4 hours (ref: Less than 2 hours) Between 2- 4 hours (ref: Less than 2 hours)	 27.25 (3.59 – 209.63) 21.45 (2.73- 168.43)	 0.001 0.004

In addition risk of wrist pain was found to be more for in case older workers (odd ratio (OR) = 1.155; $p<0.05$) compared to the younger workers and it was less in case of the more experienced workers (odd ratio (OR) = 0.283; $p<0.01$) as compared to workers with less experience of peeling (Table 3.15).

Table 3.15 Factors associated with wrist pain among workers (n= 151)

Independent factors	**OR(95% CI)**	***p*- value**
Age	1.16 (1.05- 1.26)	0.002
Years of Experience	0.28 (0.11- 0.72)	0.008

No significant relation could be established in case of pain occurrence in Neck, Lower arm and Palm with the considered predictors i.e. with age, gender, experience, hours of peeling, frequency of rest breaks, technique of peeling, perceived work fatigue, job satisfaction and education level of participants.

3.7 Discussion

During field visits, the personal, physical and psycho social characteristics of workers as well as prevailing work conditions and ergonomic risk factors at the units were studied. Field studies also showed that UEMSDs were common among the workers undertaking pineapple peeling task. The study showed that fruit processing units in the region employed larger ratio of female workers as compared to male workers and they were also found to be reporting of UEMSDs in a comparatively greater proportion.

In the study, UEMSDs were reported from almost all the major upper body parts i.e. neck, shoulder, arm, back, wrist and palm. The MSDs reported were not very severe in nature but owing to inappropriate working conditions, a significant number of workers reported of moderate to moderately high pain for different body parts. The peeling task was found to be very repetitive and forceful task along with awkward postures. This was also confirmed by the assessment of ergonomic risk using RULA method that showed more than half of the participants got the score greater than 4, indicating need for immediate investigation and action. The minimum RULA scored by any individual in the assessment was 4 which can be interpreted as need for investigation and changes soon.

Efforts were made to find if the risk of MSDs in different body parts can be significantly associated with various other ergonomic risk factors including age, gender, experience, hours of peeling, frequency of rest breaks, technique of peeling, perceived fatigue, job satisfaction and education level of participants. The risk of upper arm is seen to be highly associated with time as generally the peeling task involves highly repetitive motion of upper arm and hence, carrying this task for longer stretch of time inevitably increases the strain the upper arm as also found in some studies related to MSDs (Niu, 2010). Back pain risk was found to be significantly more in case of female workers which is in line with the argument that women are more vulnerable to pain in upper extremities (Strazdins & Bammer, 2004) but insignificant association between risk of pain occurrence in other body parts and gender of the workers suggests that it is not only gender but also the other factors like the nature of work (Coury, Porcatti, Alem, & Oishi, 2002). Hence employing male workers would hardly help in reducing MSDs significantly. Some studies suggested that age is among the possible factors affecting work related MSDs (Yu et al., 2012) and the significant association pain risk in shoulder and lower back with age indicated that age is, indeed, an important factor affecting body pains and hence the older workers are more prone to pains as compared to the younger workers. The higher pain risk was predicted in shoulder, upper back and lower back in the case of higher fatigue perceived during work which supports that the muscle fatigue experienced during work significantly affects the pain prevalence (Fedorowich, Emery, Gervasi, & Côté, 2013).

Occurrence of MSD is broadly dependent on three factors force, frequency and work posture (Roffey, Wai, Bishop, Kwon, & Dagenais, 2010; Stuart-Buttle, 1994). Since the peeling activity often involves awkward postures and also requires frequent movement and repetitive moderated force (more than 2 kg), this repetitive task for longer time increases chances of pain. This justifies the significant association of pain in different body parts like upper back, lower back and upper arm. A significant association was seen between inadequate rest breaks and risk of pain in lower back and upper arm region. The is in accordance with literature which suggest that limited work rest aggravate the MSD issues (Faucett et al., 2007).literature show that experience is an important factor influencing risk of MSDs (Ouellet & Vézina, 2014). But in case of present study, it is only seen to be significantly associated with wrist pain occurrence. Since the peeling involves force and angular movement of wrist a greater practice is supposed to give higher output without hurting their wrist. Thus experience is seen to be inversely proportional to pain occurrence. Some studies indicate psychosocial factors like job satisfaction as an important factor (Lanfranchi & Duveau, 2008) but in the present study there was no significant association seen between pain risk and the level of job satisfaction.

3.8 Conclusion

The present study confirms the prevalence of work related MSDs in case of pineapple peeling task. Predicting the association of risk of pain occurrence in different body parts with various risk factors like age, gender, experience, hours of peeling, frequency of rest breaks, technique of peeling, perceived fatigue, job satisfaction and education level of participants. It was found that pain occurrence in some of the body parts were found to be significantly associated to factors like gender, age, experience but a large number of different body pains were associated with nature of the work which is attributed by repetitive and monotonous work, awkward posture, long working hours, work overload during peak season which leads to MSDs in various body part (Dorrian, Baulk, & Dawson, 2011; Earley, Lee, & Hanson, 1990; Fedorowich et al., 2013). The musculoskeletal pain and discomfort due to awkward work postures, forces and work over- load is widely accepted as an indicator of poor job design and improper workstation design (Beshah, Kitaw, & Gelan, 2013; Stuart-Buttle, 1994). Even job specific changes can also help reduce repetitive movement and force requirement for the work, significantly.

Hence based on all the findings, following suggestions were put forward:

- Pineapple peeling task might be modified in order to facilitate and allow the change of posture during the task.
- Adequate rest pauses might be added in between the long peeling hours.
- Proper seating arrangement with back rest is might be provided for back support. Specific work tools / equipment might be developed for the task as the existing traditionally method of using common household device like knives, *Baithi*, etc. are inappropriately used for the mass peeling task.

Thus it asks for some kind of work tool or work station intervention that might help in addressing the prevailing issues related to peeling.

Chapter 4

ERGONOMIC DESIGN INTERVENTION TOWARDS DEVELOPING A SUITABLE PEELING SOLUTION

Chapter 4

ERGONOMIC DESIGN INTERVENTION TOWARDS DEVELOPING A SUITABLE PEELING SOLUTION

4.1 Introduction

In the previous chapter, ergonomic assessment of peeling task was described. out and intensity of different WMSDs induced by risk factors like repetitive force/ load, repetitive posture, long peeling hours, insufficient recovery time and perceived work fatigue were identified. Consequently, several probable measures were also suggested which might help to reduce the effect of these risk factors as the prevailing conditions suggest need for some work process as well as work tool design intervention. The present chapter looks into improving the working condition through an intervention in form of peeling equipment. In the process, different considerations had to be taken into account as just procuring and providing some new equipment or machineries might not ensure its suitable adoption and utilization in the local context. There are possibilities of adaption of technologies for work tool and equipment which are inappropriate to the users' context. Hence an effort was made to ascertain the root causes of inappropriateness leading to Inhibition to new technology. The findings were used as initial inputs to design an appropriate technology intervention that optimally suits the users' comfort and context, using a systematic holistic design approach.

4.2 Justification for intervention through equipment design

The work related discomfort issues adversely affect efficiency of the manual pineapple peeling worker and is a major bottleneck in the productivity of the small pineapple processing units. There are number of ways this situation can be intervened and improved. Some of the domains in which intervention is possible:

- Job redesign (new chronology or method of actions, job rotation, rest pauses, etc.)
- Policy framing (regarding salary structure, infrastructural issues, technology import, etc.)
- Existing tool and accessories modification (redesigning handle of tool, better handling gloves, other related gears, etc.)
- Equipment design (relook into the situation and context specific development, procuring design solutions and carrying out adaptive modification to suit the context of use)
- Work station design/modification (to suit the job considering workers various compatibility issues)

Out of these, some of domains, like policy changing, where common workers' decisions are mainly taken at government or management level and there is a little say on the matter, with action too time taking to see a difference. Thus, in the thesis work, basic working principles, from mechanical engineering knowledge domain, were used towards deciding the approach for design and development. Small modifications in existing tools appeared not to have made drastic impact. Thus it was decided to intervene through proper machine or work equipment design for pineapple peeling which would, in some ways, also include job design as well as workstation modifications. This chapter describes the context and development strategy followed for a suitable design solution. The focus was on promoting local employability and production towards improving local economy and providing more sustainable solutions.

4.3 Root causes of not using new equipment

During the field visits to fruit processing units of North East, it was apparent that the peeling methods used in these small processing units was laborious, time taking job and appeared to be a throttle to units' productivity. But, in spite of the issues, they adhered to the conventional practices in the region, by and large. There had not been much of attempt for changing present tools and techniques that can ease or accelerate the peeling process. So the present effort was set to find out as to why they were adhering to the techniques in spite of need for improving work efficiency viewing increased productivity. It was found during discussion with the local entrepreneurs that there was mismatch between the available technologies and contextual requirements, having economic socio- technical skill limitations and perception of the industry towards new change which inhibits adoption of the new practices. Some of the findings of the study are as following:

a. General characteristics of the processing unit

Most of the processing units can be characterized as home- based micro enterprises which are very small unorganized units operating from a single or double room apartment. Many such units not only had space constraints but also lack various basic infrastructural facilities like proper ventilation, light, power supply, garbage disposal mechanism, etc. Economic support limitations characterizing these uncertainties of sustaining units discourage the entrepreneurs from investing their limited resources in new equipment and machineries. Hence, they opt for the most obvious tools for the purpose which is locally available and familiar to use in spite of being time taking and more exhaustive compared to any new technological alternatives available.

b. Geographical constraints

Since these small processing units are spread all over the region and many of them are in remote and hilly areas, access is difficult and time taking. Usually processing units are established within the proximity of the raw material supply. Even reach ability by the roads is also difficult in case of some units due the difficult geographic terrain. Hence, installation as well as getting the machinery repaired at the wake of break down might become a challenging task. Dependence on such machinery would bring the production to a complete halt in case of break down. Anticipation and fear of similar conditions discourage these units from adopting such new technological alternatives. Rather they tend to rely on locally available solutions. This led the present development attempts to go along with such context.

c. Limited Capital Resources

Capital resources encompasses financial, infrastructural (like land, building, etc.) as well as the units' machinery resources. One of the advantages of small fruit processing units is that it could be started even with a very small capital investment. But it is also the biggest disadvantage for them as the limited financial resources restricts their investments in to new machineries. A limited space prevents them from installing new equipment that occupies more floor area. Hence the units resort to cheap, small space occupying alternatives despite poor performance and efficiency.

d. Seasonal nature of production

Most of the units process a large variety of seasonal fruits and pineapple is one of them. Even if they had problems in handling pineapple processing during the peak season, they are reluctant to make big investment in such machinery and equipment that would lay idle after the pineapple season unnecessarily occupying, constricting their work area and blocking the financial resources.

e. Existing Power scenario

The erratic power supply in the region is one of the major problems for industrial growth in the region. The units fully dependent on electric equipment had to face frequent interruption in work due to power cuts. Since new technological equipment is synonymous to power driven solutions, there is a doubt whether it would solve the problems or create new woes.

f. Misconception and ignorance

The general perception regarding the "new technological alternatives" among the small entrepreneurs is something like big sophisticated machinery which does the work fast but also requires a lot of power and asks for huge investments and well trained workers.
There is also a wide spread feeling regarding effectiveness of an equipment in peeling the varying size and shapes of fruits and even if there are, they are not suitable for their pockets. It is this reservation towards new technologies of the interventions that stop them from adopting these options.

g. Business model of small scale units

Most of the existing small units produce a small quantity processed items that could be consumed locally but they also process a significant amount of semi-finished products as per the orders placed by the bigger players. This demand is not the same every year. Sometimes, the demand is exceptionally high and sometimes, it is drastically low. Since the demand for the products is not steady, investing in high cost and high yield machines is not a profitable proposition for these small units. Also, many a times, storing large quantity of product is not possible due to lack of storage space. Hence, a new high capacity machine might not be very suitable to their context.

Thus it was found that there were number of contextual reasons leading to inhibition of new technological intervention among the small processing units. It forms a vicious chain of technology inhibition (Figure 4.01).

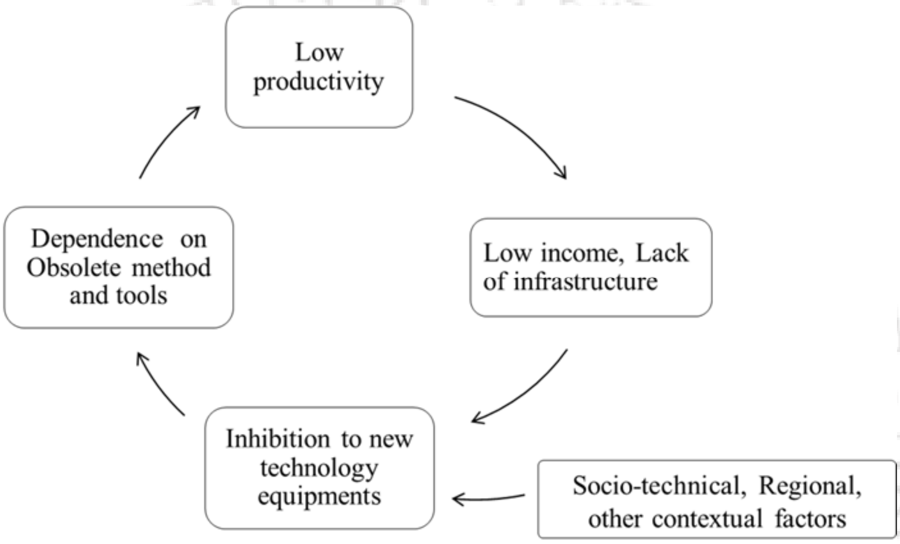


Figure 4.01 Vicious chain of technology inhibition noticed in small scale fruit- processing industry

Inhibition owes to lack of steady income and infrastructural resources as well as other contextual factors. The financial and infrastructural limitations are mostly because of low productivity which is mainly due to use of old and obsolete techniques and practices. This adherence to old techniques is, in turn, due to reluctance in using new technology solutions.

4.4 CESAM: An approach for food processing equipment design

To overcome the vicious circle of technology inhibition, we require providing solutions which are conceived considering all the contextual factors along with ergonomic issues, thereby eliminating the root causes of technology inhibition (Figure 4.02). Since, during the field studies, it was observed that no peeling solution had been designed keeping in mind the context specific requirement of small processing units, it was decided to addresses these needs through ergonomic design intervention. Literature reports methods used for food processing equipment design, especially for units in developing countries which, assumingly, had conditions somewhat similar present context of small pineapple processing units of north east under consideration.

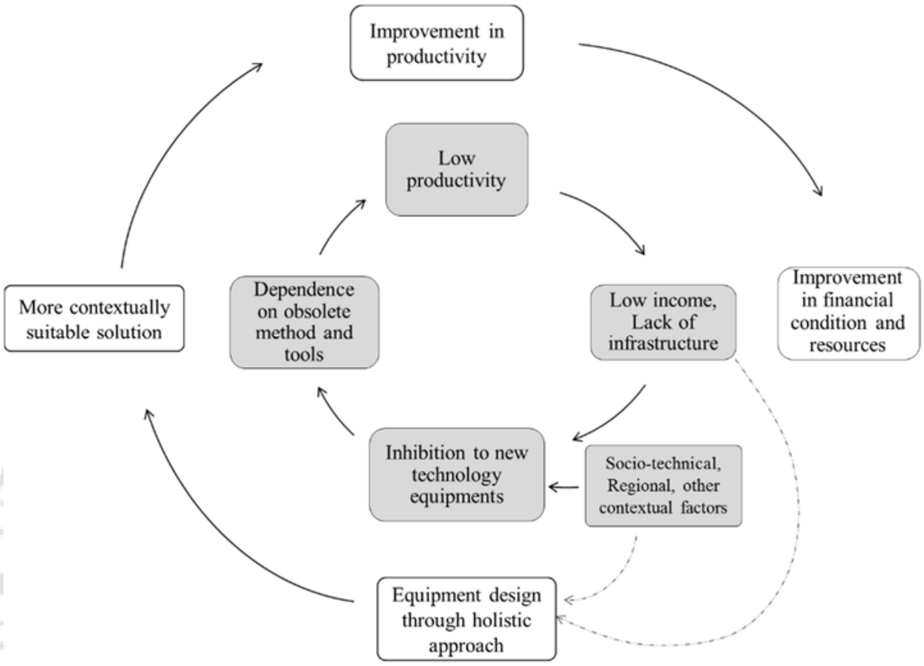


Figure 4.02 Overcoming the vicious chain of technology inhibition through holistic design approach

This method is important in the pretext that sufficient efforts had been put in the food processing equipment deign for developed countries (Ulrich & Eppinger, 2003), in contrast to developing countries where not much had been done in this area. There are two approaches for the design of food processing equipment in developing countries i.e. adoption- copy approach and local design development approach.

In **adaption- copy approach**, the imported equipment is manufactured locally just by copying the whole thing; a machinery can be transported from one continent to another but it is designed for a technical and economic context which can't be changed (Giroux, Francois, & Montpellier, 2007). Hence, if there is a direct import and installation of an outside technology, it might be abandoned due to its inappropriateness to the local context in some time even if the price is low. Many vital issues like financial limitations, repair and maintenance, etc. might be addressed if this machine is manufactured in local ways with local material, manufacturing process and expertise, this problem can be solved. This approach had its own limitations. It is mainly possible in countries where the technical and economic environment had some similarities. Legally it might also raise the IPR issues. Literature also suggests that often the new technology products used for processing food items are mostly copied, imported or adapted directly from the developed countries without understanding the socio- economic and technological context in which they are to be used and having features that are often inappropriate to produce processed items specific to tropical and sub-tropical countries (Barbier, Marouzï, & Laboratory), 1997).

In the local design development approach, the requirements and problems of the users are analysed and then a solution is conceptualized to best suit the needs of the target users. For design of food processing equipment as per the local requirements specifically in developing countries, a method was proposed by Marouze in 1999 termed CESAM (Conception d' Equipments dans les pays du Sud pour l' Agriculture et l' agrolimentaire, Methode) meaning "Method for the design of equipment in the Southern countries) for the agro -food processing". Since fruit processing equipment design is a subset of food processing equipment design and pineapple peeling comes uder the domain of fruit processing , it was decided to adopt CESAM approach for designing pineapple peeling machine. An effort was made to elaborate on CESAM approach and understand how it could be used in the present scenario. The whole method was organized into seven phases namely:

1. Launching of design project
2. Analysis of user need
3. Searching of engineering principles
4. Selection of technological solution
5. Equipment Definition
6. Equipment manufacture
7. Equipment Validation.

The process involved various knowledge domains like knowledge of agricultural raw material (physical and chemical composition, etc.), social, economic and technical knowledge of the environment of the user. It was a collaborative method in which inputs and feedbacks are taken from the concerned users. On closer comparative analysis, it was observed that this method follows the generic design methodology i.e. divergence, transformation and convergence and in many way similar to general product design method. The similarities between the two had been shown in Figure 4.03. Though the focus of the former was to design food processing equipment and all the efforts are from that preview.

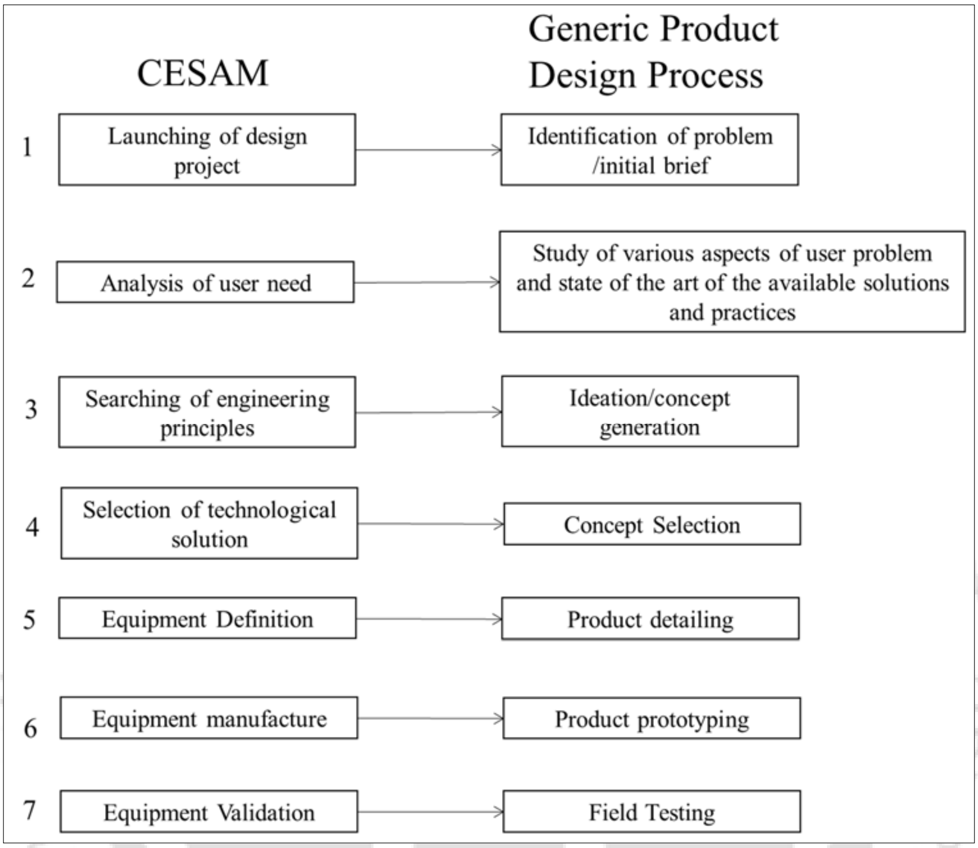


Figure 4.03 Similarities between CESAM and general product design Methodology

"Launching of design project" phase is similar to "Identification of problem or initial brief "which is considered to be the starting point of the design process. "Analysis of user need" phase is synonymous to the study of various aspects of user requirements and state of the art of the various associated solutions and practices which leads to final brief on which product ideation and concept generation synonymous to "searching the engineering principles for solution" phase. "Selection of technological solution" phase is "Concept evaluation and selection" phase. The most suitable solution is selected for further detailing which is termed as "equipment definition" phase. This is followed by "equipment manufacturing" phase analogous to "Product prototyping". The final phase has been described as "Equipment validation" which is equivalent to "Field testing" in product design method. There is not much of difference between the two approaches and they are still very generic in nature. Hence based on this generic method a more elaborate design process was evolved which could be specifically useful in developing the pineapple peeling machine for micro-small scale units. The design development strategy was taken in combination of both the approaches i.e. design development for local context as well as some part of adoption copy process to come up with an effective product.

4.5 Design process development of pineapple peeling equipment

On the basis of the method for food processing equipment design, an elaborate process for designing and developing pineapple peeling equipment had been evolved as shown in Figure 4.4.

The above mentioned design process was followed step wise to find a more acceptable and effective solution for pineapple peeling and following are the details of each step of design process had been elaborated in details.

4.6 Identification of the problem

Occupational health related issues in the small units processing pineapples had been established using ergonomic tools like body pain map, analog Borg's pain rating scale, QEC and RULA as well as different risk factors had also been identified and issues were decided to be addressed through some intervention for developing work methods through inducting better suited design solution . Hence, the problem thus identified to design work equipment in form of a mechanical peeling aid for reducing the drudgery and increasing the productivity of the workers involved in the pineapple processing (Figure 4.04).

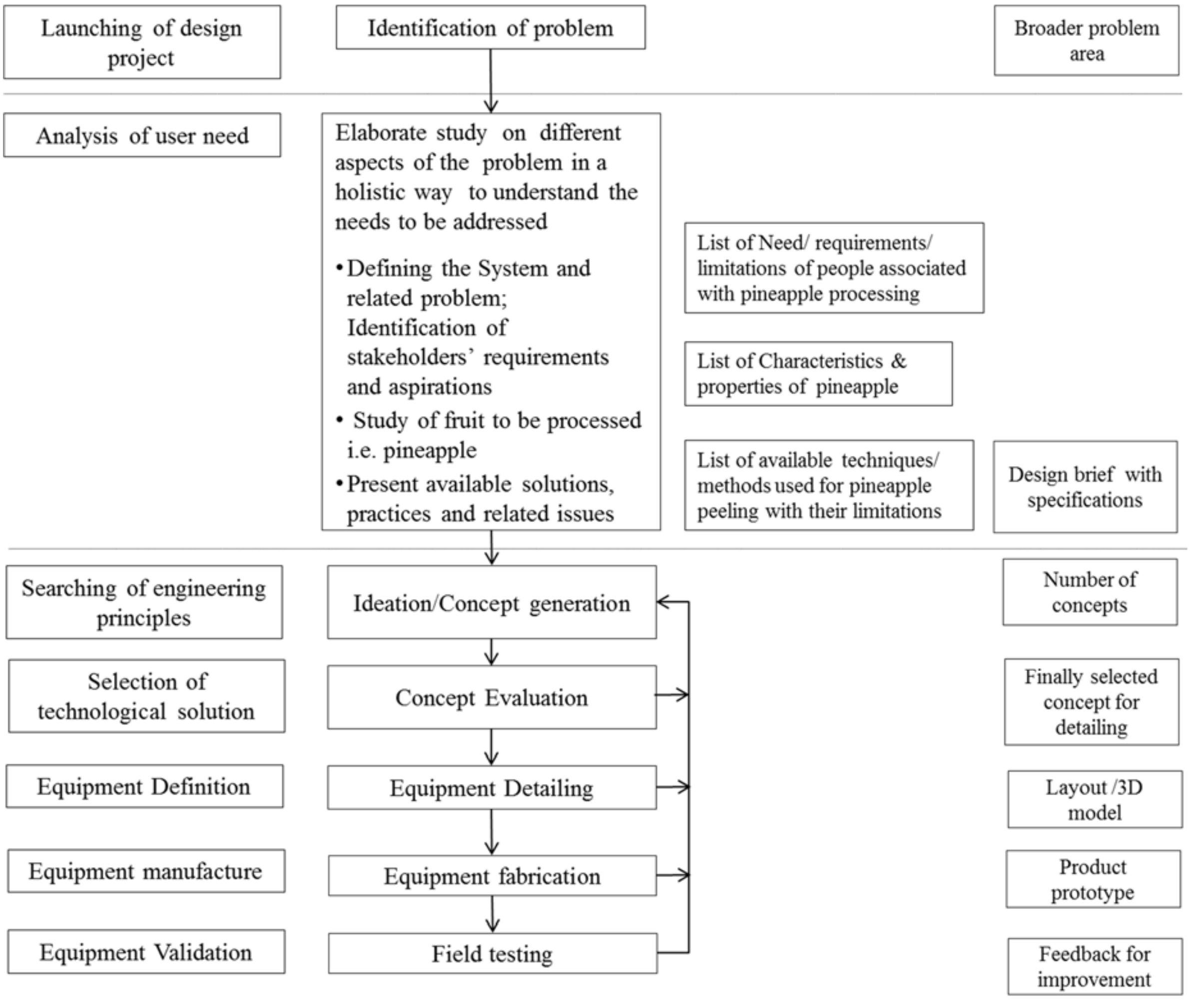


Figure 4.04 Elaborate process of designing pineapple peeling equipment with outcomes at different stages

4.7 Analysis of the problem

The analysis of problem is very important as it paves the path of final specifications on the basis of which ideation and concept generation starts. Mistakes or lapse in analysing problem could cost high both money and time wise as it might lead to improper consideration of user requirement resulting in products' failure to meet the users' aspirations. Studying the root causes for inhibition to new technology peeling solutions was also a part of this phase. Designing any solution warranted a number of considerations (Figure 4.05). These had to be looked in the context considered system.

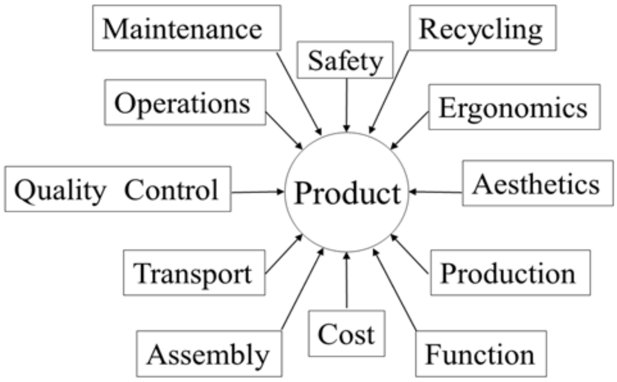


Figure 4.05 Some factors considered in design

The weightage or priority of these considerations might differ from context to context. Hence it was necessary to understand the system in context from different perspectives. These understood the working of system, its stakeholders and various properties of the material under consideration. The problem analysis had several domains to look into which help us to get the final specifications for pineapple peeling equipment to be designed (Figure 4.06).

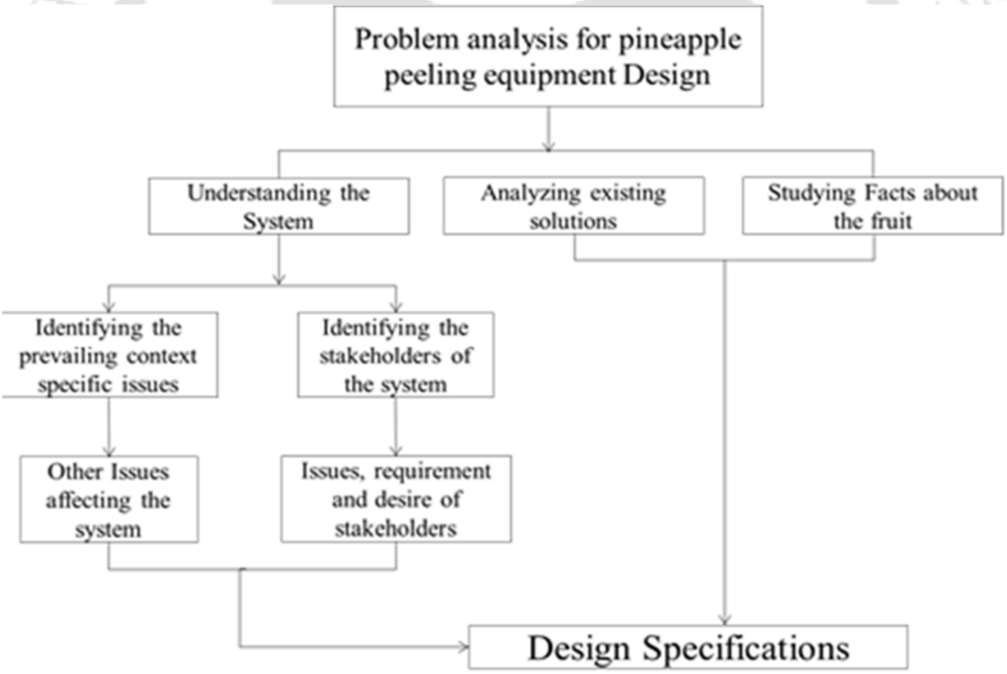


Figure 4.06 Steps for deciding the design specification

Some of the study has already been reported regarding the system specific external factor in the previous section of root-cause identification.

4.7.1 Understanding the System

Based on our interactions and observation during field studies, towards defining a general system of operation, different stakeholders and their interactions is mentioned in Figure 4.07.

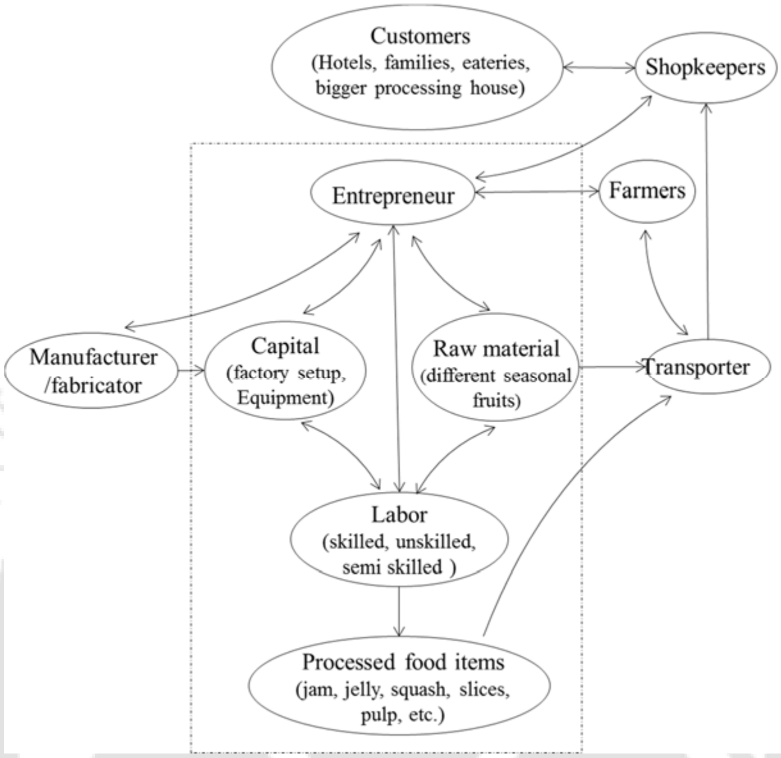


Figure 4.07 Stakeholders in small fruit processing unit system

The system had many stake holders including entrepreneur, labourer, customer, transporter, competitor, fabricator and shopkeeper. Entrepreneur managed capital resources, labour and raw material to make the production possible. Labourers used the available tools and other resources provided by him to process the fruits and produce and package different variety off product items as per direction of the entrepreneur. The equipment and machinery were either bought from the local dealer or obtained from some fabricators. The raw materials are bought by the farmer and transporter transports it to the factory units. The packaged pineapple items after being readied is sent to the consignees and shops as per the demand or order placed.

During the study it was found that though the workers were the real users of the aid who actually use it, the purchasing power entirely rests with the entrepreneur who is mainly interested in profits. Fabricator was also considered as an important stakeholder because he is the one who realised the solution.

4.7.2 The requirements and aspirations of various stakeholders

There are many stakeholders which are directly or indirectly connected to the system, there are mainly three stakeholders that would be most influenced by the induction of new device i.e. worker, entrepreneur and the fabricator. Hence, an effort was made to list the various requirements of these stakeholders.

A. Requirements and aspirations Workers

Since it was the workers who would primarily be affected by the peeling equipment to be designed, the requirements and aspirations of the workers were to be considered and addressed effectively. Based on interactions with workers, the new equipment should be

- easily quickly understandable
- fast in operation
- ask for less effort in operating
- allow the change of posture
- smooth and noiseless
- lesser number of steps
- should not spill or dirty the surrounding
- had easy mechanism of removing the processed fruit
- requirement of monitoring effort should be less
- ensure safety
- should not had adverse effect of their lobs

B. Requirements and aspirations of Entrepreneurs:

Since it is the entrepreneurs who actual had purchasing power, his aspirations had to be equally emphasized upon while designing. From entrepreneurs' perspective, the solution should make the process faster

- increase the quantity of turnout
- ensure good quality of output
- robust and ask for less repairs and maintenances
- quickly troubleshooter
- cost effective
- space effective
- less power consuming or if possible might not require power

- ensure continuous processing operation even during power cuts
- possibly multipurpose

C. Requirements of the Fabricator

Though fabricator is not the user of machine but he is the person who manufactures it and if the construction of machine is simple he can manufacture more machines in less time and also affect their price. From fabricator point of view, the machine should be

- made using locally available raw materials
- manufactured using available technologies
- lesser number of components
- easy to assemble

After analysing system and the needs / requirements from the perspective of different stakeholders, it was essential to explore the existing methods, techniques and practices presently used for peeling pineapple and critically examine the merits and demerits of each.

D. General basic requirements related to system

In addition to the requirements of stake holders, there are some other factors which, to a large extent, influence the system i.e. prevailing power supply in the region, road and transportation, network of suppliers and consumers.

4.7.3 Study of existing practices

After study of system in context, an effort was made to study presently adopted peeling practices and solutions. It was found that different solutions available can be broadly categorized under to 4 major categories i.e. hand tool like solutions, human powered solution, semi-automated solutions and fully automated solutions.

A. Small Hand tool like solutions

These are very simple tools operated using hand by gripping it with hand or sometimes leg. Using them requires force as well as some skills for better performance. Being small they are more flexible to work with but due to smaller size require more time and often effort too. Table 4.01 describes the merits and demerits of solutions used commonly used in the processing units.

Table 4.01 Critical study of different hand operated small solutions for pineapple peeling

Sr.	Solutions	Merits	Demerits
1		• Peels full fruit in one go • Removes core also • Compact • Light weight • Portable • Simple construction • Without power • Cheap	• Wastage high • Juice spill is high • Unable to peel different diameter effectively • uncomfortable handle • High force required • Not fit for industrial peeling
2		• Peels full fruit in one go • Removes core also • Compact • Light weight • Portable • Simple construction • Without power • Cheap	• Wastage high • Juice spill is high • Unable to peel different diameter effectively • Not comfortable to use • High force required • Time taking • Not fit for industrial peeling
3		• Peels full fruit with different sizes and shapes • Compact • Less force is required • Light weight • Portable • Simple construction • Without power • Cheap	• Peeling is very slow • Highly repetitive • Required to sit in an awkward posture while operation • Not very safe
4		• Peels full fruit with different sizes and shapes • Compact • Less force is required • Light weight • Portable • Simple construction • Without power • Cheap	• Peeling is very slow • Highly repetitive • Required to sit in same posture for long while operation • Not very safe
5		• Peels fruit slice in one go • Compact • moderate force is required • Light weight • Portable • Simple construction • Without power • Cheap	• Peeling is not very fast • Can peel different diameter slices • wastage • Highly repetitive • Required to adopt awkward posture during force application
6		• Can peel and remove core of half cut pineapple • Compact • cheap	• slow peeling • pineapple cut into halves • not very safe • lot of effort required • not fit for industrial use

B. Hand powered solutions

These are Hand powered solutions operated using principles of mechanical advantage in the way like pressing, bending, lifting, etc. Not much skill is required for the operations but force magnitude is relatively higher as compared to hand held tools. The mechanism is more complex as compared to the hand held tool and second or third type of lever is provided to reduce the effort required to execute peeling operation. They are generally costlier as compared to hand held tools; merits and demerits of two models are presented Table 4.02 for reference.

Table 4.02 Different human powered solutions for pineapple peeling

Sr.	Solutions	Merits	Demerits
1		• Peels full fruit in one go • Removes core as well • Compact • Light weight • Portable • Simple construction • Without power	• Wastage high • Unable to peel different diameter • Un ergonomic handle • High force required • Pineapple slices are cut from one side
2		• Peels full fruit in one go • Removes core also • Compact • Light weight • Portable • Simple construction • Without power • Pineapple slices are intact • Safe as operated with both hand	• Wastage high • Unable to peel different diameter • Un ergonomic handle • High force required • awkward as operated by both hand

In almost all the human powered models, it was observed that the wastage was high as it was not possible to adjust the diameter of cutter as per the varying diameter of the pineapple. The handle of the device was not very ergonomic to use.

C. Semi-automated solutions

These are the equipment in which some of the operations are carried out manually and some are done using machine power. This generally takes less effort and skills but requires technical knowledge of operation. It also appears costly as well as requires uninterrupted power supply and other provisions like pneumatic cylinders, air compressors, etc. Some of these examples are presented in Table 4.03 to analyses there merit and demerits.

Table 4.03 Critical study of different semi-automated solutions for pineapple peeling

Sr.	Solutions	Merits	Demerits
1		• Peels the full fruit in one go • Removes core also • Light weight • Simple operation • Fast operation • Less effort • Safe	• Wastage high • Not so compact • Not very portable • Unable to peel different diameter effectively • Requires power • Accessories like air compressor and pneumatic pump required • Costly for micro and small units
2		• Peels full fruit in one go • Removes core also • Fast	• Wastage high • Unable to peel different diameter effectively • Not Compact • Not Portable • Not so safe • Requires power • Costly
3		• Peels full fruit in one go • Fast • Peels different diameter pineapple • Less wastage	• Not Compact • Not Portable • Simple construction • requires power • costly • construction complex • fixing pineapple is difficult

D. Fully automated solutions

In these machines, one just needs to put the pineapple at one end and collected the final output from the other end. All the process in between are automated. These are very fast but require electricity as well large operations space. It is preferred for the big units which had very high turnover and where huge quantity of pineapple is processed on regular basis. Table 4.04 analyses two such systems.

Table 4.04 Critical study of different fully automated solutions for pineapple peeling

Sr.	Solutions	Merits	Demerits
1		• Peels full fruit in one go • Operation extremely fast • Removes core also • Wastage less • safe	• Very costly • Requires power • Not Compact • Too huge to be portable • Sophisticated construction • Requires high power
2		• Peels full fruit in one go • Operation extremely fast • Removes core also • safe	• Wastage • Very costly • Requires power • Not Compact • Too huge to be portable • Sophisticated construction • Requires high power

During the study it was found that most of the available aids especially human powered, semi-automated and fully automated solutions were focussed mainly on peeling of pineapples for slice preparation purposes.

During the industrial visits, it was observed that only a few units were engaged in preparing the canned pineapple slices as high investment is required for setting canning line which is not possible with many small units. A large quantity of pineapples were pulped and crushed for juice, jam, squash, jelly, etc. where they are only roughly peeled and juice is extracted and filtered to remove the impurities. It appeared that for majority of the product prepared by smaller unit like jelly, juice, and squash and for that, a rough peeling is sufficient. After ascertaining different kinds of output needed, it was necessary to ascertain the physical properties of the fruit that would help in deciding upon the mechanical principle while conceptualisation.

4.7.4 Study of facts regarding structure and properties of the fruit

After studying the technologies available for pineapple peeling we need to study the fruit so as to understand the important properties and peculiarities of fruit which might help in coming up with a better peeling solution where frequency of hand movement and hand force requirement would be reduced and productivity be improved.

For designing fruit processing equipment, understanding the different properties and structure of the fruit to be processed and getting all relevant information, in this regards, is very important. Hence, effort was made to look into structure and collect relevant information regarding the fruit.

A. Basic composition and properties

Pineapple is, basically, a compound fruit consisting of many small fruitlets. It had fibres that are spread radically but at the central core area, the fibres are oriented longitudinally. As found in a study (Montero-Calderón et al., 2009), amount force required for shear cutting varies along the axial length of the pineapple and accordingly it can be divided into three major parts upper, middle and lower. For the middle part lesser peeling force is required as compared to the upper and lower third. Maximum force is required for the lower third. The shear cutting also varies along the diameter of fruit in a radial fashion. The shear cutting force increases from centre towards the periphery but decreases slightly as it reaches the periphery. The relative acid content was also found to be higher in the lower part of the fruit than that of the upper part. The typical structure is presented in (Figure 4.08).

The flesh of the pineapple is very fibrous and juicy and becomes juicier as it ripens. Pineapple had eyes which are embedded 8- 10 mm into the flesh and the eyes are arranged in Fibonacci series. The material is reactive to iron contact hence no iron container or material should be used while processing. The fruit juice is acidic in nature and long direct contact with skin might lead to itching, corrosion and even bleeding.

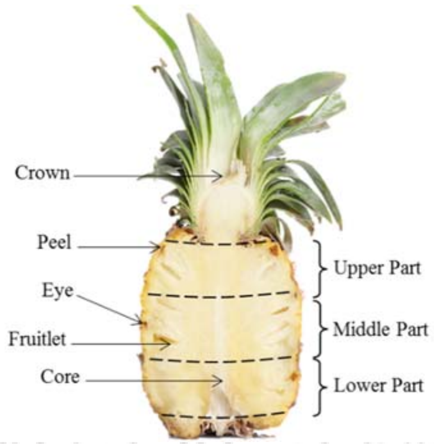


Figure 4.08 Different Parts of Pineapple fruit

B. Physical dimensions

Generally, there are two types of pineapple available in the region i.e. "queens" and "kew". "Kew" variety is generally bigger in size and is fleshier and considered more fit for slices and the peak harvest season for "kew" variety are July and August. On the other hand, "Queen" variety is harvested in November –December and is smaller in size and juicier and fit for making products like juice, jelly, squash, etc. Some important dimensions of the fruits were also ascertained after examining more than 51 pineapple samples from the pineapples cultivated in North East from both the harvest seasons. The measurements were carried out with respect to height, different diameters i.e. upper, middle and lower part diameters, thickness of peel in first peeling, second peeling and core diameter (Figure 4.09).

Figure 4.09 Measurement of important dimensions related to Pineapples

The mean, median and standard deviation of values for measurement of important obtained dimensions were tabulated in Table 4.05.

Table 4.05 Mean and median value important dimensions related to Pineapple (in mm)

Dimensions of the fruit (n=51)	Mean	Median	Std. Dev.
Height (without crown)	150.59	150	20.51
Upper Diameter	100.92	98	10.08
Middle Diameter	107.75	100	10.11
Lower Diameter	104.65	100	9.35
Peel thickness in first peeling	5.01	5	0.89
Peel thickness in second peeling	5.19	5	0.79
Core Diameter	19.37	20	1.72

These dimensions and other composition related information would be critical while designing an effective mechanism for pineapple peeling.

4.7.5 Summary of findings during the problem analysis phase

In the problem analysis phase, the problem was analysed from different point of view and some of the important findings had been summarised as below.

The study of the system in context lead to many important findings which are as following:

- Though there were many stakeholders directly and indirectly associated with the considered system, the stakeholders most practically relevant to the context are worker, entrepreneur and the fabricator.
- In present context the user of the equipment is mainly the worker whereas the buyers of the equipment are the entrepreneurs.
- The main discretion of buying lies with the entrepreneurs and hence other than addressing the workers issues, most of the design decisions had to be taken considering the entrepreneurs preferences.
- Considering the two main stakeholder and various causes of not adopting new solutions, following key requirements related to the system were identified which are as following:
    - The solution should be effective in peeling varying sizes and shapes of pineapple
    - The solution has to maintain less raw material wastage

  - The solution must have higher productivity
  - The solution must not only ask for less repairs and maintenance but should be easy to troubleshoot
  - The solution should be safe for workers (accident /risk of injuries)
  - The solution has to be comfortable to use
  - The solution should be easy to understand and operate i.e. should have greater adaptability terms of familiarity to technology
  - The solution must have lower cost
  - Solution should have power- independent operation to ensure uninterrupted work in the wake of power crisis
  - The solution with multipurpose utility would be more acceptable
  - The solution must be easy to move
  - The solution should be less space occupying
  - The solution has to ensure uniformity in overall quality of output
  - The solution desired to have visual appeal to motivate users to use it
- Study of existing equipment and solution revealed merit and demerits of different categories of solution ranging from worker efficiency, peeling effectiveness to repair and maintenance to cost of equipment and
- Study of fruit provided with different physical and structural properties which might help in conceptualization phase.

4.8 Deciding upon the appropriate category of solution

In the analysis phase, four different categories of peeling solutions i.e. Small Hand tool like solutions, human powered solutions, semi- automated solutions and fully automated solutions were identified as well as key requirements of the main stakeholders had also been listed (section 4.6.3). The peeling equipment which had to be designed would be from one of these categories. Based on the requirements of the stakeholders, if it could be specified which category of solution would be most suitable for the present context, it could largely simplify the conceptualisation of solutions. Since deciding upon the context appropriate solution category depends upon a number of considerations which even sometimes, were contradictory, it was difficult to take the decision. For example one of the requirements is that the aide should reduce the effort of workers, for which automated machines were most suitable. But as for the financial requirement, space requirement, adaptability factor, it was lest considered choice. Every solution category caters to some of the requirements but is not suitable for some other requirements. Hence, to help decide the most appropriate solution category, a tool was proposed based on the priority of the key requirements and the kind of association between requirements and the solution categories.

4.8.1 Proposed tool for determining most appropriate solution category

The decision on most suitable solution category is dependent on more than one key factor. Besides the apparent factors like power availability, it also depends on factors like size of the unit, effectiveness in terms of financial constraints, expected performance, multi- purpose use, etc. Hence, an approach similar to Quality Function Deployment (QFD) was taken to decide the final category. The QFD diagrams are used to determine how important design parameters are with respect to the various users' requirements. In present context, users' priority for key requirements are arranged in different rows from top to bottom with different solution categories in different columns from left to right. The relation between different users' requirements and solution categories are quantified and is multiplied with the corresponding priority score of the key requirements. Finally, sum of products of category- requirement relationship score and the corresponding priority score generates a final score. The final score of each category indicated its relative importance with respect to other solution categories The final score of each design parameter reflects its relative importance with respect to other design parameters (Cross, 2008). The functioning of proposed tool works on the same principle is schematically described in the Figure 4.10.

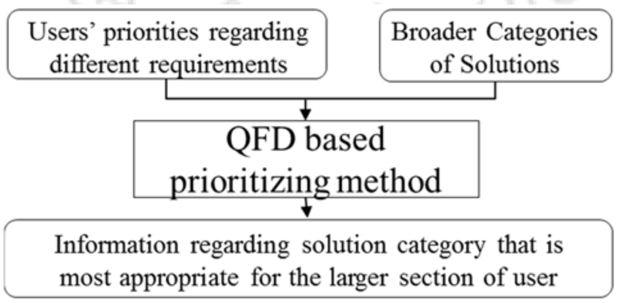


Figure 4.10 QFD based approach for deciding most appropriate solution category

The QFD like diagram, for deciding upon the category of peeling solution, would be most suitable to user context based on different user requirements. Here users' priorities for key requirements are put on y axis with different solution categories on x-axis. The relation between different users' requirements and solution categories are quantified and is multiplied with the corresponding priority score of the key requirements. Finally, sum of products of relationship score and the corresponding priority score generates a final score. The final score of each category indicates its relative importance with respect to other solution categories (Table 4.06).

Table 4.06 Table representing various components of the QFD based method

Solution categories / Priority for each requirement (in % age)	C1	C2		Cn
P1	P1 x RC1x	P1 x RC2x	--------	P1 x RCnx
P2	P2xRC1x	P2xRC2x	---------	P2 x RCnx
P3	P3xRC1x	P3xRC2x	---------	P3 x RCnx
---------	---------	---------	---------	---------
Pn	PnxRC1x	PnxRC2x	---------	Pn x RCnx
Total score	∑PnxRC1	∑PnxRC2		∑PnxRCn

The final score for each category can be calculated using the following numerical formula:

Final score for a category= ∑ (Pn x RCn)

Where Pn= priority of n^{th} requirement among all the requirements

RCn= Rating for relationship of nth category with requirements

4.8.2 Determination of ratings for category- requirement relationship

Each category solution is related to a number of requirements directly or indirectly influencing entrepreneurs purchase preference for new equipment.

The key requirements which had been identified earlier during system study, had been analyzed and rated for their relationships with different categories of solutions. To avoid biasness the ratings were taken from 11 PhD research scholars in Design from IIT Guwahati covering different fields of mechanical engineering, design, agriculture engineering, ergonomics and sustainability. The ratings were done on 1-7 rating scale with "7" being most positive relation and "1" being least positive relation. The ratings of all these 11 respondents were analyzed and mean value is considered for further calculations (*Appendix 3*). The relationship score for each requirement had been presented in the sections to follow.

a. Lower cost:

It is apparent that Small Hand tool like solutions would be relatively cheaper than other categories of solutions but since the productivity of such solutions is lowest and hence it incurs has highest running cost per unit, the overall association for small tools with "lower cost" is weaker. Similarly, since the cost of fully- automated solutions are too high, the association with "lower price" is weak (Table 4.07).

Table 4.07 Ratings for lower cost

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	3.91	5.00	3.82	1.73
Median	4.00	5.00	3.00	1.00
Std. Dev.	1.22	0.89	1.08	1.49

b. Low wastage of raw material

Since, peeling with hand tools is more flexible, the relationship ought to be strong but the manual work leads to fatigue and wastage slowly increases with time. Hence, overall association rating is moderate. The wastage in the other categories is significant but uniform with time. Hence, all other categories had slightly weaker association (Table 4.08).

Table 4.08 Ratings for relationship with lesser wastage of raw material

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	5.55	4.73	4.64	4.36
Median	6.00	5.00	5.00	4.00
Std. Dev.	1.57	1.35	1.36	1.80

c. Better Portability

In general, Hand tool like solution had less number of components and they are light and handy to carry, hence easier to carry. Even most of the Hand powered solution and good section semi-automated machines are also quite easy to move. Hence they had stronger to moderate association with "better portability" (Table 4.09).

Table 4.09 Ratings for relationship with better portability

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	6.45	5.27	4.00	2.00
Median	7.00	5.00	4.00	1.00
Std. Dev.	1.21	0.79	1.18	1.84

d. High Productivity

The rate of peeling for hand held devices is quite slow. Whereas, the rate increases as the amount of automation increases. Thus the association of small tools with the "high productivity" is weaker and it is highest for the fully automated solutions categories (Table 4.10).

Table 4.10 Ratings for relationship with high productivity

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	1.73	4.91	5.55	7.00
Median	2.00	4.00	6.00	7.00
Std. Dev.	0.65	0.94	0.52	0.00

e. Better Effectiveness in peeling of different fruit sizes

In general, since the small hand tool like solutions are more flexibly controlled during peeling, its association with peeling effectiveness is stronger. But, the manual work leads to fatigue and thus the effectiveness decreases with time. Thus, overall efficiency was moderate. On the other hand, for other categories, flexibility is generally less but the output is uniform. So, association with "overall effectiveness" was comparatively weaker (Table 4.11).

Table 4.11 Better Effectiveness in peeling of different fruit sizes

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	5.82	4.45	3.82	3.18
Median	6.00	5.00	4.00	3.00
Std. Dev.	1.25	1.44	1.33	1.83

f. Uniform Quality of output

As the degree of automation of machine increases, the Quality in terms of finishing of the product is the best manually if the amount of material is less. But in industries where a large number of pineapples had to be peeled the workers get tired and the quality eventually deters where as in case fully automated category, the quality remains the same throughout the time irrespective of quantity. Human powered machine and Semi- automated solutions might also have some degradation in quality as there is some human participation and hence some chances of error. Hence, the rating would be as mentioned in Table 4.12.

Table 4.12 Ratings for relationship with uniform quality of output

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	3.00	5.00	5.73	6.18
Median	3.00	5.00	6.00	7.00
Std. Dev.	2.00	1.10	0.65	1.40

g. Lesser Repair and maintenance

Since, the small hand tool like solutions are simple and involve less number of components, the repair and maintenance problem is lesser with just the regular sharpening of tool for better performance. The "lesser repair and maintenance" had a stronger association with hand held tools. Whereas as the association weakens as the degree of automation and the number of components increases (Table 4.13).

Table 4.13 Ratings for relationship with repair and maintenance

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	6.64	5.09	3.45	2.00
Median	7.00	5.00	3.00	2.00
Std. Dev.	0.67	0.83	1.21	1.18

h. Higher aesthetic appeal

It was seen that higher appeal could not be significantly related a particular category of solution. Hence almost similar rating was given to each category (Table 4.14).

Table 4.14 Ratings for relationship with Aesthetic look

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	3.45	3.82	4.64	4.18
Median	3.00	4.00	5.00	4.00
Std. Dev.	2.11	1.66	1.96	2.56

i. Power independent operations

Here, fully automated as well as semi-automated solutions had weaker association with power-independent operations as they are dependent on power for their operation. But, they take less effort and are very fast which is equally important. Hence, the rating as shown (Table 4.15).

Table 4.15 Ratings for relationship with power independent operations

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	6.73	6.09	2.36	1.27
Median	7.00	7.00	2.00	1.00
Std. Dev.	0.65	1.30	1.57	0.65

j. Less Space occupying

The Fully automated solutions are generally more space consuming as compared to other categories of machines. Hence, their association with "less space occupying" is weaker. The association grows stronger as we move towards small tool category (Table 4.16).

Table 4.16 Ratings for relationship with Less Space occupying

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	6.64	5.55	3.82	1.64
Median	7.00	6.00	4.00	1.00
Std. Dev.	0.67	0.82	1.17	0.81

k. Better Safety

Since Small Hand tool like solutions work most closely to the workers and there is hardly much as safety precaution, the workers are more exposed to injuries. Hence, its association with hand operated category is weaker. Whereas, the association is stronger for the semi-automated and fully automated solutions (Table 4.17).

Table 4.17 Ratings for relationship with safety

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	2.64	4.27	5.00	5.91
Median	2.00	4.00	5.00	6.00
Std. Dev.	1.75	1.10	0.45	1.70

l. Quicker Adaptability

Fully automated solutions are generally more sophisticated in operation. Hence, there is reluctance and adapting to different aspects of fully automated solutions might take longer as compared to the other categories and might even require training. Hence, its association with "quicker adaptability" is weaker (Table 4.18).

Table 4.18 Ratings for relationship with adaptability

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	5.91	5.55	5.00	3.36
Median	7.00	5.00	5.00	4.00
Std. Dev.	1.45	0.69	1.34	1.80

m. Better Comfort

Since in fully automated and Semi- automated solutions significant work is done through the machine only, least human effort is required during operations. Whereas, the Hand powered solution takes lesser effort than the Small Hand tool like solutions. Hence "better comfort" is more strongly related to the automated categories and becomes weaker moving towards hand operated small tool category (Table 4.19).

Table 4.19 Ratings for relationship with better comfort

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	2.45	4.45	5.64	6.64
Median	2.00	5.00	6.00	7.00
Std. Dev.	1.04	1.29	0.67	0.67

n. Multipurpose use

Though multipurpose use cannot be attributed to any particular category. But, as apparent in some cases, some of the small hand tool like solutions had high multi utility. Hence, the association is stronger for small hand tools (Table 4.20).

Table 4.20 Ratings for relationship with multipurpose utility

	Hand tool like solution	Hand powered solution	Semi-Automated solution	Fully automated solution
Mean	5.73	3.27	3.00	2.18
Median	6.00	3.00	3.00	2.00
Std. Dev.	1.42	1.35	1.26	1.78

All the mean value of all the ratings was tabulated one table which would then be multiplied by the percentage users' priority score for each requirement.

Mean Ratings of category- requirement relationships

Since the sample size is small and the variation is generally not very high, the mean score was considered. Mean Rating of category- requirement relationships are as given in Table 4.21.

Table 4.21 Mean scores of category- requirement relationships

Sr. No.	Categories of food processing machine / Users' Requirement	Hand tool like solution	Hand powered solution	Semi-Automated Machines	Fully automated solutions
1	Equipment Cost	3.91	5.00	3.82	1.73
2	Wastage minimization	5.55	4.73	4.64	4.36
3	Portability	6.45	5.27	4.00	2.00
4	Productivity	1.73	4.90	5.55	7.00
5	Effectiveness in peeling varying sizes	5.82	4.45	3.82	3.18
6	Overall Quality of output	3.00	5.00	5.73	6.18
7	Repair and maintenance	6.64	5.09	3.45	2.00
8	Aesthetic appeal	3.45	3.82	4.64	4.18
9	Power independent operations	6.73	6.09	2.36	1.27
10	Space	6.64	5.55	3.82	1.64
11	Safety of workers (accident /risk of injuries)	2.64	4.27	5.00	5.91
12	Adaptability of workers(familiarity to technology)	5.91	5.55	5.00	3.36
13	Comfort of workers	2.45	4.45	5.64	6.64
14	Multipurpose utility	5.73	3.27	3.00	2.18

The second part of the work was to determine, requirement priorities of the buyers, here, the entrepreneurs.

4.8.3 Determination entrepreneurs' priorities

Since the entrepreneur is the entity who is responsible for purchasing the new equipment, they were asked to rank the priorities of their key requirements which might influence their purchase decision. Since direct question might often lead to obvious answers, the questions were carefully framed and consequently, the rating were decoded and analyzed. The questionnaire is put in the appendix for quick reference. The questionnaire was administered to entrepreneurs from the 17 units engaged in pineapple processing (Appendix 4). The final average rating for each requirement (in percentage) is as presented in Table 4.22.

Table 4.22 Users' priorities of different requirements

Sr. No.	Users' Requirement parameters	Average priority score out of 7	priority *w.r.t* other parameters in %
1	Equipment Cost	4.53	7.24
2	Wastage of raw material	5.29	8.45
3	Portability	4.97	7.94
4	Productivity	5.29	8.45
5	Effectiveness in peeling varying sizes	4.09	6.54
6	Overall Quality of output	4.09	6.54
7	Repair and maintenance	5.47	8.75
8	Aesthetic appeal	1.79	2.86
9	Power independent operation	4.47	7.15
10	Space	4.18	6.68
11	Safety of workers (accident /risk of injuries)	6.12	9.78
12	Adaptability of workers(familiarity to technology)	4.09	6.54
13	Comfort of workers	3.97	6.35
14	Multipurpose utility	4.21	6.73

Now, this percentage scores for requirement priorities were multiplied with mean values of category- requirement relationship rating. The summation of product of the two for each category, gave final score that suggests which category would be most suitable.

4.8.4 Determining the order of appropriateness for different categories

To determine the order of appropriateness of categories, the users' priority score (in %) was multiplied to corresponding category- requirement relationship score (Table 4.23).

Table 4.23 Final calculations for each solution category

Sr. No.	Categories of food processing machine / Users' Requirement Criteria	Priority for each requirement (in % age)	Hand tool like solution	Hand powered machines	Semi-automated Machines	Fully automated solutions
1	Equipment Cost	7.24	7.24x3.91	7.24x5	7.24x3.82	7.24x1.73
2	Wastage of raw material	8.45	8.45x5.55	8.45x4.73	8.45x4.64	8.45x4.36
3	Portability	7.94	7.94x6.45	7.94x5.27	7.94x4	7.94x2
4	Productivity	8.45	8.45x1.73	8.45x4.90	8.45x5.55	8.45x7
5	Peeling effectiveness	6.54	6.54x6.64	6.54x5.09	6.54x3.45	6.54x2
6	Overall Quality of output	6.54	6.54x3	6.54x5	6.54x5.73	6.54x6.18
7	Repair and maintenance	8.75	8.75x6.64	8.75x5.09	8.75x3.45	8.75x2
8	Aesthetic appeal	2.86	2.86x3.45	2.86x3.82	2.86x4.64	2.86x4.18
9	Power independent operation	7.15	7.15x6.73	7.15x6.09	7.15x2.36	7.15x1.27
10	Space	6.68	6.68x6.64	6.68x5.55	6.68x3.82	6.68x1.64
11	Safety of workers	9.78	9.78x2.64	9.78x4.27	9.78x5	9.78x5.91
12	Adaptability	6.54	6.54x2.64	6.54x5.55	6.54x5	6.54x3.36
13	Comfort of workers	6.35	6.35x2.45	6.35x4.45	6.35x5.64	6.35x6.64
14	Multipurpose utility	6.73	6.73x5.73	6.73x3.27	6.73x3	6.73x2.18
	∑ Total	100	477.75	485.62	431.43	371.71

The final score shows that "small hand tool like solutions" and "hand powered solutions" get, comparatively, higher scores, whereas "semi-automated solutions" and "fully automated solutions" got, comparatively, lower score. "Small hand tool like solution" scores lower than "semi-automated solutions" on many requirements like cost, power independent operation, portability, etc. the former scores higher. But, for most critical aspects, the later scores higher especially on productivity, which is considered to be more prior by the users (4.24).

Table 4.24 Final score in descending order

Sr. no.	Category of fruit processing machine	Final scores
1	Hand powered solutions	485.62
2	Small hand tool like solutions	477.75
3	Semi- automated solutions	431.43
4	Fully automated solutions	371.71

The highest score obtained by category of hand powered fruit processing suggests this category of machine would be most suitable for the given context.

4.9 Design brief and specifications

Considering and studying the various aspects of the problem context holistically, we put down the specification for the final brief which is as following:

A. Objectives

- Providing solution for peeling pineapples fast, easily and effectively, with minimum wastage, irrespective of size and shape.
- The peeling should be smooth i.e. the outer fibers holding the peel should be cut finely in minimum repetition without damaging the inner soft portion and try to keep the juice intact as far as possible.
- The solution should be simple and be easy to manufacture using the local materials.
- The function and working should be easily understood and learn even by a non-skilled laborer.
- The solution operating without power is more preferable. The multipurpose use of the machine is desirable.

B. Essentials:

- Should assure easy repair and maintenance
- Should be easy to understand and operate
- Should prevent error occurrences, and
- Should be completely safe

With this design brief and specifications, conceptualization of the solutions was started.

4.10 Concept generation and detailing

The Concept generation phase started with making decision on what should be mechanism of peeling the fruit. Various ideas were generated for find out different ways to peel the fruit. Some of the basic thoughts for possible peeling mechanism were as following:

- Pressing the blade over the stationary fruit
- Pressing the fruit against the stationary blade
- Pressing the stationary fruit with rotating blade
- Pressing the blade over the rotating fruit
- Pressing the pineapple against the rotating blade
- Pressing the rotating fruit against stationery blade
- Pressing the rotating fruit against rotating and approaching blade
- Rotating the fruit with vertical and horizontal motion against stationary blade
- Rotating the fruit with horizontal motion against blade with vertical motion
- Rotating the fruit with vertical motion against blade with horizontal motion
- Rotating blade around the fruit with vertical and horizontal motion
- Rotating blade around the fruit with vertical motion with fruit having horizontal motion
- Rotating blade around the fruit with horizontal motion with fruit having vertical motion

Some of feasible alternatives for the present context were generated (Figure 4.11).

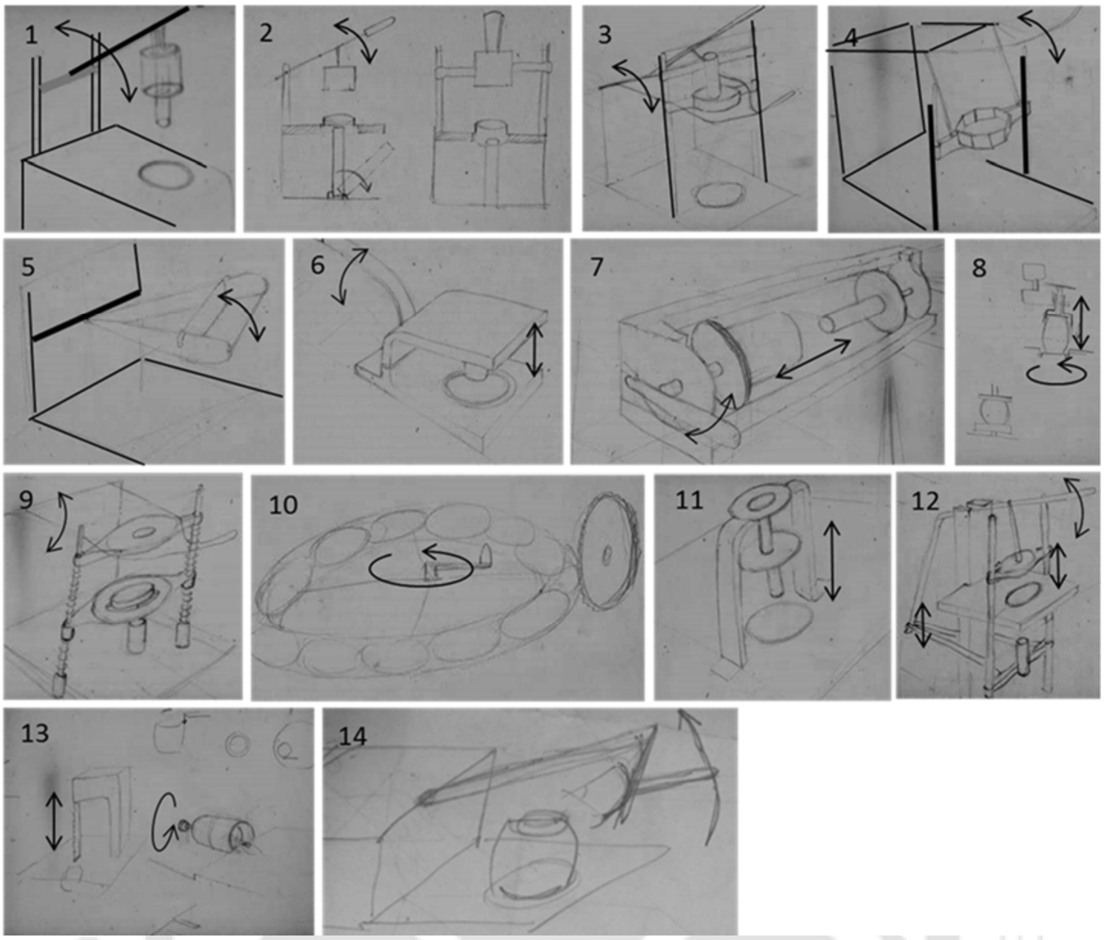


Figure 4.11 Some concepts for pineapple peeling solution : 1- solution that first removes core and then peel, 2- solution that peels first and further pressing removes core, 3- solution that removes peel and then the core from top, 4- Solution that removes only peel using octagonal blade, 5- Solution that peels the fruit using adjustable triangular blades, 6 –Solution that is peeling and coring using first class lever, 7- Solution peeling and coring using horizontal force, 8- Solution peeling the fruit by rotating it and moving blade downward, 9- Solution removing the core by pressing and then peeling using by further pressing, 10- solution peeling the fruit by rotating against a big moving disc blade, 11- Solution peeling the fruit using screwing mechanism,12- Solution peeling and coring using peeling and slicing blade from both the sides, 13- Solution peeling and coring using the moving or reciprocating blades and 14- Solution peeling the fruit moving the blade in a curved path.

The concepts were then evaluated on preliminary selection criteria as presented in Table 4.25. The weightage for each criterion was decided on the basis of users' priorities as determined through the questionnaire as well as consultation with the researchers in design from Department of Design, IIT Guwahati. The method adopted for selection is "weighted objective method" (Cross, 2005).

Table 4.25 Concept evaluation based on preliminary criteria

Criteria / Concepts (1-10 scale)	Rate of peeling (20% wt.)	Peeling Effectiveness (40 % wt.)	Effort reduction (30% wt.)	Simple easy construction (10% wt.)	Total score(rating x weightage)
Concept 1	8	5	6	7	61
Concept 2	8	5	6	6	60
Concept 3	8	5	6	7	61
Concept 4	8	5	6	7	61
Concept 5	7	5	7	7	64
Concept 6	8	6	6	6	68
Concept 7	8	5	6	6	60
Concept 8	9	7	6	7	71
Concept 9	8	8	6	7	73
Concept 10	9	5	6	6	62
Concept 11	8	5	6	7	61
Concept 12	7	8	8	6	72
Concept 13	8	5	5	8	68
Concept 14	7	8	8	8	79

4.10.1 Justification for designing pineapple slice peeling machine

It was observed that overall score obtained by concept 14 was highest. So, the concept was elected for further realization. Since the mechanism was very simple, an effort was made to realize the proof of concept.

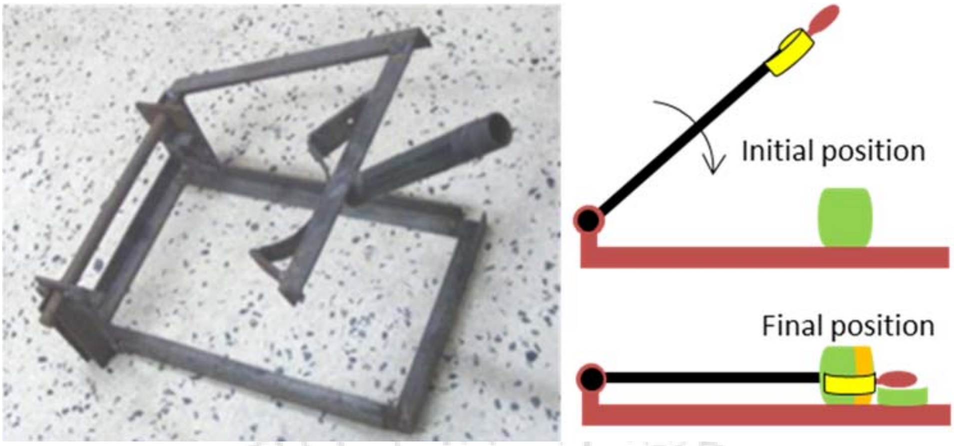


Figure 4.12 Realising proof of concept: peeling fruit by moving blade along a curve

The pineapple was supposed to be peeled in 3-4 movement of blade. During the peeling the fruit had to be gripped and held stationary and then had to be rotated to bring the unpeeled part below the blade. But the trial was not as per expectation.

- Due to fibrous nature of fruit, shear force required to peel even a small strip of peel required a lot of effort.
- The fruit had to be rotated several times for peeling.
- For proper peeling, the fruit was required to be pressed with one hand which had greater chances of injuries.

The failure of initial proof of concept gave new directions for thinking. A different approach was taken in which the whole fruit was not peeled at once but the slices were to be peeled with different diameter blades to ensure effective peeling with less wastage. The effort of peeling the sliced fruit would also be comparatively lower. It was thought that bifurcation of the actions in two parts would make the peeling process simpler. So, in this notion the fruit could be first sliced into as many pieces as required with one machine and then these slices could be peeled with the other machine. The thickness of pineapple might vary between 20 mm to 60mm with pineapple divided in three or more parts, as needed.

4.10.2 Ideation for pineapple slice peeling machine

Though a number of concepts were already generated for peeling equipment, for the design of pineapple slice peeling machine, further ideation was carried out, this time with the thought that slices would be peeled instead of the whole fruit using round vertical blade. Out of this, there were two main types of possible solutions i.e. moving the blade over the fruit or pressing the fruit over the blade. With these two types of thoughts, various concepts were generated (Figure 4.13).

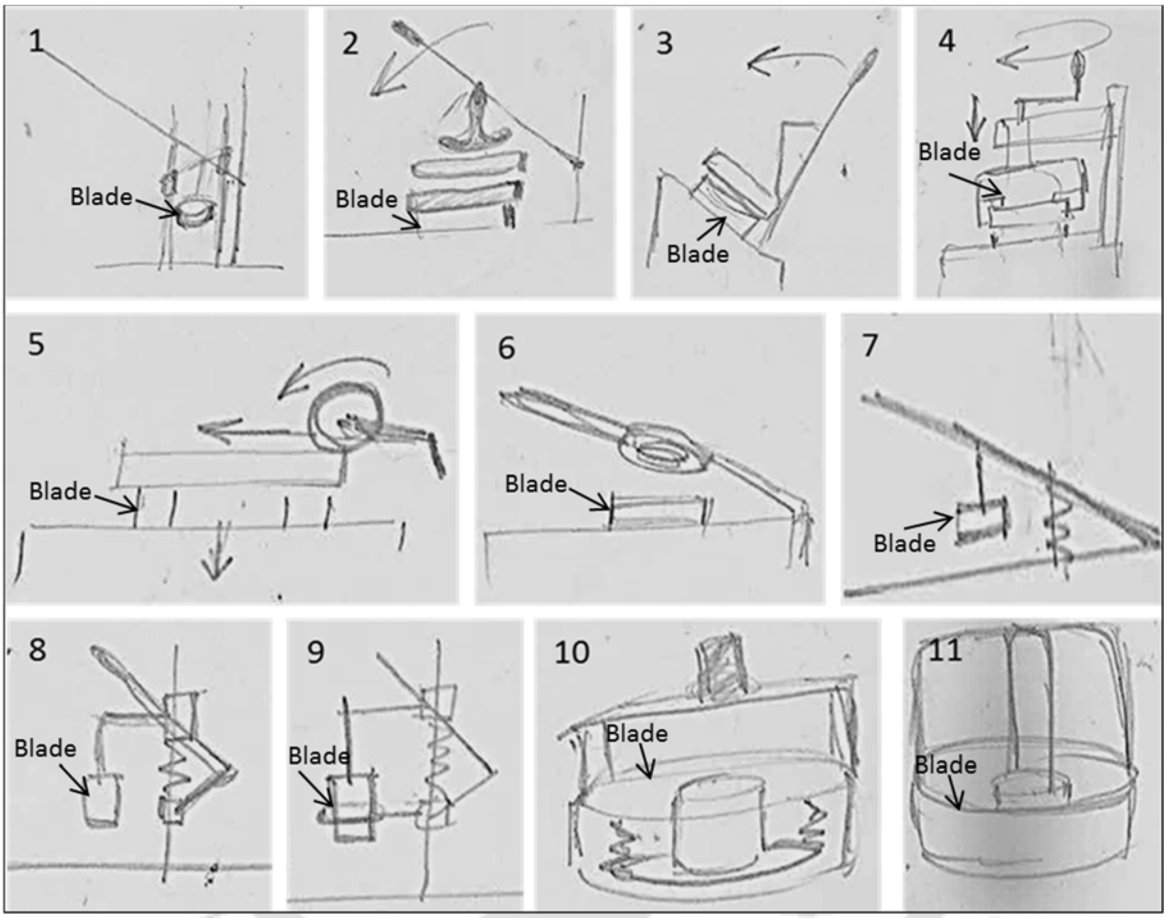


Figure 4.13 Concepts for pineapple slice peeling solution: 1-peeling the slice by moving the blade over the it, 2- Peeling the slice by pressing it against the blade vertically down, 3- peeling the slice by pressing it against a inclined blade, 4- peeling the fruit by pressing it over the blade using rotatory screw motion, 5- Peeling the slice using a rolling mechanism, 6- Peeling the slice using moving circular blade using second class lever, 7- Peeling with a similar mechanism which returns back to initial position after operation by itself, 8- Peeling the slice using a vertical blade with a more compact construction, 9- peeling the slice using the similar mechanism with a strap to ensure pineapple is not stuck inside the circular blade, 10- similar mechanism with spring loaded strap to prevent the slice from sticking in, 11- Similar mechanism with manually operating strap

The new concepts, generated, were again evaluated on the same preliminary criteria as presented in Table 4.26.

Table 4.26 Evaluation of the new concepts

Criteria / Concepts (1-10 scale)	Rate of peeling (20% wt.)	Peeling Effectiveness (40% wt.)	Effort reduction (30% wt.)	Simple easy construction (10% wt.)	Total score(rating x weightage)
Concept 1	6	6	8	8	68
Concept 2	6	6	8	8	68
Concept 3	6	7	8	8	72
Concept 4	5	6	9	6	67
Concept 5	5	7	8	8	68
Concept 6	6	7	8	8	72
Concept 7	6	6	8	8	68
Concept 8	6	6	8	8	68
Concept 9	6	7	8	8	72
Concept 10	6	5	8	8	64
Concept 11	6	5	8	8	64

Out of these concepts, three got the same total marks. Since pressing mechanism similar to that of “concept- 9” was found to be in an old machine, it was decided to modify and add the new setup to the existing part to realize the proof of concept. At first, 3 D model of old part with modifications and additions made to visualize how the equipment would look like. The 3D model was made on CATIA V5 (Figure 4.14).

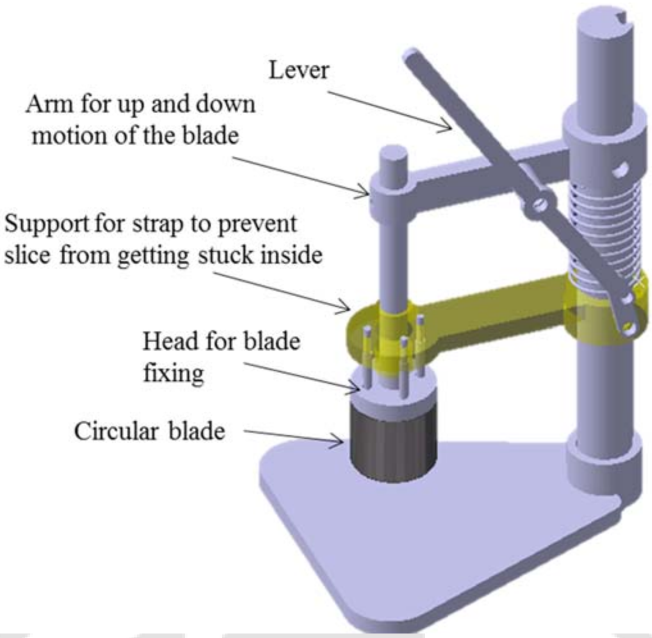


Figure 4. 14 3-D visualisation of the concept

Construction in principle had 4 main components (Figure 4.15)

- outer blade which can be replaced with bigger or smaller diameter blades
- inner blade for removing core
- metal strip to prevent the peeled slice getting stuck inside
- spring loaded ejector for preventing the core from sticking inside the core blade

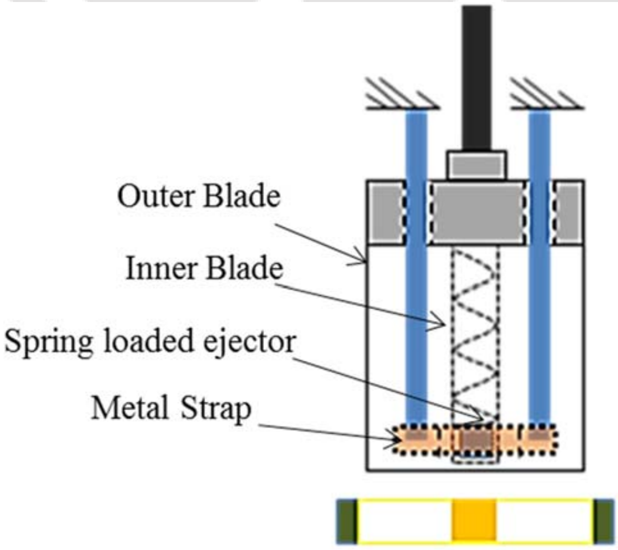


Figure 4. 15 Different components of the structure

Working principle of the solution

When the concentric blades move down they peel and remove the core from slice. As the blades retract, slice if stuck inside the blade is struck by the circular strap and forced out of the blades. Similarly core inside the blade is forced out due to spring loaded lid (Figure 4.16).

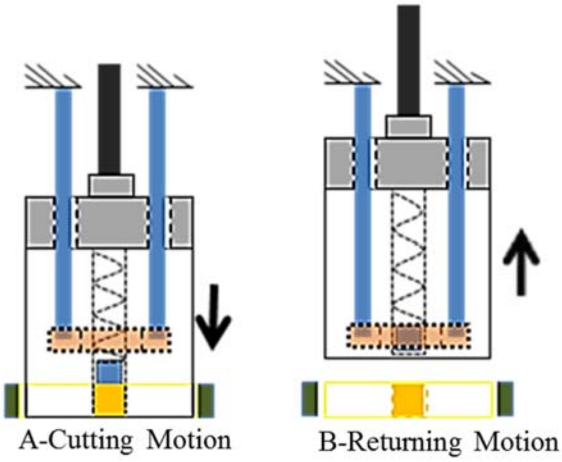


Figure 4. 16 Motion of the components during operation

After visualizing the components in operations, the proof of concept was developed using some parts of the existing old machinery.

4.10.3 Proof of concept of pineapple slice peeling machine

The 3D model was tried to be fabricated to see if it functions properly and visualize how the machine look roughly would be (Figure 4.17).

Figure 4. 17 Proof of concept of pineapple slice peeling machine

But this machine also had certain shortcomings which required to be improved.

- Machine was a bit bulky and there was good scope for material reduction
- Construction was not so simple
- Changing of blades was still difficult and time taking
- Cleaning was not so easy and fast.
- It might not effectively cater to different needs of the users.

So, further refinement and improvement of concept was required. The concept where the fruit is to be pressed on the blade was tried.

4.10.4 Refinement of the concept

To overcome the shortcoming of the peeling machine was to be further simplified. So the mechanism was divided in two parts

- The pressing mechanism
- The easily replaceable blade accessories to cater to different requirements

Hence, ideas were generated as to find out the ways the purpose can be achieved (Figure 4.18).

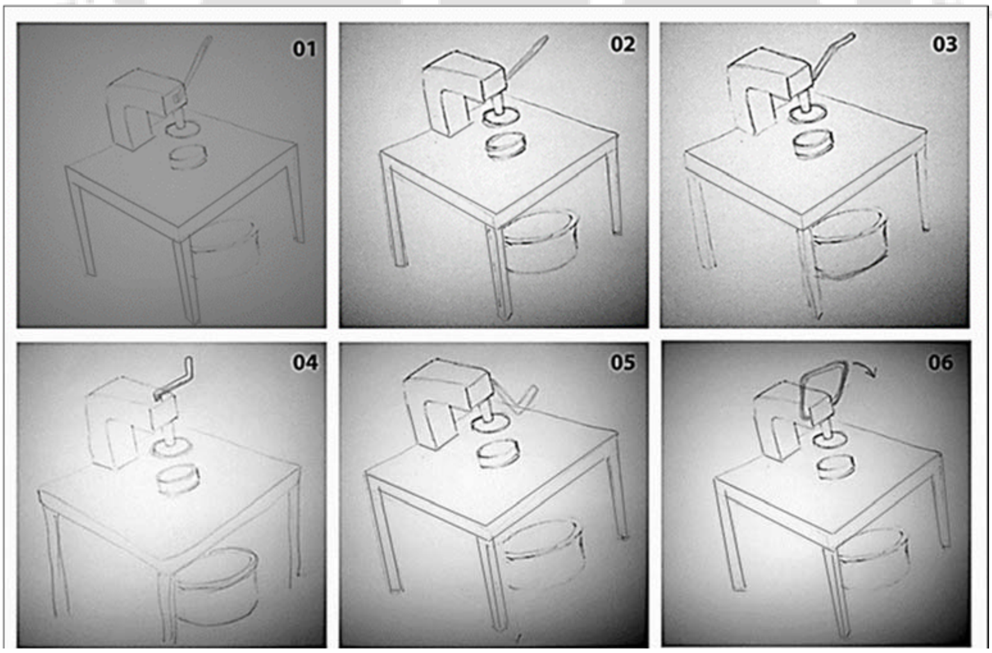


Figure 4. 18 Peeling solutions with different handle arrangements for operations

There were some existing mechanisms for pressing which were similar to "concept 2" (pressing mechanism similar to that of vertical motion of drill machine). So, with the base of pressing mechanism of bottle capping machine, the proof of concept was tried to be developed. 3-D model of the concept was made with modifications and integrations to visualize the concept in details. During problem analysis phase, it was seen that there were different output requirements of the units i.e. roughly peeled chopped pineapple for pulping and juicing, finely peeled pineapple for slice canning, requirement for both roughly and finely peeled output. The 3-D visualization of the machine was done along with its different blade accessories to meet different requirements. 3-D model of the machine and the working principle with each blade accessories have been presented in Fig.4.19.

a. Equipment with accessories for rough peeling and chopping

The model shows the arrangement of the blade for peeling and chopping. The slice had to be placed above the blades and pressed with the ram of the pressing mechanism. This peels the pineapple and divides it into four parts which falls down and collected in a container while the separated peels remain on the table itself (Figure 4.19). Considering the general diameter of the fruit studied earlier, easily changeable circular blades are provided in diameter of 90 mm, 94 mm and 96 mm.

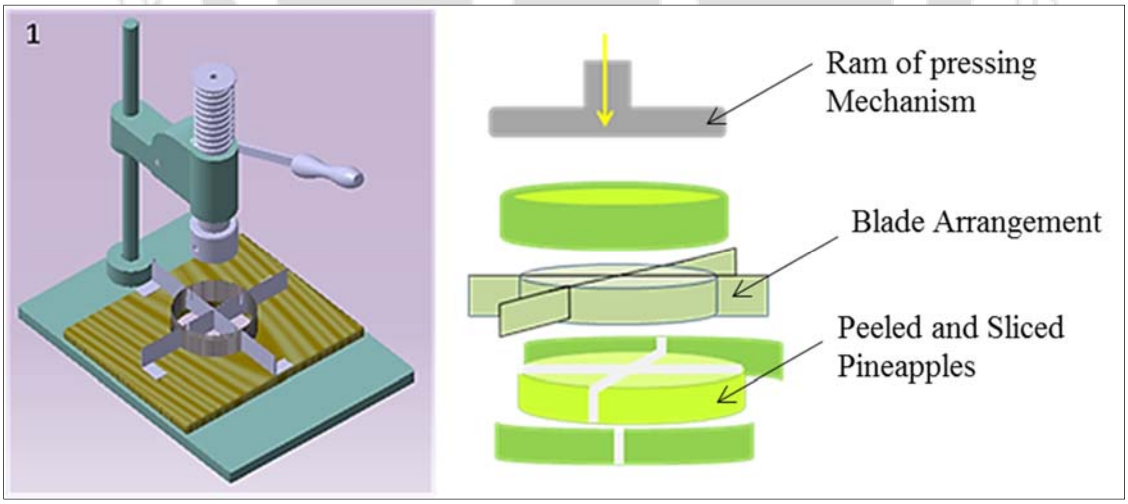


Figure 4. 19 Visualisation and working principle of the equipment for rough peeling and chopping

b. Equipment with accessories for rough peeling without chopping

The model shows the arrangement of the blade for peeling. The slice had to be placed above the blades and pressed with the ram of the pressing mechanism. This peels the pineapple without dividing which falls down and collected in a container while the separated peels remain on the table itself (Figure 4.20). Considering the general diameter of the fruit studied earlier, easily changeable circular blades are provided in diameter of 90 mm, 94 mm and 96 mm.

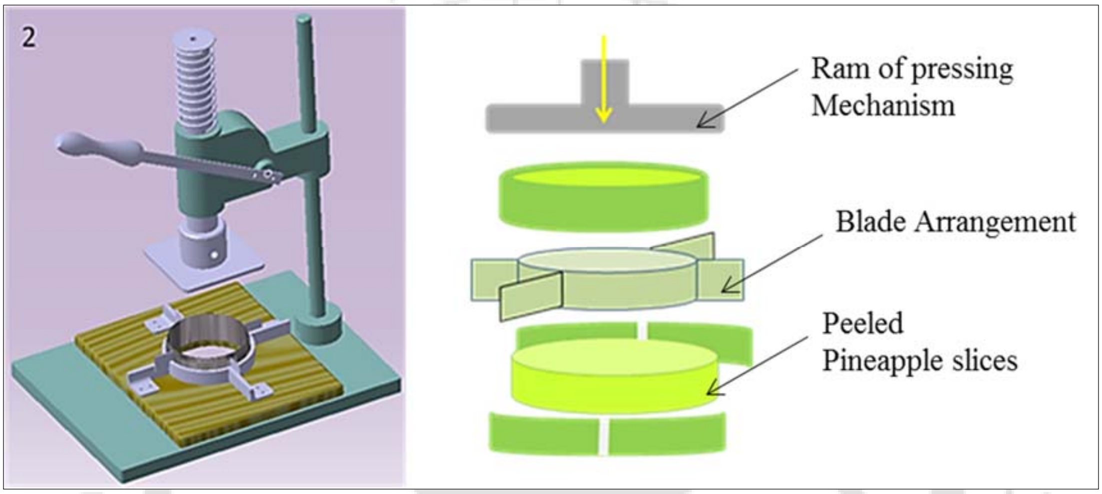


Figure 4.20 3-D visualisation and working principle of the equipment for rough peeling

c. Equipment with accessories for second peeling and core removing

The model shows the arrangement of the blade for second peeling and core removing. The slice as to be placed below the blades. The blade is pressed through the lever. The outer blade removes a layer from the roughly peeled slice and the inner blade removes the core simultaneously. A manual stripper or pusher is providing to ensure that the peeled slice is not stuck inside. Whereas the trapezoidal open shape of inner blade assures core part is not stuck inside the inner blade (Figure 4.21). The circular blade is off only one diameter (80- 85mm) for uniform diameter of the slices to be canned. The leftover after second peel can be used for juice extraction.

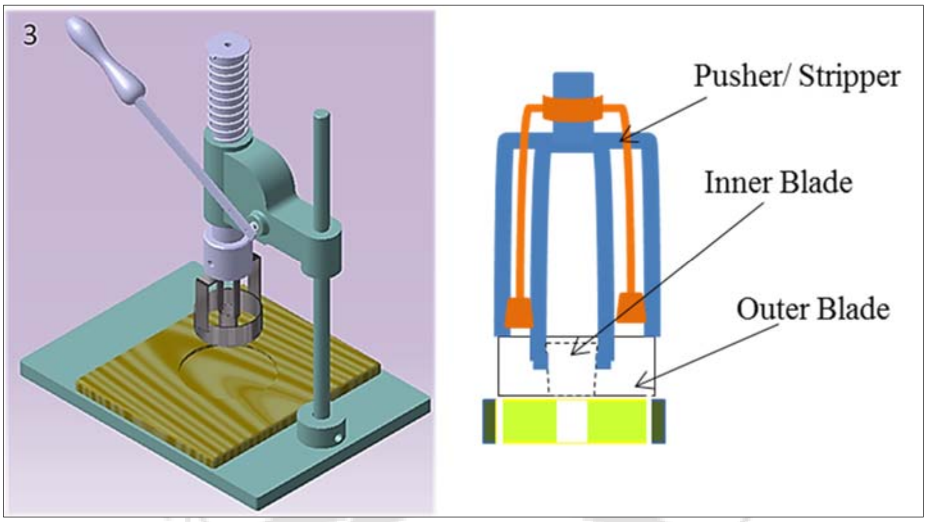


Figure 4. 21 3-D visualisation and working principle of the equipment for rough peeling

After visualizing the combinations of accessories to fulfil different requirements, the proof of concept was developed.

4.10.5 Proof of concept of peeling Solution

After visualizing the 3D model, the proof of concept was made and tested. Since, at most of the places items are prepared from extracted juice and for juice extraction roughly peeled pineapples are used, the equipment with accessories for rough peeling and chopping was selected for development. The proof of concept was found to be functionally effective. It was fast and easy to operate as well as less bulky visually and required lesser material. It had simple push down lever mechanism which was spring loaded to send the lever back to initial position after every peeling stroke (Figure 4.22).

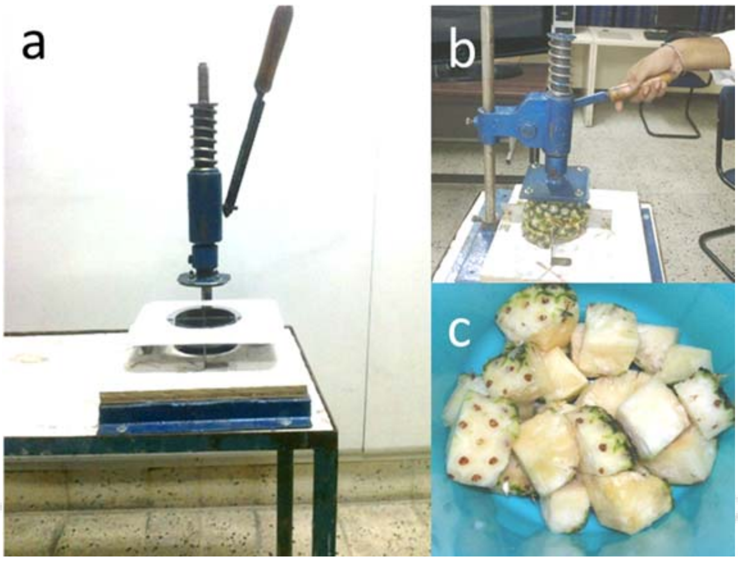


Figure 4. 22 Proof of concept: a- Assembly, b- Working and c- Output

4.11 Critical dimensions of the Pressing Mechanism

Though the proof of concept was functional, it had certain limitations like dimensional considerations which had to be considered in the final product. One such critical decision is regarding how much should the lever be rotated to cut peel the fruit comfortably. For this pitch diameter of the pinion had to be decided. This diameter also decides the dimension of casted casing of the equipment.

4.11.1 Pitch radius of the Pinion

If similar type of pressing mechanism is used in the final machine, then vertical displacement of the press had to be looked into. The pressing job in the setup is done through Rack and Pinion type of arrangement. In the present setup, for the comfort of the workers, the lever should not have more than 60° rotation (Figure 4.23).

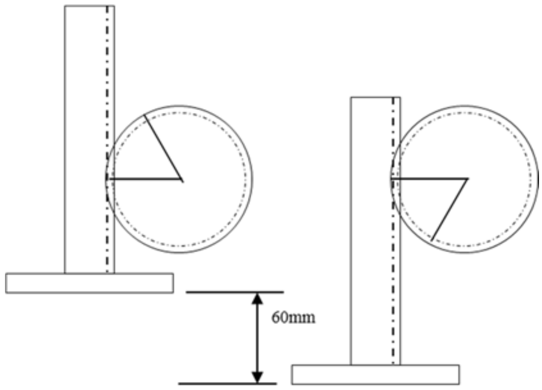


Figure 4. 23 Displacement required for 60° rotation of pinion

Therefore,

60mm=2πR/6

R= 60x6/ 2π = 57.29 ≈ 60 mm.

Since required dimension of the pinion is similar to the existing equipment and it is a critical in determining the dimension of pressing mechanism, the dimension of final peeling mechanism is similar.

4.11.2 Dimensional modification of the handle for better operation

Since pressing with straight handle was difficult in the peeling equipment, the handle was modified to reduce stress on the hand while operation (Figure .24).

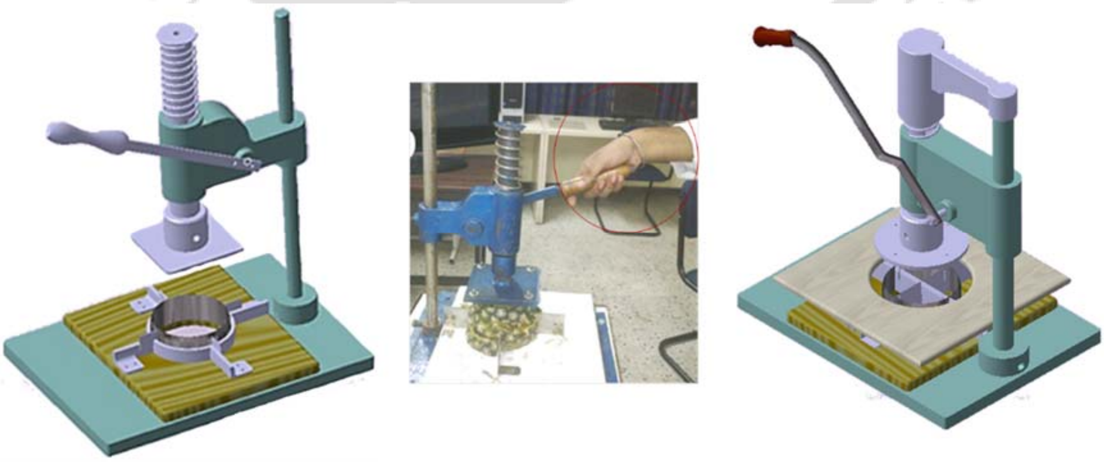


Figure 4. 24 Modification of handle to reduce stress

4.12 Concept generation and realization of pineapple slicing machine

In addition to pineapple peeling equipment, an effort was also made to develop a slicing machine which could be help especially in units where canning is done. The old / traditional solutions for slicing are either by knife or through a machine which had several issues

- Rejection is significant as fruit had tendency of getting tilted during operation
- The fruit is ejected out often
- The operation is noisy
- The machine is not very safe
- It took several iteration for slicing one full pineapple
- The operation is fully power dependent

Hence these problems were tried to be solved through a new pineapple slicing machine.

4.12.1 Ideation for design of pineapple slicing machine

While designing the peeling machine, a slicing machine, which could help to get uniform size slices, was also thought of. Since there were some units where pineapple slicing was also done, this could especially help them. To have the benefit of high productivity without interrupting the work during power crisis we tried to make a solution which might have dual mode. There are different ways of slicing pineapple in uniform sizes with some of them as following:

- Slicing the pineapple with single blade
- Slicing the pineapple with multiple blade
- Rotating and moving the blade around the stationary fruit
- Rotating and moving the fruit towards the stationary blade

Hence, ideation for the pineapple slicing machine was done to figure out different possibilities (Figure 4.25).

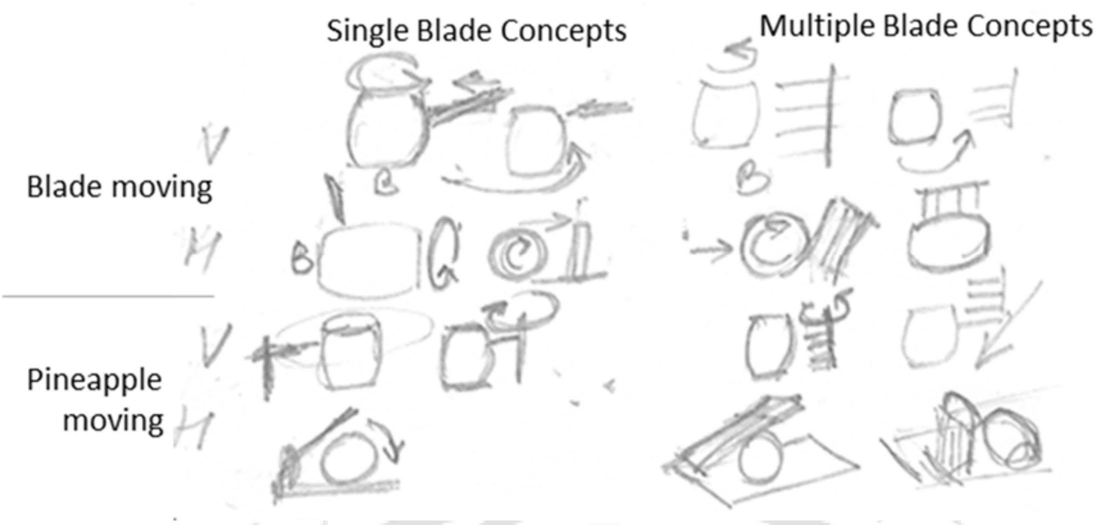


Figure 4.25 Ideation for pineapple slicing machine

Out these initial ideas, the idea of multiple blades was chosen on the criteria that it could

- slice the whole pineapple in one go
- had simple mechanism

On the basis of this idea, concept was further worked upon and evolved (Figure 4.26).

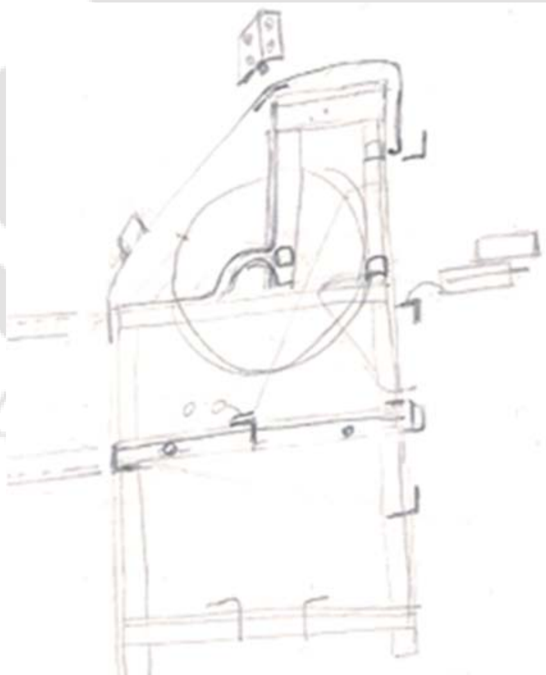


Figure 4. 26 Concept detailing for better visualisation

Since we could not find any existing similar set up which could be worked upon and modified, tried to design the machine from the beginning.

4.12.2 Determining the height of slicing machine and 3D modelling

Since the manual handle was to place on the periphery of the bigger wheel, hands reach was ascertained for scaled model of 50th percentile human manikin. Accordingly, dimension of machine frame is determined. Since, the reach is acceptable for 50th percentile human manikin it would be fine for higher percentile population as the hand length will be longer; increase proportionally with height (Figure 4.27).

Figure 4.27 Deciding the optimum height of the slicing machine

The concept was then visualized using 3D modelling. The model showed the clearly where the fruit had to be placed and where it would fall after being cut (Figure 4.28).

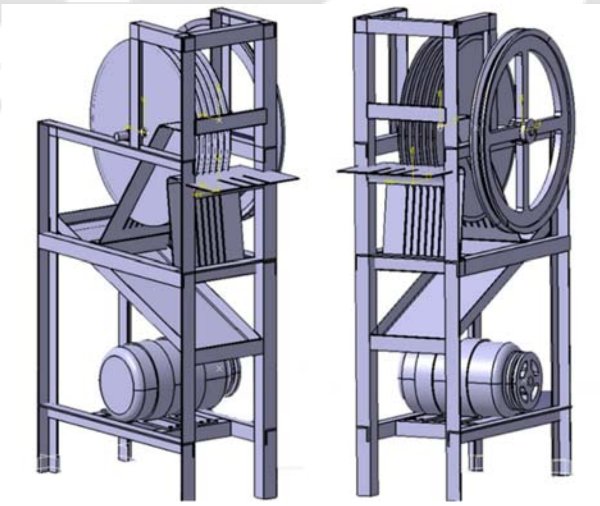


Figure 4.28 3-D visualisation of the slicing machine from different perspetive

The feeding was assumed to be done using an external pusher. Since the machine had to be operated with power, different critical components of the machine were required to be designed.

4.12.3 Design and selection of the critical parts

Since machine involved motorized power some of the critical parts required to be designed.

Selection of motor

For selecting the motor, we need to know the required "revolution per minute (rpm)" and what power rating we require. Power is determined by

$P = \tau . \omega$

Where P is power

τ is torque

ω is angular velocity

Through experiments we could determine the optimum speed for the blade. At 200 rpm the slicing was found to be smooth without jerk (Figure 4.29).

Figure 4.29 Determination of optimum slicing speed

But the force require for cutting the fruit could not be determine as every fruit varies in its strong, juiciness and fiber content . So the power can't be calculated directly through the formula. Here we assumed that since the blades are used to cut a fruit, 1 HP rating motor would be sufficient. Due to unavailability of 1 HP motor, 1.5 HP motor was selected.

a. Selection of blade

The proper material of the blade had to be stainless steel of Grade 316. Since the full pineapple had to be cut from the rotating blade, the radius of the blade had to be larger than diameter of the pineapple. It had been seen that the diameter of the pineapple are around 120 mm, considering the spacer width and other clearance, we decided to have blade of radius 225mm. the weight of each blade was found to be 2 kg.

b. Selection of pulley and belt

For the electric drive, we opted to use V- belt for power transmission because slip during the power transmission is least for these belts. Moreover, it is compact and occupies less space.

For rating up to 1.5 HP (2 KW) and speed 750 rpm, Type A of V-belt is acceptable and for Type "A" belt, the width of the belt is 13mm, thickness is 8 mm and minimum pitch diameter is 125 mm (Rattan, 2005).

Therefore d=125mm

D = 125x750/200 = 470 mm

Where d = the pitch diameter of smaller pulley

D = the pitch diameter of the larger pulley

$L= 2C+ \pi (D+d) /2+ (D-d)^2/4C$

Where C = center distance between two pulleys

L = Pitch length of the belt

d = pitch diameter of smaller pulley

D = pitch diameter of the larger pulley

C= 600 mm (Figure 4.30)

$L= 2x600+ \pi x(125+470)/2+ (470-125)^2/4x600$

L= 2184.2 mm

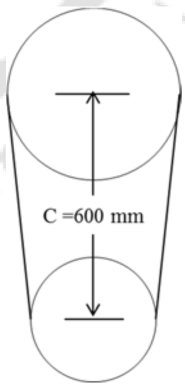


Figure 4.30 Centre distance between two pulleys

For Belt Type A, pitch length (L) - Inside length (Li)= 36mm

Therefore, L_i = L- 36= 2184.2- 36= 2148.2 mm

The standard size of the belt nearest to 2148.2 mm, is taken Li= 2159mm

Hence the selected belt is A2159: V Belt

F_l = Correction factor for belt length = 1.05

F_a= Correction factor for industrial service=1.1

α_s= angle of wrap for smaller pulley= 180- 2Sin^{-1}(D-d)/2C

where C = center distance between two pulleys

α_s= 180-2Sin^{-1}(345/1200)= 146.58°

F_d= Belt pitch length correction factor= 1.16

Equivalent pitch diameter – 125x1.16= 145 mm

No. of Belts= Transmission power x F_a/ KW rating of Belt x F_dxF_l

= 1.5 x 1.1/ (2x1.16x 0.9) = 0.79 ≈ 1

c. Design of shaft

Shaft is an important element of the machine over which cutting blades are mounted and to which power is transmitted through belt to rotate the blades.

P = Power rating= 1.5 KW=1500 W

r = radius of smaller pulley= d/2= 125/2 = 62.5mm

t = thickness of the belt= 8 mm

ω = angular velocity = 750 rpm

$v = \omega\,(r + t/2) = 2\pi n\,(r+t/2)/60 = 2\pi \times 750\,(62.5 + 4) = 5.22$ m/sec

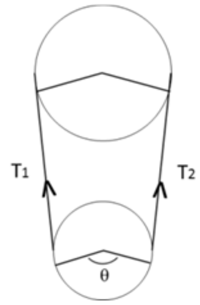


Figure 4.31
Tensions in two sides of the belt

$P = (T_1 - T_2)\,v$ (Figure 4.31)

$1500 = (T_1 - T_2)\,v = (T_1 - T_2) \times 5.22$

$(T_1 - T_2) = 287.36$ N …. 1

$T_1/T_2 = e^{\mu\theta}$

Where μ=Friction coefficient

θ= wrapping angle= $\pi - 2\sin^{-1}(345/1200) = 2.558$ rad

$T_1/T_2 = e^{2.558 \times 0.22} = 1.76$ …. 2

$T_1 = 1.76\,T_2$

On solving 1 and 2 , we get T_2= 378.1 N and T_1= 665.46N

$(T_1 + T_2) = 1046$ N …… 3

Now, Weight of each blade= 2 kg

Force due to each blade = mg = 2x 9.8= 19.6 N

Torsional moment= $M_t = 60 \times 10^6 \times P/(2\pi N)$

Where P= power rating

N= velocity of the pulley

$M_t = 60 \times 10^6 \times 1.5/(2\pi \times 200) = 71619.72$ N-mm

Equalizing the forces

$F_I + F_J = 1046 + (6 \times 19.6) = 1163.6$

$F_I + F_J = 1163.6$

Where F_I and F_J are the forces at bearing points "I" and "J" respectively

Taking moment about A (Figure 4.32)

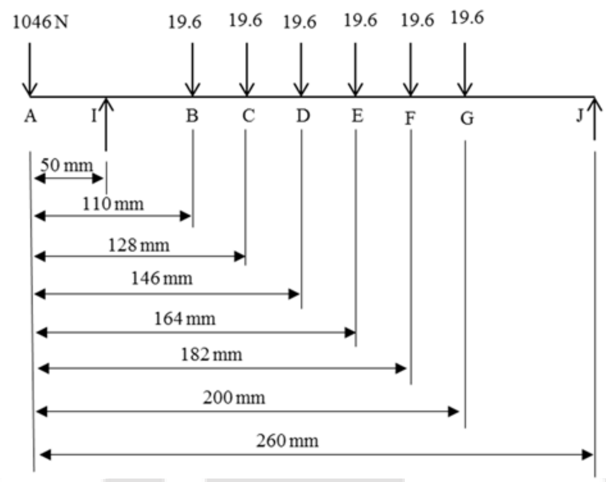


Figure 4.32 Forces at various points

$50F_I + 260F_J = 18228$

$F_I = -190.25$ N

and $F_J = 1353.84$ N

Since all the forces are in vertical plane, calculating the bending moment (Figure 4.33)

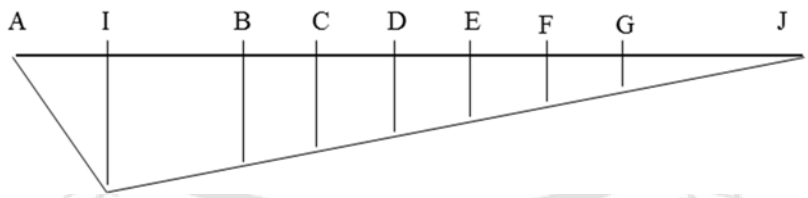


Figure 4.33 Bending Moment at various point

$M_{Av} = 0$

$M_{Iv} = 210 \times (-190.25) - 19.6\ (60 + 78 + 96 + 114 + 132 + 150)$

$= -52374$ N-mm

$M_{Bv} = 150 \times (-190.25) - 19.6\ (18 + 36 + 54 + 72 + 90)$

$= -32065.5$ N-mm

$M_{Cv} = 132 \times (-190.25) - 19.6\ (18 + 36 + 54 + 72)$

= -28641 N-mm

M_{Dv}= 114 x(-190.25) - 19.6 (18+ 36+ 54)

= -23805.3 N-mm

M_{Ev}= 96 x(-190.25) - 19.6 (18+ 36)

= -19322.4 N-mm

M_{Fv}= 78 x(-190.25) - 19.6 (18)

= -15192.3 N-mm

M_{Gv}= 60 x(-190.25)= -11415N-mm

M_{Jv}=0

Max Mb=52374 N-mm

Material available for shaft is En24

For En24, S_{ut}=1250 N/mm^2

S_{yt}=980 N/mm^2

0.3 S_{yt}= 0.3x 980= 294 N/mm^2

0.18 S_{ut}=0.18x1250 =225 N/mm^2

Lesser of the two is considered. Since the shaft has keys,

τ_{Max}=max. Torque= 0.75(225)= 168.75 N/mm^2

$d^3= 16[\sqrt{(K_b. M_b)^2+ (K_t. M_t)^2}]/\pi\ \tau_{Max}$

As the load is gradually applied,

Kb= Combined shock and fatigue factor for bending moment=1.5

Kt= Combined shock and fatigue factor for torsional moment=1

$d^3= 16[\sqrt{(1.5x52735)^2+ (71619.72)^2}]/\pi\ x168.75$

d = 14.75≈ 20 mm

d. Bearings Design

The estimated life of bearing for 8 hrs. work = 4000 -8000 hours (Bhandari, 2013).

Considering the distribution of force at the two bearing points (Figure 34)

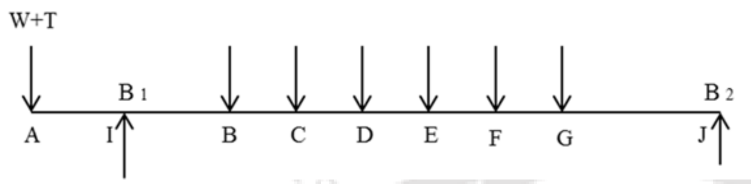


Figure 4.34 Force distribution at bearing points

Force at B_1 (F_I) = 1353.84 N

Force at B_2 (F_J) = -190.25 N

There is no axial thrust on the bearing as the bearing is subjected to purely radial load

So $F_{a1}= F_{a2}=0$

In case purely radial load

X=1, Y=0

P1=1353.84 N

P2= -190.25 N

$L=60n\ L_h/10^6=60\text{x } 200\text{x}8000/10^6$

L= 360 million rev.

$L=(C/P)^3$

$C= PL^{1/3}\text{x (Load factor)}$

$C1= 1353.84(360)^{1/3}\text{x}2=19261.85$ N

$C2= 190.25(360)^{1/3}\text{x}2=2706.8$ N

For C1= 19261.85 N and d=20 mm

Bearing 6404 (D= 72mm, d=20 mm, B=19 mm)

For C2=2706.8 N and d=20 mm

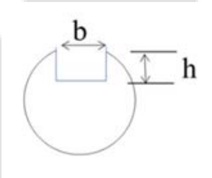
Bearing 1640 (D= 42mm, d=20 mm, B=8 mm)

Since force at C1 is higher, we select bearing 6404 which bears higher force.

e. Key design

The spacers which hold the blade tight and intact during rotating cutting motion and therefore they required to be keyed to the shaft strongly. The key suitable for this kind of rotating load is square key.

For square key



b = h = 0.25 d

Where b= width of the key

h= height of the key

d= diameter of the shaft

For d= 20 mm, b = 0.25 x 20 = 5 mm

For d= 25 mm, b = 0.25 x 25 = 6.25 ≈ 7 mm

Final dimensions of the Shaft with bearing positions

Material used for shaft= En24

D= 25cm

d= 20 mm

Nut = M 22 x 2

4.12.4 Proof of concept of pineapple slicing machine

After designing the critical parts, the proof of concept was generate to establish the functionality of the concept. The thicknesses of the slices were also seen to be uniform (Figure 4.35).

Figure 4. 35 Proof of concept of the slicing Machine; a- Assembly, b- Working, c- Output

The proof of concept had made partial success as only motorized mode had been worked upon till now. The concept could be further evolved to ensure efficient operations and incorporate both electric and manual modes.

4.13 Cost determinations

Determining the cost of the equipment is an important step as it is a major criteria on which the entrepreneurs decide if the solutions is to be purchased or not. Hence, we determined the cost of peeling machine as well as the slicing machine considering various finance related aspects.

4.13.1 Cost considerations for peeling machine

The cost estimation embraces various aspects like

- The labor cost incurred on fabricating the product

- The marketing and transportation cost involved in dissemination of the solution
- Profit margin of the manufacturer
- Other fixed and running cost raw material cost, rents, taxes, etc. related to the establishment

Since the proof of concept of peeling machine fabricated by a vendor, it does not give a detailed breakage in different cost heads. Instead a lump sum price was quoted which embraced all charges. The amount charged by the vendors was as following:

- Fabrication of press mechanism, square cut base, all accessories, bush fittings, drillings, rotating mechanism etc. cost approx. 3500/- for the first prototype(including packaging)
- Blade fabrication including material some of steel and some of mild steel, turning, rimming operation, milling of slots, polishing, sharpening of edge, bending, spot welding, drilling, etc. cost approx. 1500/- for the first prototype

The total comes around 5000/- which includes their profit margin of vendors as well. The cost would further reduce if there is a mass production of such equipment.

On the contrary, since the above mentioned cost is one for making the proof of concept, there might be a slight increase in the cost of final design. Hence, keeping in mind, the costs incurred from different perspectives i.e. fabrication, marketing, transportation, etc., the estimated price for the final equipment could be approximately around Rs. 8,000- 10,000.

4.13.2 Cost of slicing machine

Being semi-automated, the slicing machine had larger number of components which include motor, belt, pulleys, bearings, moving blade, iron frame, etc. and thus the cost is also significantly higher.

The cost mainly compromises of the following:

- Cost of materials which is purchased and assembled or fabricated
- Cost of labor incurred in fabricating and assembly
- Cost of marketing shipment and installation of the machine

- Other fixed and running cost raw material cost, rents, taxes, etc. related to the establishment

Fabricating the proof of concept gives a fair idea of the different costs and expenses. The major cost is incurred on the materials and components including costly blades, motor and accessories, frame, bearing, belt and pulleys roughly summing up to Rs. 35,000. Then there were charges incurred on fabrication which might be fairly around Rs. 5,000. Hence, keeping in mind, the costs incurred from different perspectives and a reasonable profit margin the cost one unit might be quoted approximately at Rs. 50,000. Though the price might reduce if there is a demand and mass production of such equipment.

4.14 Task visualization of using solutions in the system

After testing the proof of concept, an effort was made to see how the solution would be inducted in the present system in context.

4.14.1 Use scenario for small units without canning facilities

There are many small units which don't have canning facilities and they go manly juice extraction and the products made from extracted juice. So they just roughly peeled pineapples that can be pulped and the juice be filtered for further use. Also many small units face frequent power cuts. The following method would suit these types of scenarios. Here working can be divided in to three phases (Figure 4.36).

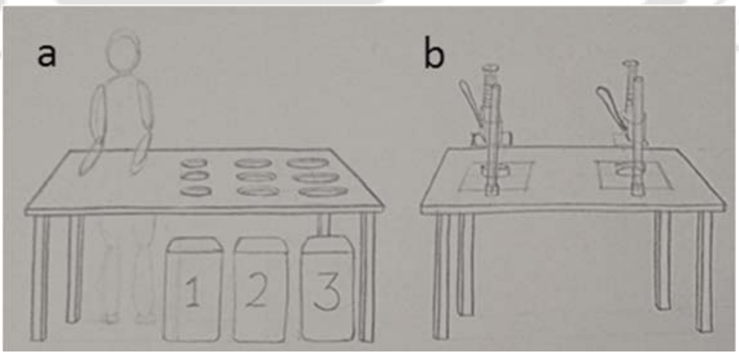


Figure 4.36 Operation at small units for rough peeling; a- Slicing pineapple and collecting it in different bins, b-peeling with different diameter blade

The steps to be taken are in the following sequence.

- Slicing the pineapple in 3-4 slices depending upon length of the pineapple using knife
- Separating pineapple slices using table with multiple holes of different sizes
- Rough peeling and chopping using different diameter blades to reduce wastage

This roughly peeled output can be used to extract juice from which all the impurities can be removed by filtering.

4.14.2 In case of small units with canning facilities

Here the juice can be extracted through rough peeling and chopping as explained earlier. In addition for slice making following steps can be taken to ensure that slices are obtained with lesser wastage. The steps are explained in Figure 4.37.

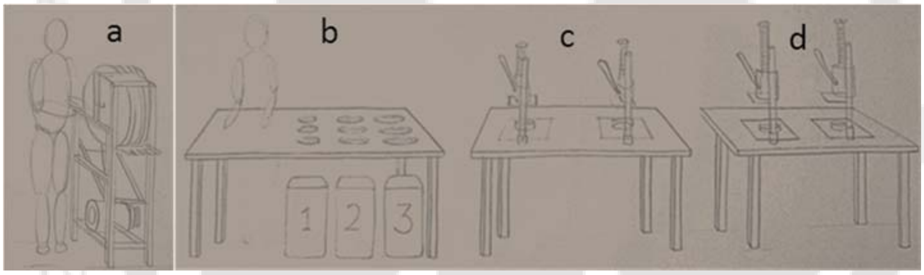


Figure 4.37 Use scenario in pineapple canning units; a- uniform slicing, b- sorting as per sizes, c- First peeling and d- Second peeling and coring

- The fruit can be sliced into uniform thickness slices using the slicing machine
- The slices can then be Separated using table with multiple holes of different sizes
- The slice, according to its sizes can peeled roughly intact without chopping

- This roughly peeled intact slice shall be peeled using another accessory that removes the peels and eyes which are left during rough peeling as well remove the core from the slice. The leftover after the second peel can be utilized for juice extraction and the peeled slices can be used for canning.

4.15 Conclusion

The requirements as well as solutions meant for capital intensive industries found mainly in advanced countries might not be suitable to the labor intensive context of the industrially developing countries. Thus, a holistic system approach was used to gather requirements for addressing their work related issues pertaining to pineapple peeling. A support tool was proposed and used to decide upon most appropriate solution category for the given context. The solutions were conceptualized, screened during the preliminary selection and consequently selected few solutions that was evolved and detailed and developed in an iterative way for a better solution. The following chapter evaluates the design on the same key requirements which had been considered during the design from users' point of view as well as buyers' point of view.

Chapter 5

EVALUATION AND RESULTS

Chapter 5

EVALUATION AND RESULTS

5.1 Introduction

The chapter elaborates on different assessments carried out as a part of the process during design and development of pineapple peeling equipment to establish its efficacy. During equipment design process, a series of evaluations were done at various stages. Also, a method was proposed for determining broader solution category which would be suitable for larger number of local entrepreneurs. The chapter also discusses validation of that tool. Different evaluations have been depicted in form of flow chart in the Figure 5.01.

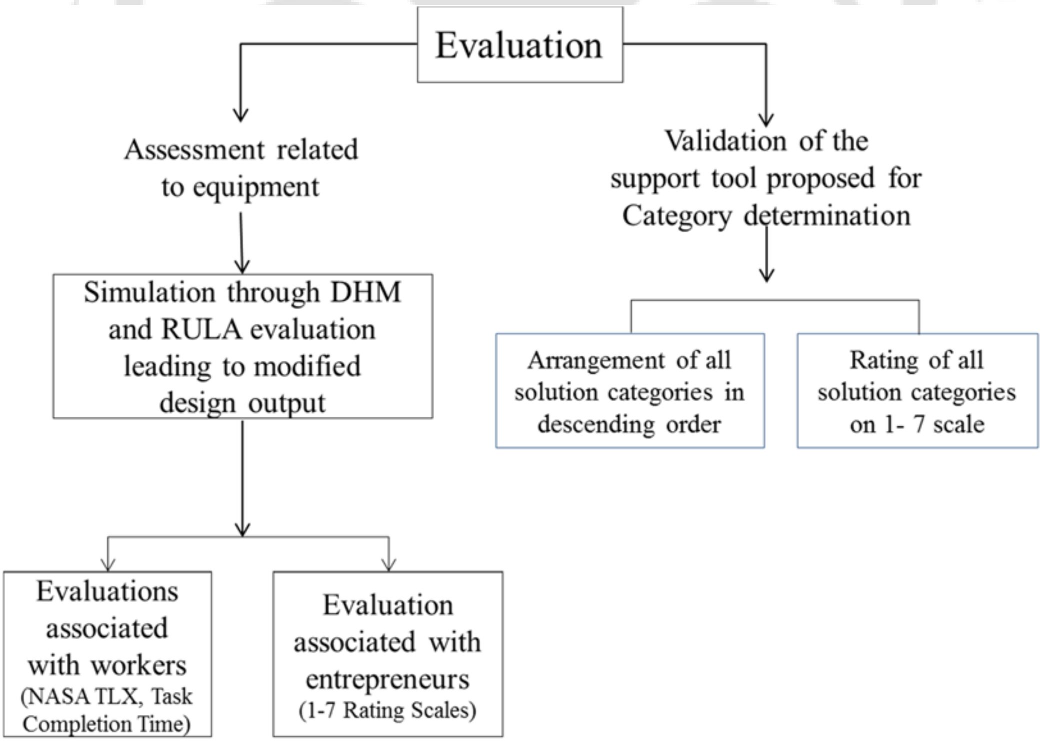


Figure 5.01 Summary of the evaluations of Equipment and Evaluation of proposed tool

At first, virtual simulation was carried out using Digital Human Modelling (DHM). RULA was performed on different percentile male and female manikins to virtually assess the level of ergonomic risk at critical positions like initial and final operating positions. The design had been accordingly modified and improved upon wherever necessary. This improved version was then assessed by the workers (users) as well as the entrepreneurs (buyers). For workers engaged in pineapple peeling, the evaluation was carried out by directing the workers to use the equipment and give their feedback through ratings on NASA TLX questionnaire (*Appendix 5*). For better understanding correct feedback, the questionnaire was also translated into *Hindi*. Simultaneously, task completion time (TCT) was observed and noted. For entrepreneurs, a comparative analysis of new and old peeling technique/solutions was done through buyers' ratings of the two solutions with respect to the key requirements. The two rating were then compared using T-Test (for normally distributed data) as well Mann Whitney U- test (for data not distributed normally). During the design process, a support tool was used to determine the most appropriate solution category for the given context out of different available categories of available solutions. An effort was also made to establish if category of solution suggested by the proposed tool as "most suitable solution category" matched with the preferences of the entrepreneurs who are the actual buyers and implementers of the new solutions.

5.2 Risk assessment of task through virtual simulation

After the design intervention had been tested for its functionality in principle, it was tested for its effectiveness in reducing of ergonomic risk associated with peeling task. But, before the actual evaluating the ergonomic efficacy on workers performing the task with the new machine, a virtual simulation through Digital Human Modeling (DHM) was carried out to ascertain the associated risk level. Since the people in the region, under consideration, have slightly lesser height than general Indian population (Chakrabarti & Design, 1997), 50th and 90th percentile male (h= 1755 and 1841 mm) and female manikins (h= 1629 and 1710 mm) were considered for virtual assessment using RULA in CATIA V5. Since, the main interaction of the worker is for pressing the lever to perform peeling; the assessment was conducted for most critical positions their initial and final postures. But before proceeding for RULA, we needed to determine the force required to operate the new equipment as RULA scores are also dependent on force requirement for operating equipment.

5.2.1 Determination of force required for peeling operation using new equipment

Since RULA score is directly affected by muscle use score and force load score, if the force requirement or repetitiveness of job is greater, the score increases significantly. Thus, an effort was made to determine the force required to operate the peeling machine (Patel, Sanjog, Kumar, & Karmakar, 2014; Patel, Sanjog, Kumar, Karmakar, & Pradesh, 2013). For the force determination, a normal pineapple slice was pressed peeled over a weighing machine which measured the force needed to press peel the fruit (Figure 5.02).

Figure 5.02 Measurement of force required to press peel the pineapple slice

The length of effort arm is known and since, the pitch diameter of the pinion is known, we take it as the load arm (Figure 5.03).

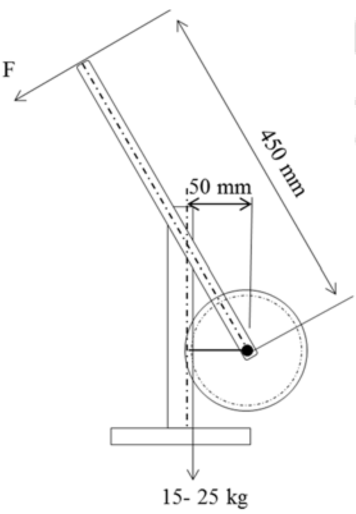


Figure 5.03 Force at load arm and effort arm

Load arm length = 50 mm

Effort arm length = 450 mm

Maximum force required for peeling the slice = 25 kg (approx.)

Effort required at lever end to generate cutting force = 25 x 50/ 450 = 2.7 kg (approx.)

Hence force required for the peeling operation at lever handle is more than 2 kg. After determining the force required by workers for operating the new equipment RULA was carried out for critical operating positions in a simulated environment using DHM.

5.2.2 RULA assessment using Digital Human Modelling (DHM)

After determining the force required by the workers to operate the equipment, the workers' postures at critical position was evaluated virtually using RULA. Digital human modelling (DHM) was carried out using software CATIA V5. The 3-D model of the solution was put together with the male and female mannequins and their postures were studied for the critical positions i.e. initial and final position. The inputs from this assessment was used to improve the solution virtually as well as in realization. The assessment was done for 50^{th} and 90^{th} percentile heighted male and female population. At first, the evaluation was done for 50^{th} percentile male and female workers (in terms of height) as shown in Figure 5.04. The RULA score was found to be of magnitude 6 suggesting for changes soon.

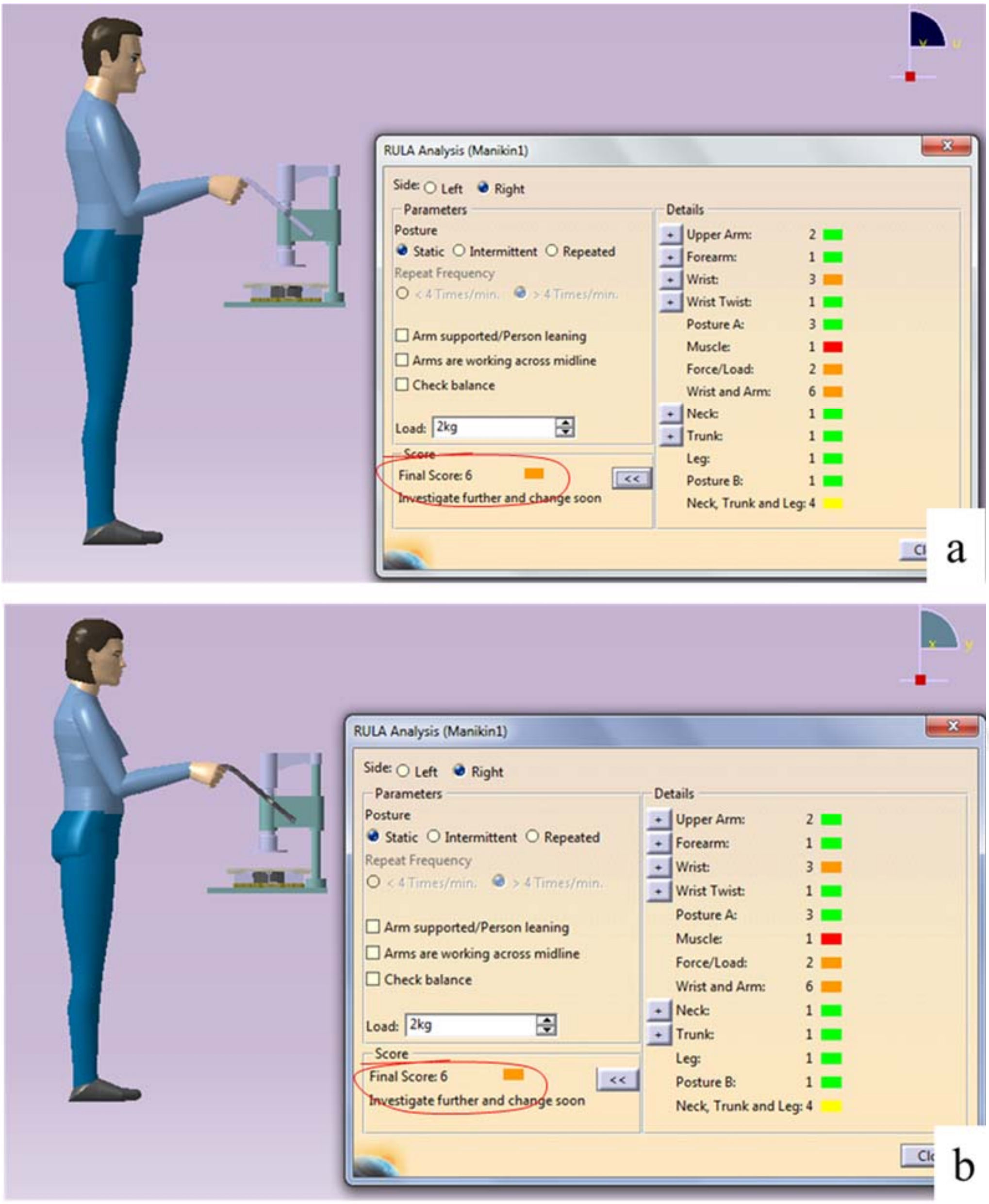


Figure 5.04 RULA for initial position; a- for 50th percentile male and b- 50th percentile female population

As compared to males, the table height (on which the equipment was fixed) for the female population had to be lowered for proper pressing.

RULA score for 90th percentile heighted male and female population for initial position is presented in Figure 5.05.

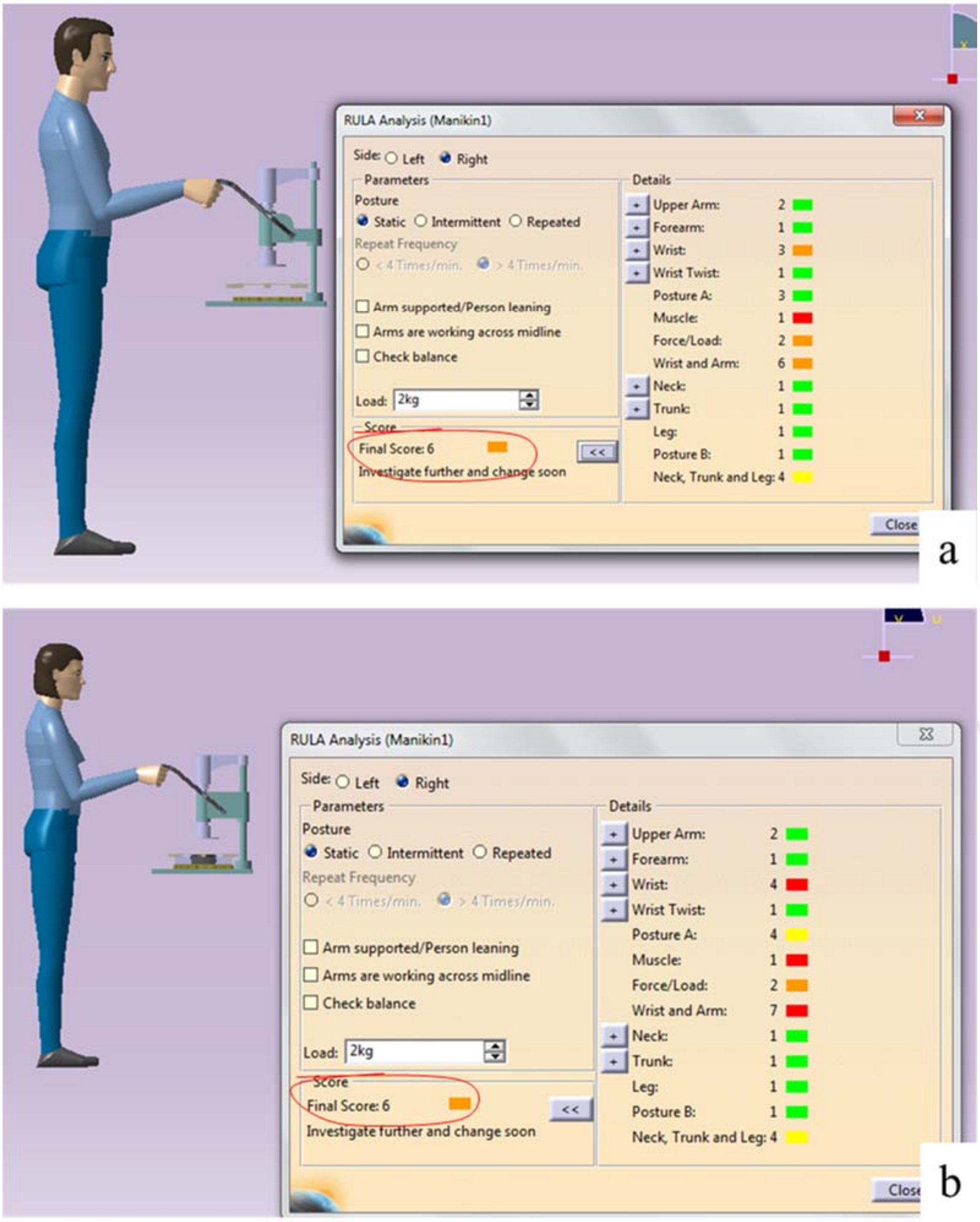


Figure 5.05 RULA for initial position; a- for 90th percentile male and b- 90th percentile female population

The table height had to adjusted and lowered for the female population. The posture was observed to be acceptable for initial position for both the 50th and 90th percentile height of male and female population but the magnitude of force was high which enhanced the grand RULA score to 6.

This was followed by evaluation was carried for the final position of peeling operation for both the 50th and 90th percentile male and female population as shown in Figure 5 and Figure 6.

The RULA score for 50th percentile male and female population for final position is shown in Figure 5.06.

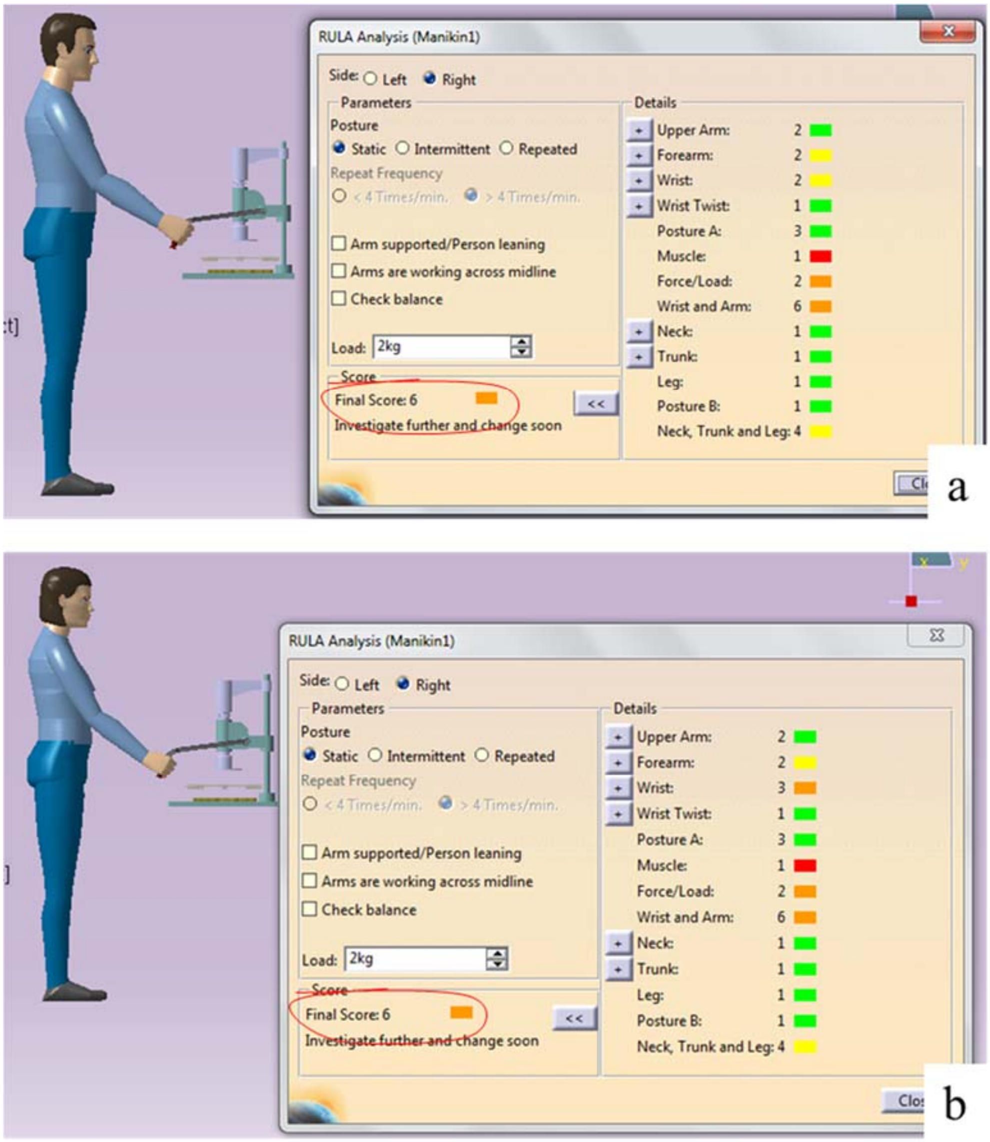


Figure 5.06 RULA for final position; a- for 50th percentile male and b- 50th percentile female population

For this position too, the table height of the equipment was required to be adjusted according to the gender of the population and because of the high magnitude of force, the final RULA score was found to be 6. Similar is the score for final position of 90th percentile height of male and female population with a RULA score of 6 as shown in figure 5.07.

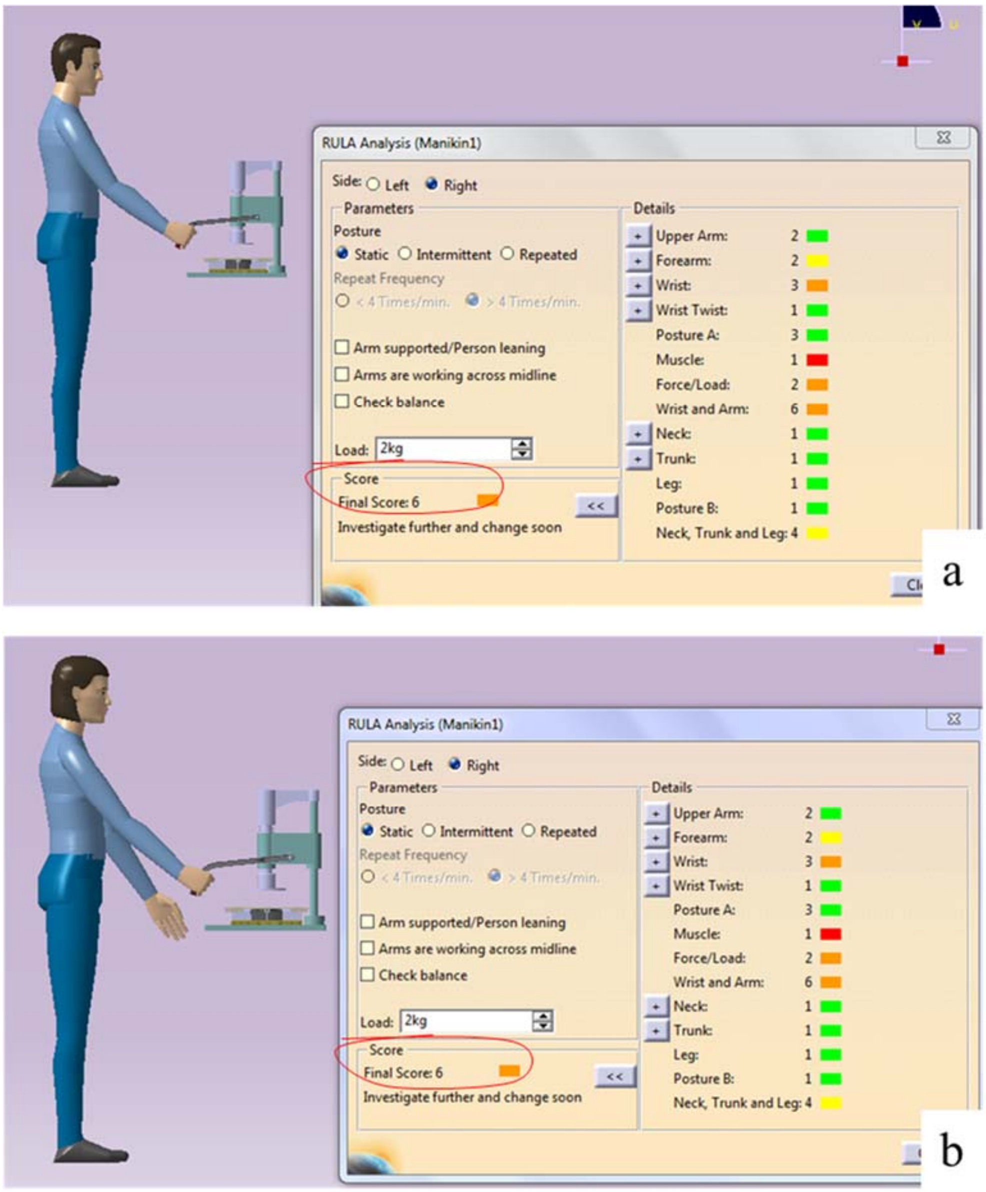


Figure 5.07 RULA for final position; a- for 90th percentile male and b- 90th percentile female population

5.2.3 *Findings of the assessment*

The final findings of the virtual simulation using DHM could be summarized as following:

- The RULA score for the postures, for 50th and 90th percentile heighted male and female population, were found to be acceptable (1 or 2) as far as individual body parts were concerned for both the initial and final positions.

- The wrist score was seen to be significantly higher (score 6) due to larger radial deviation.

- For both the initial and final positions the RULA scores were found to be higher (with grand score 6) in case of both male and female manikins of different percentile because the force requirement to peel the fruit by pressing lever was more than 2kg.

Hence, the force of operation was required to be reduced in order to bring down the level of ergonomic risk involved in the task. This can be effectively achieved by increasing the length of effort arm.

5.3 Modifications on the basis of virtual RULA assessment using DHM

In the present arrangement, the length lever arm was found to be 450 mm and the corresponding force requirement for the peeling operation was 2.7 kg. For reducing the force requirement to a magnitude lesser than 2 kg, length of the effort arm i.e. length of lever had to be extended. Since, magnitude force requirement is inversely proportional to length of the effort arm,

Optimum length of effort arm =

Present Force requirement x Present length/ Max. Permissible force

Present Force requirement = 2.7 kg

Present length = 450 mm

Max permissible force = 2 Kg

Optimum length of the effort arm = 2.7 x 450/ 2 = 607.5 mm ≈ 610 mm

Thus, the effort arm was extended by 610mm to reduce the effort. As the peeling operation, with extended length and present position of the lever, was difficult, its orientation was changed to have easier work posture during operations. In the new arrangement, the lever required to be horizontally pulled instead of pressing it down in an awkward posture. Since, one hand was engaged in operating the lever and other for placing the fruit in precise position over the blade, one of the arrangements was that lever would be operating by left hand and right hand would be engaged in placing the fruit. The other arrangement was vice versa. Though both the arrangements were possible in the equipment, the evaluation was done with the former. The assessment was carried out and the RULA evaluation was done for initial and final position.

5.4 RULA assessment with modified lever using DHM

At first assessment was carried for the initial position for male and female population with 50^{th} percentile height (Figure 5.08).

Figure 5.08 RULA for initial position; a- for 50th percentile male and b- 50th percentile female population

The final RULA score was reduced to 4 for initial position for 50^{th} percentile height of male (Figure 5.8 a) and female population (Figure 5.8 b) with small adjustment of the table height for different genders. Similar assessment was carried out for 90^{th} percentile male and female population (Figure 5.09).

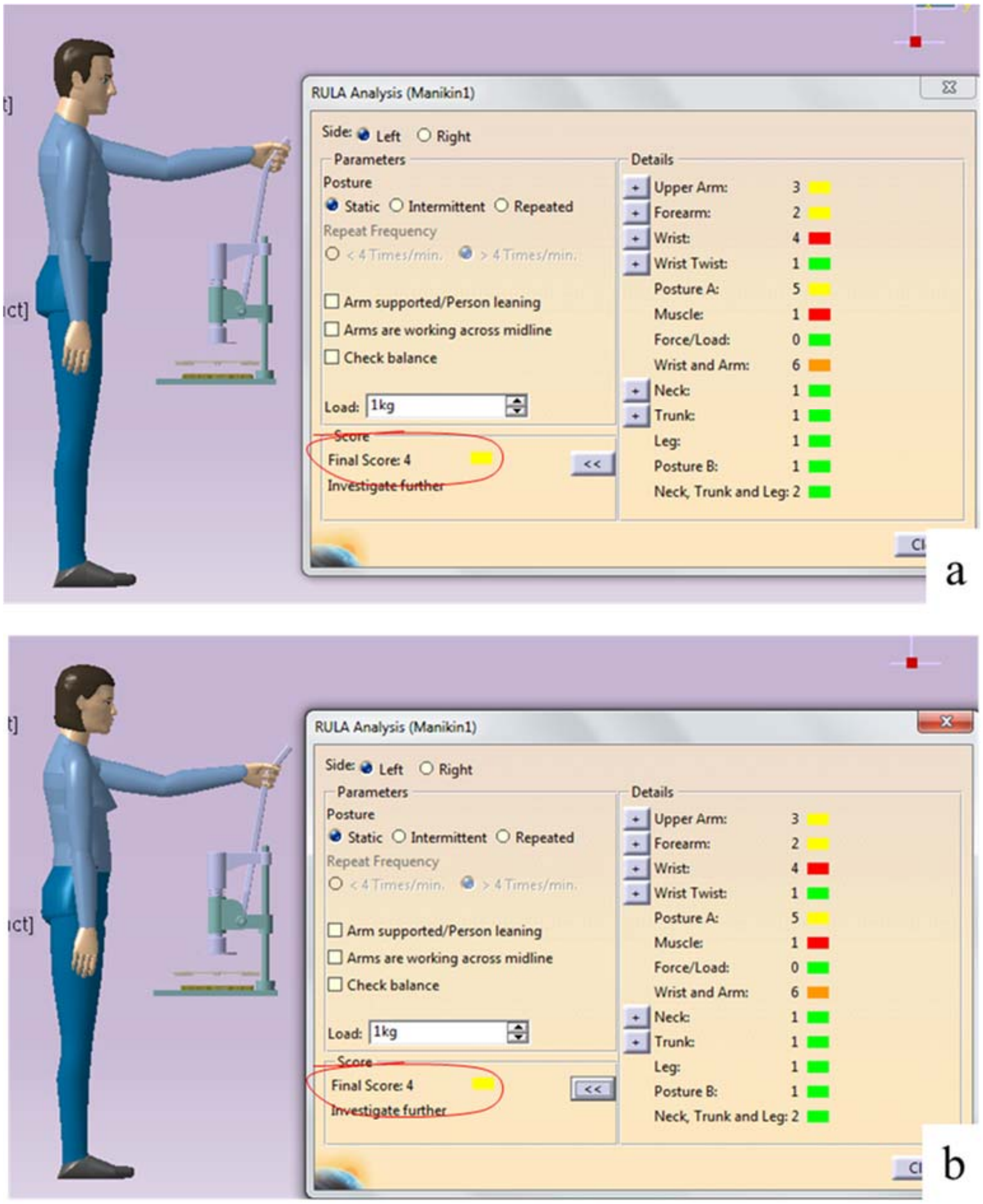


Figure 5.09 RULA for initial position; a- for 90th percentile male and b- 90th percentile female population

The final RULA score was reduced to 4 limit for initial position for 90th percentile height of male (Figure 5.9a) and female population (Figure 5.9b) with small change in the holding point for different genders. Similarly, evaluation was done with 50th percentile male and female population for final position (Figure 5.10).

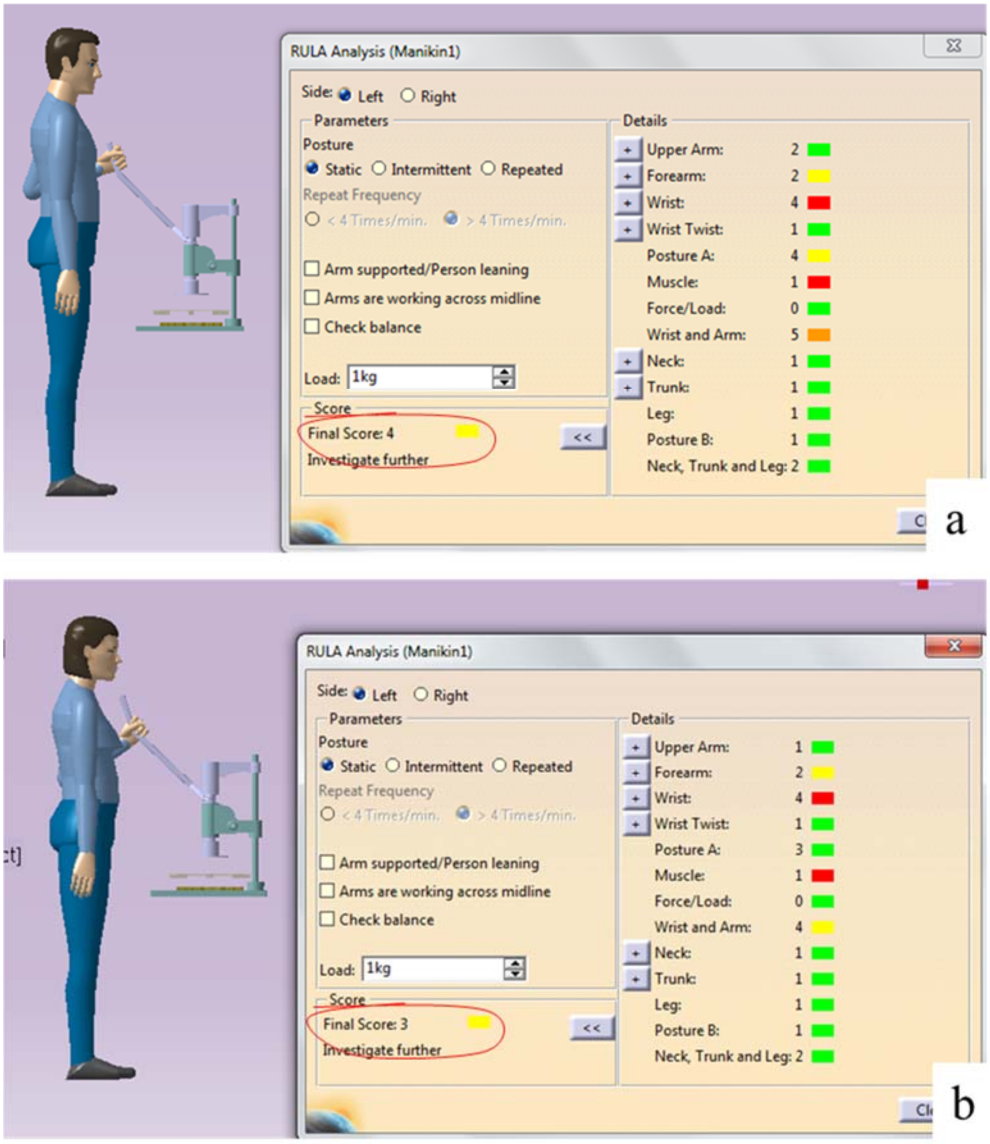


Figure 5.10 RULA for final position; a- for 50th percentile male and b- 50th percentile female population

The final RULA score was found reduced to 4 for final position for 50th percentile high male (Figure 5.10 a) and female population (Figure 5.10 b) with small change in the holding point for different genders.

This was followed by the assessment of male and female population with 90th percentile height for final position (Figure 5.11).

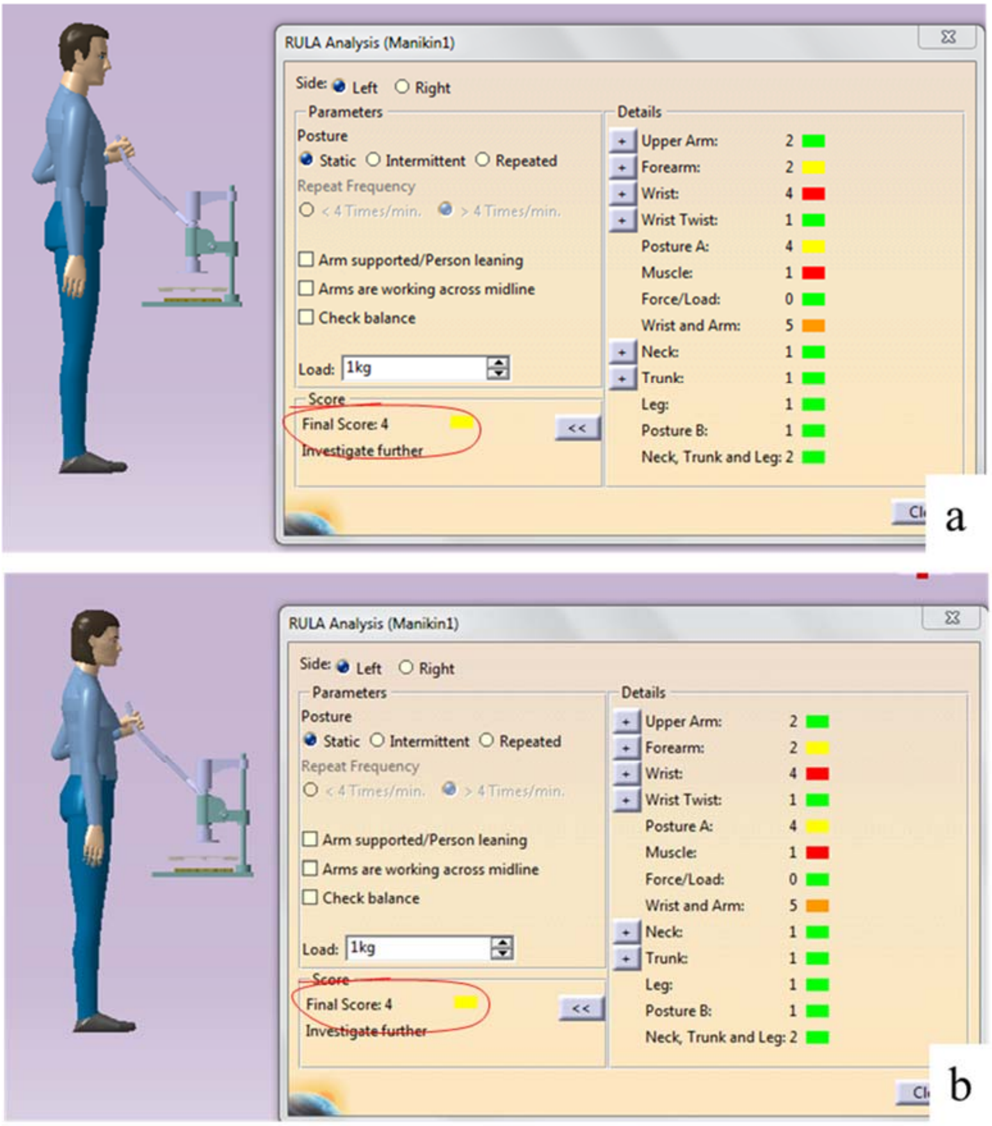


Figure 5.11 RULA for final position; a- for 90th percentile male and b- 90th percentile female population

The final RULA score was found reduced to 4 for final position for 90th percentile height of male (Figure 5.11 a) and female population (Figure 5.11b) with small change in the holding point for different genders.

Findings of assessment of the modified design:

- RULA score were found to be within the acceptable range for almost all individual body parts.

- For both the initial and final positions the RULA scores were found to be lower in case of male as well as female manikins of different percentile height because the force requirement to peel the fruit by pressing the lever was less than 2kg.
- It was seen that male and females, having lower percentile height, had different holding points on the lever.

Hence, the lever with an adjustable height could have served the purpose of different percentile male and female population.

5.5 *The modification on the basis of virtual assessment using DHM*

On the basis of virtual assessment of the new lever, new modified lever was provided to the equipment (Figure 5.12)

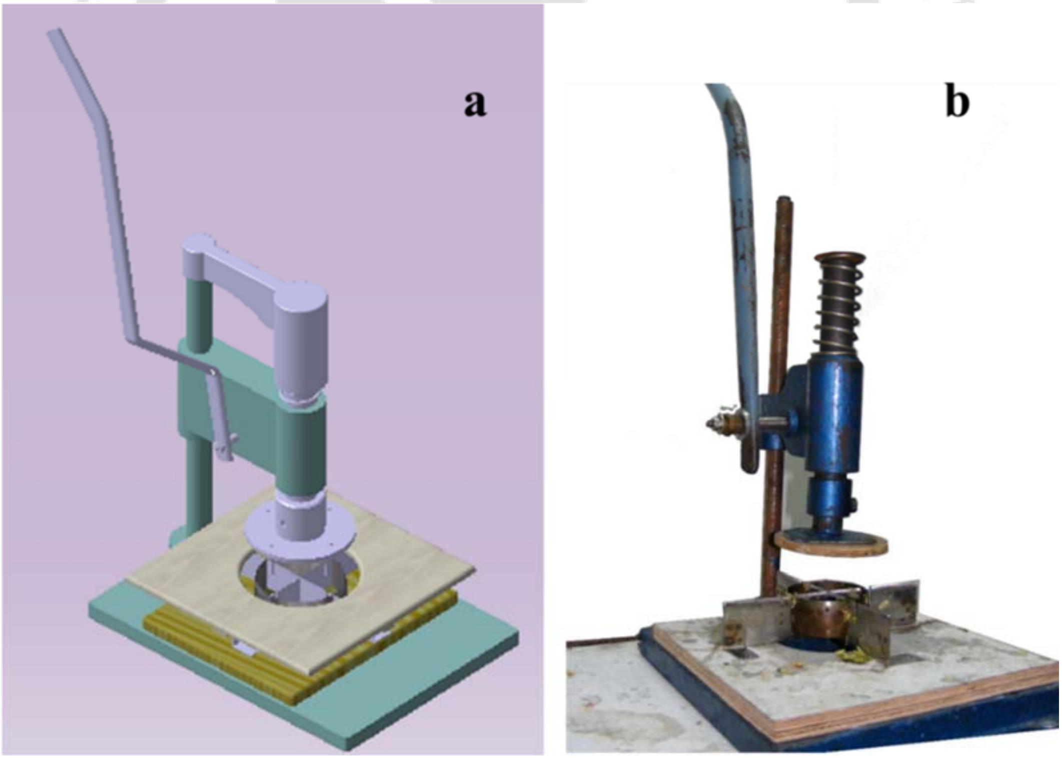


Figure 5.12 Realization of virtual modification in the equipment

This improved proof of concept was then evaluated for its performance by the workers who were asked to use the solution for peeling operation.

5.6 Performance evaluation involving workers

The performance evaluation of solution by participant workers was done objectively as well as subjectively (Figure 5.13). Objective assessment was accomplished through determination of Task completion time (TCT) whereas the subjective evaluation by the workers was done through ratings using NASA TLX (Task Load Index). For the better comprehension and precise response of the questionnaire, the questions were carefully translated in Hindi. The study was done on 11 participants and they were observed peeling pineapples using old/ traditional solutions i.e. knife, *Baithi*, etc. and new solution i.e. newly designed peeling equipment. The time was recorded and they were then told to give their subjective feedback using NASA TLX.

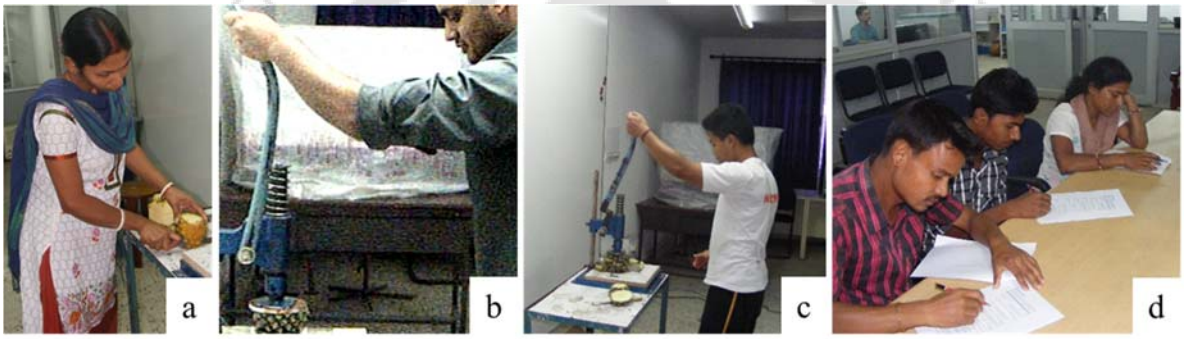


Figure 5.13 Performance evaluation of the traditional and new peeling solutions by workers; a- peeling task using traditional work tool i.e. knife, b- initial position and c- final position of new peeling equipment (illustrating peeling process using new solution), d- comparative rating of new and traditional peeling solutions by the workers

Since sample size was small and the data unlikely to be normally distributed, Mann Whitney U- test was used to compare the data regarding the two solutions. The data were analysed using SPSS version 20.

5.6.1 Task Completion Time (TCT)

In "Task Completion Time" study, time taken by workers using their old peeling method was compared with that required for the new equipment. The average time taken by the group of workers in peeling the fruit using new technique was found to be lesser as compared to the traditional technique as shown in Table 5.01.

Table 5.01 Mean TCT for peeling with old and new equipment

Sr. No.	Peeling technique	Mean (in Sec)	Standard Error
1	Using traditional equipment	63.82	± 17
2	Using new equipment	42.82	± 3.6

The standard deviation in case of the traditional tool was very high as some traditional techniques had faster rate of peeling (but had higher effort requirement). Since the samples size was not normally distributed, Mann Whitney U- test was used to check if the method with new equipment took lesser time compared to the traditional techniques. It was found that the mean rank for the traditional technique (mr = 11.86) was higher than the method using new technique (mr = 11.14). As the sample size was small, the significance level for one tailed test was found to be 0.41.

5.6.2 Subjective workload assessment using NASA TLX

After completion of Task using the old as well as the new method, respectively, the participants reported the feedback of the used methods using NASA TLX (Didomenico & Nussbaum, 2008, 2011; Sharma, Simpson, Lopresti, Schmeler, & Otr, 2014; Yiyuan, Tangwen, Dayong, & Shan, 2011) which covers 5 subscales i.e. Mental Demand [TLX-MD], Physical demand [TLX-PD], Performance [TLX-P], Effort [TLX-E] and Frustration [TLX-F] and it was found that all the subclasses of load were reported higher for operation through old/ traditional techniques as compared to new method using new equipment (Figure 5.14).

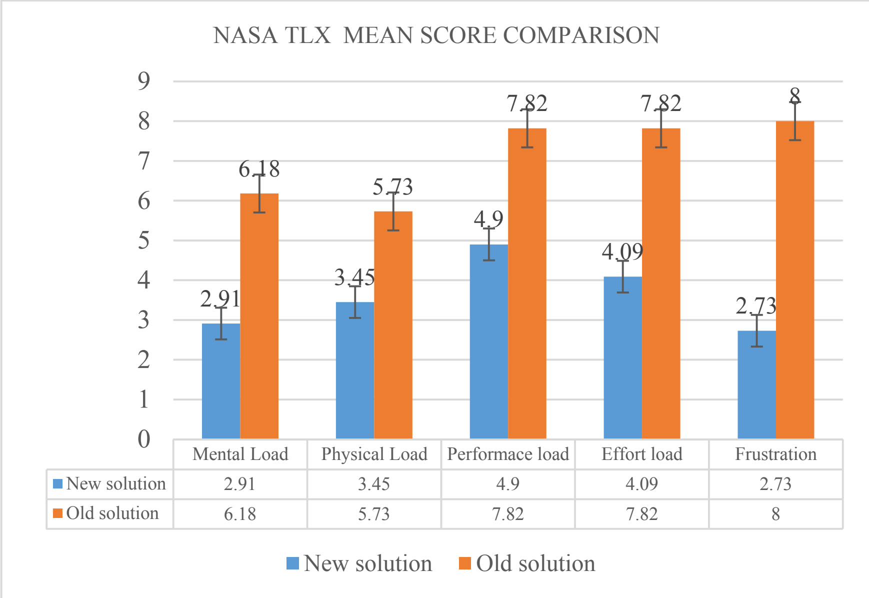


Figure 5. 14 Subjective workload across different subclasses of NASA- TLX

Since, the data obtained was not normally distributed; we tried to see if there was any significant decrease in the load while using the new solution as compared to the old one, using Mann Whitney U test. For all the subclasses of loads i.e. Mental demand [TLX-MD], Physical demand [TLX-PD], Performance [TLX-P], Effort [TLX-E] and Frustration [TLX-F], the mean ranking for old machine was greater as compared to the new solution, suggesting that greater load is required for the operation using old technique. It also found to be significant ($p < 0.05$) in case of Performance [TLX-P], Effort [TLX-E] and Frustration [TLX-F]. Since tool which they use previously for peeling was mainly a knife, some users, who were habituated of using knife, felt that mental and physical load required in both the cases are similar. The insignificant difference in case of Mental demand [TLX-MD] and Physical demand [TLX-PD] can be attributed to the above tendency and mean rankings are not found significant in these two cases. After analysing the workers performance, objectively and subjectively, for old and new solutions, the later was, by and large, found to be faster and less load requiring method (Table 5.02).

Table 5.02 Comparison of load scores of new and old peeling solution using Mann Whitney U- test

Sr. No.	NASA TLX Subclasses	Mean rank for new equipment (±SD)	Mean rank using for old equipment (±SD)	p-value
1	Mental Demand [TLX-MD]	12.05	10.95	0.35
2	Physical demand [TLX-PD]	13.14	9.86	0.11
3	Performance [TLX-P]	13.41	9.59	0.08
4	Effort [TLX-E]	14.86	8.14	0.01
5	Frustration [TLX-F]	15.55	7.45	0.00

Now, the new equipment required to be assessed for entrepreneurs' preferences.

5.7 *Assessment by entrepreneurs*

After the performance evaluation of the design by the workers, it was evaluated by entrepreneurs as they are the one who actually decide on buying/ implementing the design solution. Total 17 entrepreneurs had participated in the study (Figure 5.15).

Figure 5.15 Assessment of traditional and new peeling solutions by entrepreneurs

In the given assessment, the entrepreneurs were demonstrated in- principle working of the peeling solution and also acquainted with those features which are of key importance for them while buying a new solution like price, modes of operation, space requirement, materials used, kind of possible output, service support, etc. (*Appendix 6*). They were, then, told to rate new peeling solution and their traditionally used solution on a common set of key requirements identified during problem identification phase in chapter 4 (*Appendix 7*).The results were compared to see if there is any change in perception.

5.7.1 Statistical test before data analysis

Before the analysis of data, the statistical tests were carried out to ascertain the reliability of the instrument. The data was also tested for its normality.

5.7.2 Reliability Test of the questionnaire administered to the entrepreneurs

The questions were put in two different ways. For each requirement to ascertain the consistency of respondents' feedback, reliability of instrument was checked. Gutmann split half coefficient for each requirement of both the solutions was obtained (Table 5.03)

Table 5.03 Determination of reliability using Guttmann Split half coefficent

Sr. No.	Key Requirements	Guttmann split half coefficient	
		Questionnaire for New solution	Questionnaire for Traditional solution
1	Peeling effectiveness (different diameter)	0.88	0.84
2	Lower/ acceptable material wastage	0.68	0.73
3	High Productivity (output rate)	0.71	0.83
4	less frequent repair and maintenance	0.82	0.76
5	safe operation	0.67	0.8
6	Easy/ comfortable operation	0.67	0.79
7	Ease of understanding and operating	0.87	0.68
8	Lower cost	0.72	0.73
9	Non electric operation	0.92	0.45
10	multipurpose use possibility	0.92	0.74
11	Ease of carrying and moving	0.7	0.8
12	Less space occupying	0.75	0.54
13	Uniform quality of output	0.79	0.59
14	Looks of the product	0.89	0.67

Reliability of instrument used for assessing both the solution i.e. new intervention and the traditional work tool and method was found to be significantly high on almost all the requirement criteria, with Gutmann split half coefficient ranging from 0.45 to 0.92.

5.7.3 Normality Test of the data

To ascertain if the data is normally distributed, Shapiro-wilk test of normality was used. The null hypothesis (H_0) is that the data is normally distributed with respect to new as well as the traditional method for the considered key requirement criteria. The table below shows findings of the test (Table 5.04).

Table 5.04 Findings of Shapiro –wilk Test for normality

Sr. No.	Key Requirements	Data for new/ traditional Solution	p- value [H_0: Data are normally distributed (rejected if p value is less than 0.05)]
1	Peeling effectiveness (different diameter)	New	.116
		Traditional	.116
2	Lower/ acceptable material wastage	New	.184
		Traditional	.184
3	High Productivity (output rate)	New	.028
		Traditional	.028
4	Less frequent repair and maintenance	New	.265
		Traditional	.265
5	safe operation	New	.012
		Traditional	.012
6	Easy/ comfortable operation	New	.004
		Traditional	.004
7	Ease of understanding and operating	New	.031
		Traditional	.031
8	Lower cost	New	.128
		Traditional	.128
9	Non electric operation	New	.049

		Traditional	.049
10	multipurpose use possibility	New	.259
		Traditional	.259
11	Ease of carrying and moving	New	.873
		Traditional	.873
12	Less space occupying	New	.900
		Traditional	.900
13	Uniform quality of output	New	.949
		Traditional	.949
14	Looks of the product	New	.854
		Traditional	.854

The data for some of the requirement criteria was found normally distributed whereas for some, it was not. The requirements with normally distributed data were given in Table 5.05.

Table 5.05 Requirement criteria for which data was normally distributed

Requirement criteria	p- value	H_0: Data are normally distributed
Peeling effectiveness	0.116	Retained
Lower Wastage	0.184	Retained
Lesser Repair and maintenance	0.265	Retained
Lower cost	0.128	Retained
multipurpose use possibility	0.259	Retained
Less space occupying	0.068	Retained
Uniform quality of output	0.445	Retained

The requirements which didn't have normally distributed data were given below in Table 5.06. It was seen that hypothesis that data was normally distributed, was rejected for criteria like higher productivity, safe operation, comfort of workers, ease of understanding, nonelectric operation, ease of carrying and moving and look of the product.

Table 5.06 Requirement criteria for which data is not normally distributed

Requirement criteria	p- value	H_0: Data are normally distributed
Higher productivity	0.03	Rejected
safe operation	0.01	Rejected
Better comfort of workers	0.00	Rejected
Ease of understanding and operating	0.03	Rejected
Non electric operation	0.05	Rejected
Ease of carrying and moving	0.02	Rejected
Looks of the product	0.01	Rejected

Since we needed to determine if there was a positive change in the entrepreneurs' preference for the new intervention with respect to the traditional peeling solution, we used one tailed Paired T-test. But, since T- Test can only be used for normally distributed data, it could only be used for some of requirements with normal data. For the other data which was not normally distributed, Mann Whitney U- test (nonparametric test) was used.

5.7.4 Change in entrepreneurs' preference with new intervention

For normally distributed data related to requirement criteria, one- tailed paired T- test was used to determine if there is a change in the entrepreneurs' preferences in case of the different solutions i.e. old/ traditional solution and new solution. Similarly, for data which is not normal, non-parametric test is used.

5.7.4.1 One -tailed paired T- test analysis

In the present test, the null hypothesis is

H_0: The average difference of score is greater than or equal to zero (Difference= old/ traditional solution rating – new solution rating).

The rating for "peeling effectiveness" in case of old/ traditional solution (m= 4.09, s= 0.773) is less compared to newly demonstrated solution (m= 5.24, s=1.228), t (16) = -3.226, $p \leq 0.0025$. The negative t- value indicates that the respondents' preference for new intervention is better than their present used peeling aid. The p-value is less than 0.05. Hence we reject the null hypothesis.

The rating for "lower wastage" in case of old/ traditional solution (*m*= 4.32, *s*= 1.103) is less compared to newly demonstrated solution (*m*= 5.35, *s*=0.825), t (16) = -3.113, $p \leq 0.0035$. The negative t- value indicates that the respondents perceive in case of new solution wastage would not be high but minimum. The p-value is less than 0.05. Hence we reject the null hypothesis.

The rating for "Lesser Repair and maintenance" in case of old/ traditional solution (*m*= 5.53, *s*= 1.096) is less compared to newly demonstrated solution (*m*= 5.74, *s*=0.752), t (16) = -0.554, $p \leq 0.293$. Since the p- value is greater than 0.05, the chance of getting this result by error is more. Hence the null hypothesis is not rejected and this signifies that there might be preference of old/ traditional solution over the new solution.

The rating for "Lower Cost" in case of old/ traditional solution (*m*= 5.74, *s*= 0.504) is less compared to newly demonstrated solution (*m*= 5.94, *s*=0.583), t (16) = -0.979, $p \leq 0.171$. The p- value > 0.05 which indicates that there is high chances that the result, we got, might be because of the sampling error. Hence the null hypothesis is not rejected.

The rating for "multipurpose use possibility" in case of old/ traditional solution (*m*= 5.53, *s*= 1.038) is less compared to newly demonstrated solution (*m*= 5.68, *s*=0.883), t (16) = -0.447, $p \leq 0.330$. The p- value > 0.05 which indicates that there is high chances that the result, we got, might be because of the sampling error. Hence the null hypothesis is not rejected.

The rating for "Less space occupying" in case of old/ traditional solution (*m*= 6.15, *s*= 0.552) is more compared to newly demonstrated solution (*m*= 6.03, *s*=0.599), t (16) = 0.387, $p \leq 0.193$. The p- value > 0.05 which indicates that there is high chances that the result, we got, might be because of the sampling error. Hence the null hypothesis is not rejected.

The rating for "uniform Quality of output" in case of old/ traditional solution (*m*= 5.0, *s*= 1.075) is more compared to newly demonstrated solution (*m*= 5.41, *s*=0.734), t (16) = -1.146, $p \leq 0.134$. The p- value > 0.05 which indicates that there is high chances that the result, we got, might be because of the sampling error. Hence the null hypothesis is not rejected.

In all the cases where null hypothesis is not rejected i.e. the average difference score is greater than or equal to zero, implies that there is not much difference between the two categories as far these parameters or might be the old/ traditional solution is better. In case of quality of output, the result shows that people feel that the new solution is not significantly better. This might be because the solution demonstrated was specifically meant for rough peeling to be used for the small units where the fruits are roughly peeled and juice is extracted and filtered for making different items.

5.7.4.2 Mann Whitney U- test Analysis

For the requirement with data which is not distributed normally, Mann Whitney U-Test (non-parameter test) was used to see change in preferences of user in case of present solution and new solution. The hypothesis for this test is as following:

H_0: Mean rank of the new intervention is better than traditional solution.

The following table shows the results for the requirement criteria with non-normal data distribution (Table 5.07).

Table 5.07 Comparison of mean rank of old an solution using Mann Whitney U-Test

Requirement criteria	Mean Rank (New Equipment)	Mean Rank (Old Equipment)	p- value
Higher productivity	25.71	9.29	0.00
safe operation	25.24	9.76	0.00
Better comfort of workers	24.35	10.65	0.00
Ease of understanding and operating	19.97	15.03	0.07
Non electric operation	19.26	15.74	0.14
Ease of carrying and moving	15.79	19.21	0.15
Looks of the product	18.71	16.29	0.24

In case of rate of peeling, safety and comfort, the ratings of new solution is better than existing product. All the requirement criteria, where the hypothesis stating that the ratings for new solution was better, got rejected, suggests that the new solution was no better than the traditional solution. These criteria were adaptability, power and portability. In case of the looks of product, the ratings are alike for new as well as the traditional solution. This is because product liking on the basis of visual appeal is very subjective matter and moreover the first priority of the entrepreneur is the functional efficacy as compared to visual appeal. In addition, the new solution does not make a striking difference as far as visual looks are concerned because the new design just demonstrates the working principle and had to be further worker upon to be made marketable.

5.8 Validation of the support tool for determining solution category

Though a greater preference of new intervention over the traditional solution, with respect to major key requirements is, in itself, a kind of confirmation to appropriate category selection, effort was made to objectively validate the support tool determining appropriate solution category. Thus, this approach might help in taking similar decisions while designing other fruit processing equipment.

To check the validity, the entrepreneurs were explained about the different category of solutions and they were asked how much they would rate different solution categories appropriate to their context of use (*Appendix 8*). The process was divided in two parts as shown in the Figure 5.14.

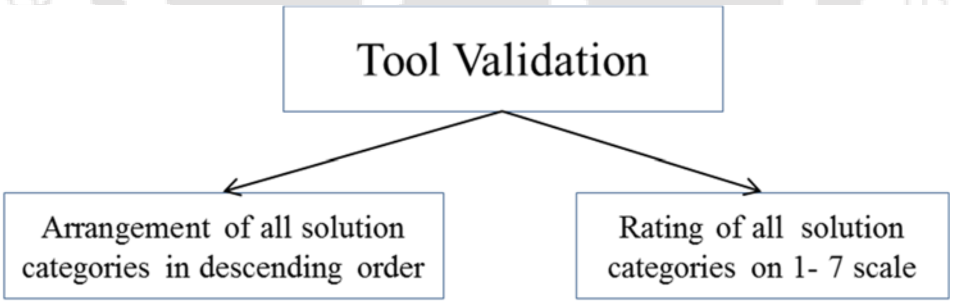


Figure 5.16 Validation process of QFD tool based approach

On one hand, The entrepreneurs were also asked to directly arrange the categories in descending order as per their appropriateness to the context of use i.e. most favoured choice would be ranked 1st and least to be ranked 4th. On the other, the solution categories were rated for contextual appropriateness on 1-7 scale, "1" being least appropriate and "7" being the most appropriate. The survey was done over 17 entrepreneurs. The survey was conducted prior to discussing and asking them to rate the solution we had arrived at. The result were analysed using SPSS 20.0.

5.8.1 Orderly arrangement of Categories by entrepreneurs

In the response of first question asking to rank the 4 categories, 58.8% of respondents raked human powered solutions as first choice. Whereas, 35.3% and 5.9% of respondents ranked semi- automated solutions and Small hand tool like solutions as first choice, respectively. Fully automated category had not been considered by anybody as first choice (Figure 5.15).

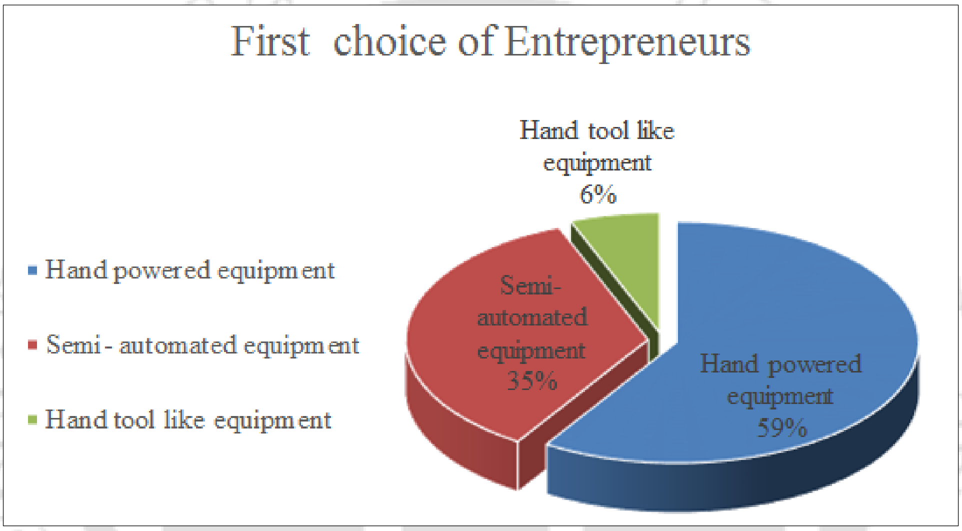


Figure 5.17 First preference of respondents

41.2 % of the respondent ranked Semi-automated solutions (Category 3) as second preference. Whereas, 23.5% of respondents ranked each hand operated tool (Category 1) and human powered solutions (Category 2) as second preference (Figure 5.16).

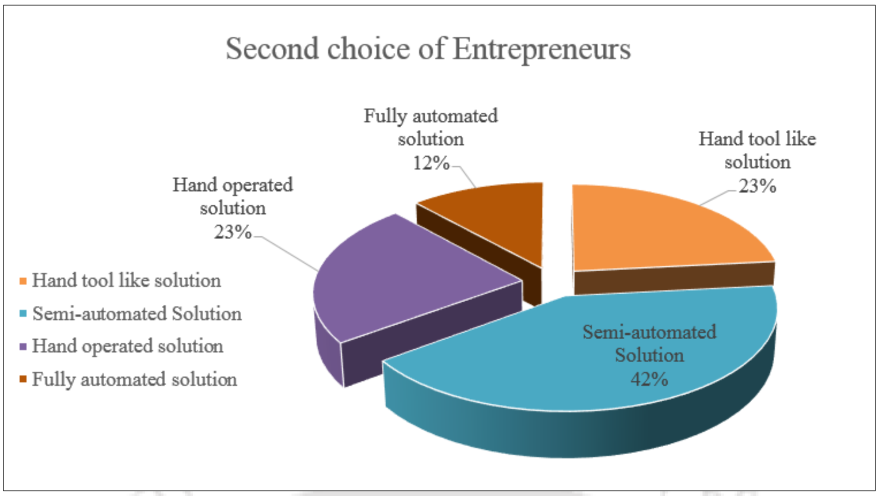


Figure 5.18 Second preference of the respondents

58.8% of respondent ranked hand tool like solutions (Category 1) as third preference and 23.5% of respondents ranked semi- automated solution (category 3) as third choice (Figure 5.17).

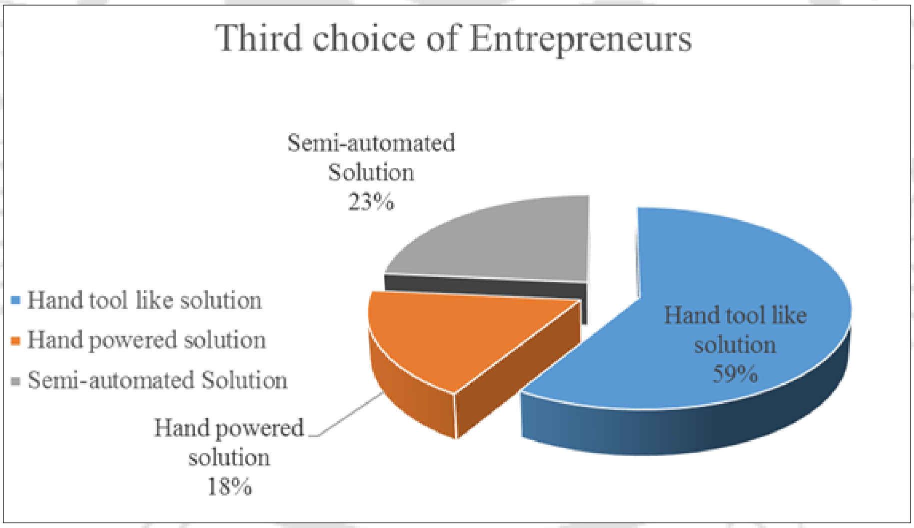


Figure 5.19 Third preference of the respondents

88.2% of the respondents selected fully automated solutions (category 4) as the fourth preference whereas, 11.8 % of the respondents ranked hand tool like solutions (category 1) as fourth preference (Figure 5.18).

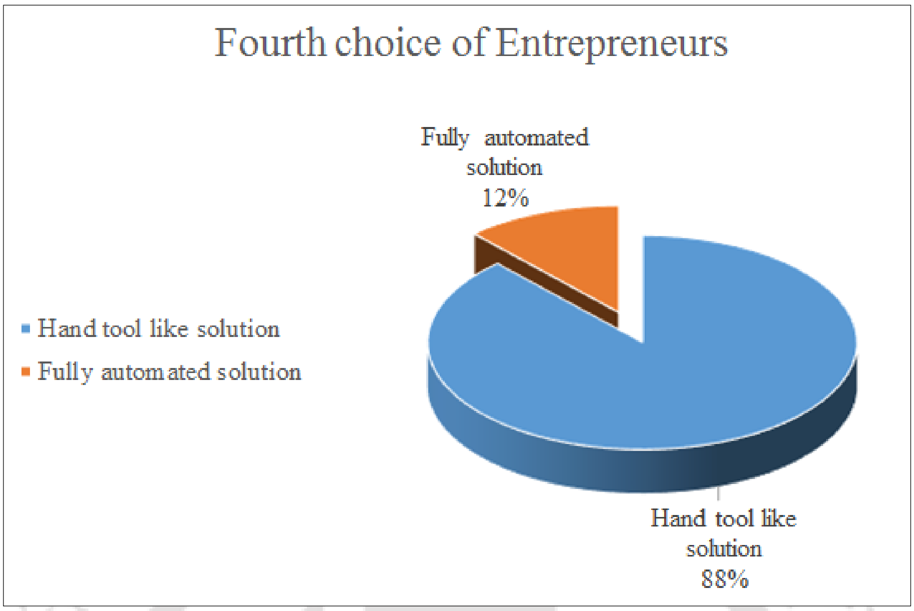


Figure 5.20 Fourth preference of the respondents

5.8.2 Rating given to different solution categories for their appropriateness

The second part of the questionnaire contained three questions which were meant to understand how people rank all solution categories on the scale of appropriateness. Three questions were asked in his context and for each 1-7 rating scale was used (*Appendix 9*).

Reliability of the questionnaire checked through Cronbach's alpha and it was found to be alpha was found to be 0.904. The category wise mean score and the standard deviation was calculated which is shown in Table 5.08.

Table 5.08 Mean score rating of different categories for appropriateness

Category	Mean	SD
Small hand tool like solutions	4.10	1.46
Hand powered solutions	5.25	1.481
Semi-automated solutions	4.57	1.404
Fully automated solutions	1.49	1.189

The mean of scores as rated by the respondents, show the partially similar trend as predicted by the support tool. Human powered solutions (category 2) with highest mean score of 5.25 ranks first and fully automated solutions (category 4) with the lowest mean score of 1.49 ranked fourth.

But there had been difference in the order of preference of Semi-automated solutions and Hand tool like solution. The support tool predicts Hand tool like solution and semi- automated solutions at 3rd and 2nd place whereas the user preferences indicate otherwise. Semi-automated solutions (category 3) with second highest mean score of 4.57 ranks second, whereas, Hand tool like solutions (category 1) with third highest mean score of 4.1 ranks third.

5.9 Suggestions for the final marketable product

Though the equipment was operational in principle, it was observed during the evaluation process that the equipment required many modifications for evolving into a better marketable product. Some of the suggestions/considerations that might be kept in mind for improvements are as following:

- The pressing ram hinders the visibility while placing the fruit so it needs to be improved
- The wrist rotation is still higher which requires to be further optimized
- Since, after placing the slice both the hands are free, it would be safer to have handle which engages both the hands for pressing
- Loose play of lever had to be removed
- Proper stable base had to be ensured before operations
- Different mode of operation i.e. power driven, leg operated, etc. might be explored for future scope.

5.10 Conclusion

Though the evaluation of the intervention, in a way, was a validation of the process adopted for the intervention design, evaluation was carried out in 2 parts with first, the assessment of the new equipment and second, the validation of the method tool. Equipment evaluation involved workers and entrepreneurs. For workers, the objective evaluation was carried out measuring task completion time (TCT) whereas subjective evaluation was done using NASA TLX. The second part is the evaluation of entrepreneurs (buyers') preference. During the evaluation, a significant difference was found between the traditional and new solution in workers performance evaluation as well as preference rating of the old and new solution by the entrepreneurs.

For, validation of the proposed tool, the highest percentage of users had preferred the solution category predicted by the tool. But the order of preference of in case of “hand tool like solutions” and “semi-automated solution” was reversed. The study showed that category indicated by the proposed tool to be more suitable was also confirmed by the preference evaluation test as same solution category had been as the first preference of the larger section of the users. But there were differences in the order of preferences of the other categories. The proposed tool predicts that 2nd and 3rd suitable category of solutions were “Hand tool like solutions” and “Semi-automated solutions”, respectively. Whereas when put directly to the respondents / users regarding the most suitable category for their use context, the “Semi-automatic solution category” and “Hand tool like solution” were rated 2nd and 3rd , respectively. From the tool’s perspective, this difference in order might be due to the reason that the score indicating suitability of the category takes into account many requirements. Many of those with comparatively low priorities have exceptionally high positive association with “Hand tool like solution category” pushing their score high, making it more suitable than “semi-automated solutions”. From users’ preference perspective, it might be understood as that the users are fairly more critical about different factors while making the first preference. But as far as second preference is concerned the people tend to be more liberal on certain requirements especially those with comparatively lesser priorities. Thus “semi- automated solutions” had been rated higher than “hand tool like solutions”.

Chapter 6

DISCUSSION AND CONCLUSION

Chapter 6

DISCUSSION AND CONCLUSION

6.1 Introduction

The chapter summarises the research work carried out in the thesis and discusses different findings of the research. The research summarised in three phases i.e. investigation into prevalence of ergonomic issues among the pineapple peeling workers, addressing the issues through ergonomic design intervention and evaluating the design process. The chapter finally concludes with a summary of thesis contribution, the limitations of the present study and the future scope of work in the area.

6.2 Salient findings and Discussion

As pineapple processing is an important industry with a large presence in North East India and pineapple peeling appearing a major bottle neck in productivity of the industry, an effort was made to establish if the problems related to manual pineapple peeling task was significant from ergonomic perspective (H_1). Thereafter we tried to see if a design intervention could help in improving the presently prevailing conditions effectively (H_2). Hence, at first, the study of existing issues was carried out and assessment of the present conditions was done from ergonomic perspective.

6.2.1 Ergonomic assessment

The study aimed at assessing the occupational health related issues and associated levels of ergonomic risk prevalent among the manual pineapple peeling workers in small fruit processing units of North East India. It also identifies ergonomics risk factors associated with pineapple peeling task. A cross- sectional survey was conducted using questionnaire based interview, pain self-report and direct observation of the activities; level of ergonomic risks involved was assessed using Rapid Upper Limb Assessment (RULA). Participants reported of pain in different body parts.

- A higher percentage of participants reported pain in shoulder (49%), upper arm (43%) and lower back (52.32%). While some had also reported of pain in neck (13.2%), lower arm (15.9%), wrist (12.6%) and palm (6%).
- Around 60% of participants reported to have QEC score with high risk level
- For RULA, 89.4% of the participants had a grand score greater than equal to 5 which falls under action level 3 that indicates for investigation and changes are required soon.
- Using logistic regression, an effort was made to establish association between pain in different body parts and factors, like age, gender, hours of peeling, frequency of rest breaks, perceived work fatigue and experience. They were found to be associated with occurrence of pain in at least one of the body parts i.e. neck, Upper back, lower back, upper arm, lower arm and wrist.

This section established the first hypothesis (H_1) that there were ergonomic issues related to pineapple peeling in small fruit processing units. It also identifies the different risk factors associated with MSDs in various body parts. The findings suggested that preventive action is required to address the risk factors in order to improve the occupational health of the workers.

6.2.2 Establishing efficacy of Ergonomic Design Intervention

Before testing the machine's performance with the workers, RULA was used to assess the level of involved risk in operation by simulating the critical task position using different percentile heights of male and female manikin and scaled 3-D model of equipment in DHM. Accordingly, modifications were done to ensure reduction in postural risks and force needed for operation. The results showed that there was significant reduction in the RULA score apparent after the modifications.

- It was observed that grand score for both male and female mannequins for 50^{th} as well as 90^{th} percentile height was 6 for both initial and final position of operation.

- When the lever length was increased from 450mm to 610 mm, the force was reduced and the grand score reduced to 4 for all the positions with 50th and 90th percentile heighted male and female mannequins.

This improved machine was then evaluated by 11 workers for its performance using NASA TLX. Meanwhile, task completion time was determined during the process.

- It was observed that for all subclasses of load, the old /traditional solution had greater load but using Mann Whitney U test, it was found to be significantly higher in case of Performance [TLX-P], Effort [TLX-E], Frustration [TLX-F] (p=0.05).
- Task completion test showed that mean time taken by new solution for peeling a pineapple was 42.8 sec as compared to old traditional solution which takes 63.8 sec.

For entrepreneurs, the functional demonstration of this solution along with other necessary details which a buyer wishes to know while purchasing a product i.e. cost, dimensions, different accessories, way to install, material, etc. they were then, they were asked to rate the new and old traditional solution, they currently use, on the same set of requirement criteria. Total of 17 entrepreneurs participated. Thereafter, student T- test and Mann Whitney U- test was used to establish if the new solution is better than the traditional solution.

- The result showed that for many key requirements with higher priority i.e. safety, higher productivity, lower raw material wastage, the new solution was ranked well than old/ traditional solution.
- But for some like price, repair and maintenance the hypothesis was rejected i.e. the new solution was not better than the old solution which is generally knife. This might be because there are certain requirements criteria in which the present traditional solution fit well. It also confirmed the reason why people adhere to these traditional solutions. But, most of the requirements, for which the users express greater priority, the new solution is ranked to be a better than old solution.
- The evaluation involving workers suggested many consideration for improvement of the solution while developing it into a marketable product discussed in chapter 5.

This section pertaining to ergonomic design intervention followed by evaluation, fairly, establishes the second hypothesis (H_2) which posits that that it is feasible to come up with an effective solution with a better acceptability to the local entrepreneurs.

6.2.3 Validation of the proposed QFD tool based approach

The research used a QFD tool based approach to decided most contextually appropriate design solution for peeling which could be numerically expressed as following.

Final score for a category= $\sum (P_n \times RC_n)$

Where P_n= priority of n^{th} requirement among all the requirements

RC_n= Rating for relationship of nth category with requirements (discussed in detail in Chapter 4)

The solution category indicated by the approach was then conceptualized and found to be, by and large, better than the existing solution during evaluation. Though better rating of new solutions for most of the critical and highly rated requirements indirectly confirms the accuracy of the tool, an effort was made to validate it through entrepreneurs. They were shown videos and pictures of each category of solutions, giving them affair idea about each type of solution category (*Appendix 4*). They were then asked to arrange these categories in a descending order according to suitability to their context of use. They were then asked to answer three question that ask the same question in three different ways. In each question, they were asked to rate all four solution categories on 1-7 rating scale for their suitability to the context of use (*Appendix 8*). The rankings showed that

- 59% of the participant ranked "Hand Operated Solution" as their first preference
- 41.2 % of the respondent ranked semi-automated whereas 59% of participant chose Hand tool like solution as their third preference. This is opposite to what has been predicted by the category determining tool.
- The mean rating (on 7 point scale)for appropriateness of four broader categories of pineapple peeling solution i.e. Hand tool like solution, Hand powered solution, Semi-automated solution and Fully- automated solution was 4.1, 5.25,4.57 and 1.49, respectively.

The proposed tool predicts that 2nd and 3rd suitable category of solutions were "Hand tool like solution" and "Semi-automated solution", respectively. Whereas, the respondents / users rated them just the reverse. From the tool's perspective, this difference in order might be due to the reason that the score indicating suitability of the category takes into account many requirements. Many of those with comparatively low priorities had exceptionally high positive association with "Hand tool like solution category" pushing their score high, making it more suitable than "semi-automated solutions". Form users' preference perspective, it might be understood as that the users are fairly more critical about different factors while making the first preference. But as far as second preference is concerned the people tend to be more liberal on certain requirements especially those with comparatively lesser priorities. Thus "semi- automated solutions" had been rated higher than "hand tool like solutions".

6.3 Summary of knowledge Contribution

The thesis, for the first time, had undertaken a systematic and in depth study related to pineapple peeling task from ergonomic perspective as well as from holistic point of view (taking into account various factors related to the small fruit processing units in context). The thesis embarks on a detailed process for developing an ergonomic design intervention in form of pineapple peeling machine. A similar approach could also be followed for design development of other fruit and food processing equipment. The thesis also proposed and evaluated a support tool to decide the solution category of product for fruit processing equipment. This could help the designer giving them direction to the fruit processing equipment design process. Thus, it would reduce the time and effort of designer involved in design of such products.

6.4 Future scopes of work

Though thesis extensively examine various aspects related to the area of pineapple peeling task and the holistic approach for designing of an effective peeling solution, it is more focused and confined to certain work domains due limitations of time and resources. Hence, there is a good scope for future research and improvements in the area.

6.4.1 Improvements and optimization from marketability perspective

The present research work is focussed mainly into evaluating if there is a significant improvement due new intervention and assesses positive change in entrepreneurs' preference with respect to various key requirements. This had been achieved through developing the proof of concept and testing it. But transformation of a proof of concept into a marketable product requires a lot of optimisation and betterment asking for further research in the area form different perspective. For e.g. possibilities of leg operated peeling solution might further reduce the workers effort as compared to a hand operated solution and hence required to be worked upon, possibilities of improving the fruit mounting mechanism, etc.

6.4.2 Improvements through Longitudinal study

The present research is mainly focused on cross-sectional study. But for better and effective solution, there is a need longitudinal study in the field for improvements. Hence, solution might be given to the field workers and study related issues are in longer time frame.

6.4.3 Evolution of the design process

The present study is limited to design solution based on selecting most suitable option from the different categories of old/ traditional solutions. There could be many new solution categories that might emerge might by combining two categories like a category of manual peeling tool that also had some automation or a category of equipment with dual mode of operations i.e. human and motor powered, combining the advantages of both the categories. Exploration into these possibilities offers a good scope of work in the domain.

6.4.4 Research scope in fruit processing industry specific to the region

The present work is limited to the issues and improvements pertaining to pineapple peeling task in the small fruit processing units of North east India. But, since the region is home to a large number seasonal fruits and vegetables, all having different properties and specialities, there is huge scope of work in the area. During the field studies, issues related processing of bamboo shoot, *bhoot jolakia* (Asamese chilli), garlic, juice extraction from Assamese lemon, jack fruit processing, etc. were also reported by some units which has larger commercial implications and hence required to be further looked into.

REFERENCES

1. Adzimah, S. K., & Seckley, E. (2009). Modification in the design of an already existing palm nut - fibre separator, *3*(November), 387–398.

2. Ajayi, O. O., & Olukunle, O. J. (2008). Design of Gari Fryer. *Journal of Agricultural Engineering and Technology*, *18*(1), 51.

3. Alam, A. (2002). Mechanization in Agriculture and On-farm Agro-processing, *55*(1), 17–31.

4. Arvidsson, I., Balogh, I., Hansson, G.-Å., Ohlsson, K., Akesson, I., & Nordander, C. (2012). Rationalization in meat cutting - consequences on physical workload. *Applied Ergonomics*, *43*(6), 1026–32. doi:10.1016/j.apergo.2012.03.001

5. Barbier, M. T., Marouzï, C., & Laboratory), F. G. (1997). A TRIZ-based Creativity Tool for Food Processing Equipment Design. *The TRIZ Journal*.

6. Batchelar, J., Willets, D., Mauley, R. de, & Greening, J. (2013). *A UK Strategy for Agricultural Technologies* (p. 51). London.

7. Bationo, F., Marouze, C., Boujut, J. F., A, F., & Giroux. (2009). Socio-technical networks : a tool for integrating the maintenance dimension in the design of equipment for small food processing units in Western Afica. *Journal of Design Research*, *8*, 4–5.

8. Beshah, B., Kitaw, D., & Gelan, M. (2013). Workstation Design in an Ethiopian Small Scale Leather Garment Industry. *Procedia - Social and Behavioral Sciences*, *75*, 434–442.

9. Bhandari, V. B. (2013). *Introduction to Machine Design* (pp. 283– 383). New Delhi: Tata McGraw-Hill Education.

10. Bhattacharya, A. (2014). Costs of occupational musculoskeletal disorders (MSDs) in the United States. *International Journal of Industrial Ergonomics*, *44*(3), 448–454.

11. Bhattacharyya, & Chakrabarti, D. (2012). Design development scopes towards occupational wellness of women workers: specific reference to local agro based food processing industries in NE India. *Work (Reading, Mass.)*, *43*(4), 403–9.

12. Bhattacharyya, N., & Chakrabarti, D. (2012). Ergonomic basket design to reduce cumulative trauma disorders in tea leaf plucking operation. *Work (Reading, Mass.)*, *41 Suppl 1*, 1234–8. doi:10.3233/WOR-2012-0308-1234

13. Bhattacharyya, N., & Chakrabarti, D. (2012, September 6). Design development scopes towards occupational wellness of women workers: Specific reference to local agro based food processing industries in NE India. *Work (Reading, Mass.)*.

14. Borah, R., & Kalita, M. (2012). Ergonomic evaluation of pounding of rice with traditional tool. *Work (Reading, Mass.)*, *43*(4), 411–6.

15. Chakrabarti, D., & Bhattacharyya, N. (2012). Ergonomic design intervention strategy for work tools development for women agro based workers in Northeast India. *Work (Reading, Mass.)*, *41 Suppl 1*, 1330–4.

16. Chakrabarti, D., & Design, N. I. of. (1997). *Indian anthropometric dimensions for ergonomic design practice* (p. 161). National Institute of Design.

17. Champoux, D., & Brun, J.-P. (2003). Occupational health and safety management in small size enterprises: an overview of the situation and avenues for intervention and research. *Safety Science*, *41*(4), 301–318.

18. Chiasson, M.-È., Imbeau, D., Aubry, K., & Delisle, A. (2012). Comparing the results of eight methods used to evaluate risk factors associated with musculoskeletal disorders. *International Journal of Industrial Ergonomics*, *42*(5), 478–488.

19. Coury, H. J. C. G., Porcatti, I. A., Alem, M. E. ., & Oishi, J. (2002). Influence of gender on work-related musculoskeletal disorders in repetitive tasks. *International Journal of Industrial Ergonomics*, *29*(1), 33–39. doi:10.1016/S0169-8141(01)00047-6

20. Cross, N. (2005). *Engineering Design Methods Strategies for Product Design* (p. 140).

21. Cross, N. (2008). *Engineering Design Methods: Strategies for Product Design* (p. 230). Wiley.

22. Daniele Archibugi, J. M. (1997). *Technology, Globalisation and Economic Performance* (p. 1). University of London.

23. Deka, B. C., Sharma, S., & Choudhury, S. (2008). Packaging system for long distant transportation of Khasi mandarin. *Indian Journal of Horticulture*, *65*(4), 491–493.

24. Deka, B., Sharma, S., Choudhury, S., & Pal, R. (2008). Development of packaging system for distant transportation of'Kew'pineapple (Ananas comosus). *Indian Journal of Agricultural Sciences*, 340–342.

25. deLooze, M., Pikaar, R., Colombini, D., & Occhipinti, E. (2006). Preventing upper limb work-related musculoskeletal disorders (UL-WMSDS): New approaches in job (re)design and current trends in standardization. *Applied Ergonomics*, *37*(4), 441–450.

26. Díaz-Bonilla, E., & Reca, L. (2000). Trade and agroindustrialization in developing countries: trends and policy impacts. *Agricultural Economics*, *23*(3), 219–229.

27. Didomenico, A., & Nussbaum, M. A. (2008). Interactive effects of physical and mental workload on subjective workload assessment, *38*, 977–983.

28. Didomenico, A., & Nussbaum, M. A. (2011). International Journal of Industrial Ergonomics Effects of different physical workload parameters on mental workload and performance. *International Journal of Industrial Ergonomics*, *41*(3), 255–260.

29. Diouf, J. (1997). *The state of food and agriculture, 1997 - w5800e.pdf* (p. 243). Rome.

30. Dorrian, J., Baulk, S. D., & Dawson, D. (2011). Work hours, workload, sleep and fatigue in Australian Rail Industry employees. *Applied Ergonomics*, *42*(2), 202–209.

31. Dorward, A. (2013). Agricultural labour productivity, food prices and sustainable development impacts and indicators. *Food Policy*, *39*, 40–50.

32. Earley, P. C., Lee, C., & Hanson, L. A. (1990). Joint moderating effects of job experience and task component complexity: Relations among goal setting, task strategies, and performance. *Journal of Organizational Behavior*, *11*(1), 3–15.

33. Faucett, J., Meyers, J., Miles, J., Janowitz, I., & Fathallah, F. (2007). Rest break interventions in stoop labor tasks. *Applied Ergonomics*, *38*(2), 219–26.

34. Fedorowich, L., Emery, K., Gervasi, B., & Côté, J. N. (2013). Gender differences in neck/shoulder muscular patterns in response to repetitive motion induced fatigue. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *23*(5), 1183–9.

35. Foglemen, M. T., Freivalds, A., & Goldberg, J. H. (1993). An ergonomic evaluation of knives for two poultry cutting tasks. *International Journal of Industrial Ergonomics*, *11*, 257–265.

36. Foundation, S. D. (2009). Compendium of Papers, 1–176.

37. Gangopadhyay, S. (2012). From the Guest Editor Humanizing Work and Work Environment : A challenge for developing countries, *43*, 9815.

38. Giametta, F. (2013). Login / Logout. In *ISHS Acta Horticulture 679:iii WOCMAP Congress on Medicinal and Aromatic Plants* (Vol. 5, pp. 1–2). Belgium.

39. Giroux, C. M., Francois, & Montpellier. (2007). Local Design capacity building of light to small scale food processing equipment- A strategic way for adding value for produce. In *Addressing the challenges facing agricultural mechanisation input supply and farm product processing* (p. 38).

40. Hammock, B. T. (2010). *Ergonomics in the Poultry Industry A Review of 25 Years of Industry Efforts* (p. 10). Reston.

41. Hui, Y. H. (2008). *Handbook of Fruits and Fruit Processing* (p. 712). Wiley India Pvt. Limited.

42. Husain, K. A., Sabir, M. S., & Iqbal, M. (2010). DEVELOPMENT OF A MACHINE FOR COLD PULPING OF TOMATO, *47*(4), 383–387.

43. Jahromi, M. K., Rafiee, S., Jafari, A., Bousejin, M. R. G., Mirasheh, R., & Mohtasebi, S. S. (2008). Some physical properties of date fruit (cv . Dairi), 221–224.

44. Kothari, C. R. (2004). *Research Methodology: Methods and Techniques* (p. 401). New Age International.

45. Koya, B. S. O. O. A., & Adeosun, O. O. (2008). A Table Mounted Device for Cracking Dika Nut (Irvingia gabonensis), 1–8.

46. Kumar, B. (2011). *Indian Horticulture Database-2011* (p. 112). Gurgaon: National Horticulture Board.

47. Kumar, P., & Chakrabarti, D. (2011a). Design development of a pineapple eye removing device. In *International Conference on Ergonomics and Human Factors* (p. 51). Chennai.

48. Kumar, P., & Chakrabarti, D. (2011b). UNDER-UTILIZED URBAN SCRAP THROUGH SUSTAINABLE DESIGN, 978–981. doi:10.3850/978-981-08-7721-7

49. Lall, S. (2010). The Technological Structure and Performance of Developing Country Manufactured Exports. *Oxford Development Studies*, *28*(July 2013), 337–369.

50. Lanfranchi, J.-B., & Duveau, A. (2008). Explicative models of musculoskeletal disorders (MSD): From biomechanical and psychosocial factors to clinical analysis of ergonomics. *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology*, *58*(4), 201–213.

51. Londhe, D., Pawar, G., & Bhosale, P. (2013). *Ergonomic Evaluation of Pedal Operated Maize Sheller*. Rahuri: LAP LAMBERT Academic Publishing.

52. M. S. Sidhu. (2005). fruit and vegetable processing industry in India An appraisal of ppsot reform period. *Economics and Political Weekly*, 3056.

53. Marras, W. S., & Karwowski, W. (2006). *Interventions, Controls, and Applications in Occupational Ergonomics* (p. 848). CRC Press.

54. McAtamney, L., & Corlett, N. E. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics*, *24*(2), 91–9.

55. McCullough, E. B., Pingali, P. L., & Stamoulis, K. G. (2008a). *The Transformation of Agri-food Systems: Globalization, Supply Chains and smallholder farmers* (p. 92). Earthscan.

56. McCullough, Pingali, P., & Stamoulis, K. (2008b). *The transformation of agri-food systems: globalization, supply chains and smallholder farmers* (p. 41).

57. Meksawi, S., Tangtrakulwanich, B., & Chongsuvivatwong, V. (2012). Musculoskeletal problems and ergonomic risk assessment in rubber tappers: A community-based study in southern Thailand. *International Journal of Industrial Ergonomics*, *42*(1), 129–135.

58. Montero-Calderón, M., Rojas-Graü, M. A., & Martín-Belloso, O. (2009). Mechanical and chemical properties of Gold cultivar pineapple flesh (Ananas comosus). *European Food Research and Technology*, *230*(4), 675–686.

59. Murgia, L., Rosecrance, J. C., Gallu, T., & Paulsen, R. (2012). Risk evaluation of upper extremity musculoskeletal disorders among cheese processing workers : A comparison of exposure assessment techniques, 49–55.

60. Naderiboldaji, M., Jannatizadeh, A., Tabatabaeefar, A., & Fatahi, R. (2008). Development of 11 Mass Models for Iranian Apricot fruits based on some physical attributes (cv . Shahroud-8 and Gheysi-2), 65–76.

61. Nag, A., Vyas, H., & Nag, P. K. (2010). Gender differences, work stressors and musculoskeletal disorders in weaving industries. *Industrial Health*, *48*(3), 339–48.

62. Nag, P. K., & Nag, A. (2007). Hazards and health complaints associated with fish processing activities in India—Evaluation of a low-cost intervention. *International Journal of Industrial Ergonomics*, *37*(2), 125–132.

63. Neill, D. H. O. (2000). Ergonomics in industrially developing countries : does its application differ from that in industrially advanced countries ?, *31*.

64. Nin-Pratt, A., & McBride, L. (2014). Agricultural intensification in Ghana: Evaluating the optimist's case for a Green Revolution. *Food Policy*, *48*, 153–167.

65. Niu, S. (2010). Ergonomics and occupational safety and health: an ILO perspective. *Applied Ergonomics*, *41*(6), 744–53.

66. Norman, R., & Wells, R. (1998). Ergonomic Interventions for Reducing Musculoskeletal Disorders : An Overview , Related Issues and Future Directions Ergonomic Interventions for Reducing Musculoskeletal Disorders : An Overview , Related Issues and Future Directions ., (May), 1–34.

67. Onwualu, A. P., District, M., Engineering, W., State, O., Engineering, P. H., Engineering, E. C., … Technologies, E. (2009). Sustainablity and cost of agricultural mechanizationin Nigeria as affected by macro- Economic Policies. *Journal of Agricultural Engineering and Technology*, *17*(2).

68. Ouellet, S., & Vézina, N. (2014). Work training and MSDs prevention: Contribution of ergonomics. *International Journal of Industrial Ergonomics*, *44*(1), 24–31.

69. Owolarafe, O. K., & Shotonde, H. O. (2004). Some physical properties of fresh okro fruit. *Journal of Food Engineering*, *63*(3), 299–302.

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

71. Patel, T., Sanjog, J., Kumar, P., Karmakar, S., & Pradesh, A. (2013). Analytical Study of Isometric Muscular Strength of Agricultural Workers : Indian Perspective. In *International Conference on Ergonomics and Human Factors* (pp. 56–65).

72. Phiri, K., & Wycliff, H. (2005). " The Global Food & Product Chain — Dynamics , Innovations , Conflicts , Strategies " Approaches to Successful Development of Low-Cost Fruit Juice Extraction Technologies : A Case Study to Improved Rural Livelihood in Malawi, 2005.

73. Rai, A., Gandhi, S., Kumar, N., Sharma, D. K., & Garg, M. K. (2012). Ergonomic intervention in Aonla pricking operation during preserve preparation in food processing industries, *41*, 401–405.

74. Raji, A. O., & Olofin, A. F. (2011). Design and Development of Leaf Protein Juice Extraction Machine, *3*(1), 69–77.

75. Rattan. (2005). *Theory of Machines* (pp. 330 – 369). New Delhi: Tata McGraw-Hill Education.

76. Roffey, D. M., Wai, E. K., Bishop, P., Kwon, B. K., & Dagenais, S. (2010). Causal assessment of awkward occupational postures and low back pain: results of a systematic review. *The Spine Journal*, *10*(1), 89–99.

77. Roha, S. (2013). Physico- chemical properties of pineapple variety N36 harvested and stored at different maturity stages, *20*(1), 225–231.

78. Samaila, R. S., Olotu, F. B., & Obiakor, S. I. (2008). Development of mannually operated fruit juice extractor. *Journal of Agricultural Engineering and Technology*, *16*(2), 22–28.

79. Sema, A., Maiti, C. S. and D. (2011). PINEAPPLE CULTIVATION IN NORTH EAST INDIA - A PROSPECTIVE VENTURE. In *ISHS Acta Horticulturae 902: VII International Pineapple Symposium* (pp. 69–78).

80. Shahnawaz, M., & Sheikh, S. A. (2011). Physicochemical characteristics of Jamun fruit, *3*(10), 301–306.

81. Sharma, V., Simpson, R. C., Lopresti, E. F., Schmeler, M., & Otr, L. (2014). Clinical evaluation of semiautonomous smart wheelchair architecture (Clinical evaluation of semiautonomous smart wheelchair architecture (Drive-Safe System) with visually impaired individuals Clinical evaluation of semiautonomous smart wheelchair, *49*(1), 1–13.

82. Shirahatti, S. ., Badiger, M. S., & Prakash, K. . . (2010). agricultural engineering intervention to increase productivity of women in agriculture: some studies from india. Food & Agriculture Org.

83. Sikri, R. (2009). India's "Look East" Policy. *Asia-Pacific Review*, *16*(1), 131–145. doi:10.1080/13439000902957624

84. Simonya, K. J., & Imokheme, P. A. (2008). DEVELOPMENT OF AN AXIAL FLOW MOTORIZED SORGHUM THRESHER. *Journal of Agricultural Engineering and Technology*, *16*(2).

85. Simonyan, K. C., A, I. S. emordi, & J C Adama. (2008). DEVELOPMENT OF A LOCALLY DESIGNED RICE DESTONING MACHINE. *Journal of Agricultural Engineering and Technology*, *18*(1), 74.

86. Singh, D., Wangshu, L., & Prahlad, v c. (2008). P ROCESSING AND MARKETING FEASIBILITY OF UNDERUTILIZED. In *IAMO Forum 2008*.

87. Singh, P., Singh, J. P., & Chopra, C. S. (2003). Techno-Economic study on processing of Aonla products. *Beverage and Food World*, 68–69.

88. Singh, S. P. (2006). Improved Farm Tools and Equipment for Women Workers for Increased Productivity and Reduced Drudgery. *Gender, Technology and Development*, *10*(2), 229–244.

89. Sinha, A. N. . (2005). *Volume I Vision, Strategy and Action Plan for Food Processing Industries in India* (Vol. I, p. 4).

90. Sircar, J. (2006). SME Definition.pdf. *Ministry of Small Scale Industries Notification*, pp. 1–2.

91. Sormunen, E., Oksa, J., Pienimäki, T., Rissanen, S., & Rintamäki, H. (2006). Muscular and cold strain of female workers in meatpacking work. *International Journal of Industrial Ergonomics*, *36*(8), 713–720.

92. Sormunen, E., Remes, J., & Hassi, J. (2009). Factors Associated with Self-estimated Work Ability and Musculoskeletal Symptoms among Male and Female Workers in Cooled Food-pro- cessing Facilities, 271–282.

93. Stellman, J. M. (1998). *Encyclopaedia of Occupational Health and Safety: Chemical, industries and occupations* (p. 4230). International Labour Organization.

94. Strazdins, L., & Bammer, G. (2004). Women, work and musculoskeletal health. *Social Science & Medicine*, *58*(6), 997–1005.

95. Stuart-Buttle, C. (1994). A discomfort survey in a poultry-processing plant. *Applied Ergonomics*, *25*(1), 47–52.

96. Swain, S. K., Gupta, J. P., Mohanty, S. K., & Sahoo, P. . . (2009). ERGONOMIC EVALUATION OF A PEDAL OPERATED CASHEW NUT SHELLER. In *HWWE 2009* (pp. 144–177).

97. Ulrich, K. T., & Eppinger, S. D. (2003). *Product Design and Development* (Vol. 2003, p. 366). McGraw-Hill Education (India) Pvt Limited.

98. VeerAiyan, N., Thangavelu, B., Alakiyamanavalan, & Lakshmi, P. (2014). Impact of modernization of harvesting in tea plantation to improve the productivity and quality. *IOSR Journal of Environmental Science, Toxicology and Food Technology*. Retrieved from http://iosrjournals.org/iosr-jestft/papers/vol8-issue9/Version-3/I08935559.pdf

99. Wilkinson, J. (2004). The Food Processing Industry , Globalization and Developing Countries, *1*(2), 184–201.

100. Yiyuan, Z., Tangwen, Y. I. N., Dayong, D., & Shan, F. U. (2011). Procedia Engineering Using NASA-TLX to evaluate the flight deck design in Design Phase of Aircraft.

101. Yu, W., Yu, I. T. S., Li, Z., Wang, X., Sun, T., Lin, H., … Xie, S. (2012). Work-related injuries and musculoskeletal disorders among factory workers in a major city of China. *Accident; Analysis and Prevention*, *48*, 457–63.

102. Zjenane, C., & Mattbieu Tockert. (2006). A competency based qualification programme in automation technology and process control applied to agro- industries in developing countries. In *Addressing the challenges facing agricultural mechanisation input supply and farm product processing* (p. 41).

Appendix 1: Quick Exposure Check

Quick Exposure Check (QEC)

QEC has been designed to:

- assess the changes in exposure to musculoskeletal risk factors of the back, shoulders and arms, hands and wrists, and neck before and after an ergonomic intervention
- involve the practitioner (i.e. the observer) who conducts the assessment, and the worker who has direct experience of the task
- indicate change in exposure scores following an intervention

The QEC Guide gives more detailed information about each question and the background to QEC.

Worker's name: ______________________

Worker's job title: ______________________

Task: ______________________

Assessment conducted by: ______________________

Date: ______________ Time: ______________

Action(s) required: ______________________

____

____

For more information on the Quick Exposure Check contact:
The Robens Centre for Health Ergonomics
European Institute of Health and Medical Sciences
University of Surrey, Guildford GU2 7TE
Telephone 01483 689 213
www.surrey.ac.uk/robens/erg

Robens UniS

Worker's name ______________________ Date ____________

Observer's Assessment

Back

A When performing the task, is the back
(select worse case situation)

- A1 Almost neutral?
- A2 Moderately flexed or twisted or side bent?
- A3 Excessively flexed or twisted or side bent?

B Select ONLY ONE of the two following task options:

EITHER

For seated or standing stationary tasks. Does the back remain in a static position most of the time?

- B1 No
- B2 Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). Is the movement of the back

- B3 Infrequent (around 3 times per minute or less)?
- B4 Frequent (around 8 times per minute)?
- B5 Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C When the task is performed, are the hands
(select worse case situation)

- C1 At or below waist height?
- C2 At about chest height?
- C3 At or above shoulder height?

D Is the shoulder/arm movement

- D1 Infrequent (some intermittent movement)?
- D2 Frequent (regular movement with some pauses)?
- D3 Very frequent (almost continuous movement)?

Wrist/Hand

E Is the task performed with
(select worse case situation)

- E1 An almost straight wrist?
- E2 A deviated or bent wrist?

F Are similar motion patterns repeated

- F1 10 times per minute or less?
- F2 11 to 20 times per minute?
- F3 More than 20 times per minute?

Neck

G When performing the task, is the head/neck bent or twisted?

- G1 No
- G2 Yes, occasionally
- G3 Yes, continuously

Worker's Assessment

Workers

H Is the maximum weight handled MANUALLY BY YOU in this task?

- H1 Light (5 kg or less)
- H2 Moderate (6 to 10 kg)
- H3 Heavy (11 to 20kg)
- H4 Very heavy (more than 20 kg)

J On average, how much time do you spend per day on this task?

- J1 Less than 2 hours
- J2 2 to 4 hours
- J3 More than 4 hours

K When performing this task, is the maximum force level exerted by one hand?

- K1 Low (e.g. less than 1 kg)
- K2 Medium (e.g. 1 to 4 kg)
- K3 High (e.g. more than 4 kg)

L Is the visual demand of this task

- L1 Low (almost no need to view fine details)?
- *L2 High (need to view some fine details)?

* *If High, please give details in the box below*

M At work do you drive a vehicle for

- M1 Less than one hour per day or Never?
- M2 Between 1 and 4 hours per day?
- M3 More than 4 hours per day?

N At work do you use vibrating tools for

- N1 Less than one hour per day or Never?
- N2 Between 1 and 4 hours per day?
- N3 More than 4 hours per day?

P Do you have difficulty keeping up with this work?

- P1 Never
- P2 Sometimes
- *P3 Often

* *If Often, please give details in the box below*

Q In general, how do you find this job

- Q1 Not at all stressful?
- Q2 Mildly stressful?
- *Q3 Moderately stressful?
- *Q4 Very stressful?

* *If Moderately or Very, please give details in the box below*

* *Additional details for L, P and Q if appropriate*

***L**

***P**

***Q**

TH-1340_09610503

Exposure Scores Worker's name ________________ Date ________

Back

Back Posture (A) **& Weight** (H)

	A1	A2	A3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1 ☐

Back Posture (A) **& Duration** (J)

	A1	A2	A3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2 ☐

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3 ☐

Now do **ONLY** 4 if static
OR 5 and 6 if manual handling

Static Posture (B) **& Duration** (J)

	B1	B2
J1	2	4
J2	4	6
J3	6	8

Score 4 ☐

Frequency (B) **& Weight** (H)

	B3	B4	B5
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 5 ☐

Frequency (B) **& Duration** (J)

	B3	B4	B5
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 6 ☐

Total score for Back
Sum of scores 1 to 4 **OR**
Scores 1 to 3 plus 5 and 6 ________

Shoulder/Arm

Height (C) **& Weight** (H)

	C1	C2	C3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1 ☐

Height (C) **& Duration** (J)

	C1	C2	C3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2 ☐

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3 ☐

Frequency (D) **& Weight** (H)

	D1	D2	D3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 4 ☐

Frequency (D) **& Duration** (J)

	D1	D2	D3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 5 ☐

Total score for Shoulder/Arm
Sum of Scores 1 to 5 ________

Wrist/Hand

Repeated Motion (F) **& Force** (K)

	F1	F2	F3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 1 ☐

Repeated Motion (F) **& Duration** (J)

	F1	F2	F3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2 ☐

Duration (J) **& Force** (K)

	J1	J2	J3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 3 ☐

Wrist Posture (E) **& Force** (K)

	E1	E2
K1	2	4
K2	4	6
K3	6	8

Score 4 ☐

Wrist Posture (E) **& Duration** (J)

	E1	E2
J1	2	4
J2	4	6
J3	6	8

Score 5 ☐

Total score for Wrist/Hand
Sum of Scores 1 to 5 ________

Neck

Neck Posture (G) **& Duration** (J)

	G1	G2	G3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 1 ☐

Visual Demand (L) **& Duration** (J)

	L1	L2
J1	2	4
J2	4	6
J3	6	8

Score 2 ☐

Total score for Neck
Sum of Scores 1 to 2 ________

Driving

M1	M2	M3
1	4	9

Total for Driving ________

Vibration

N1	N2	N3
1	4	9

Total for Vibration ________

Work pace

P1	P2	P3
1	4	9

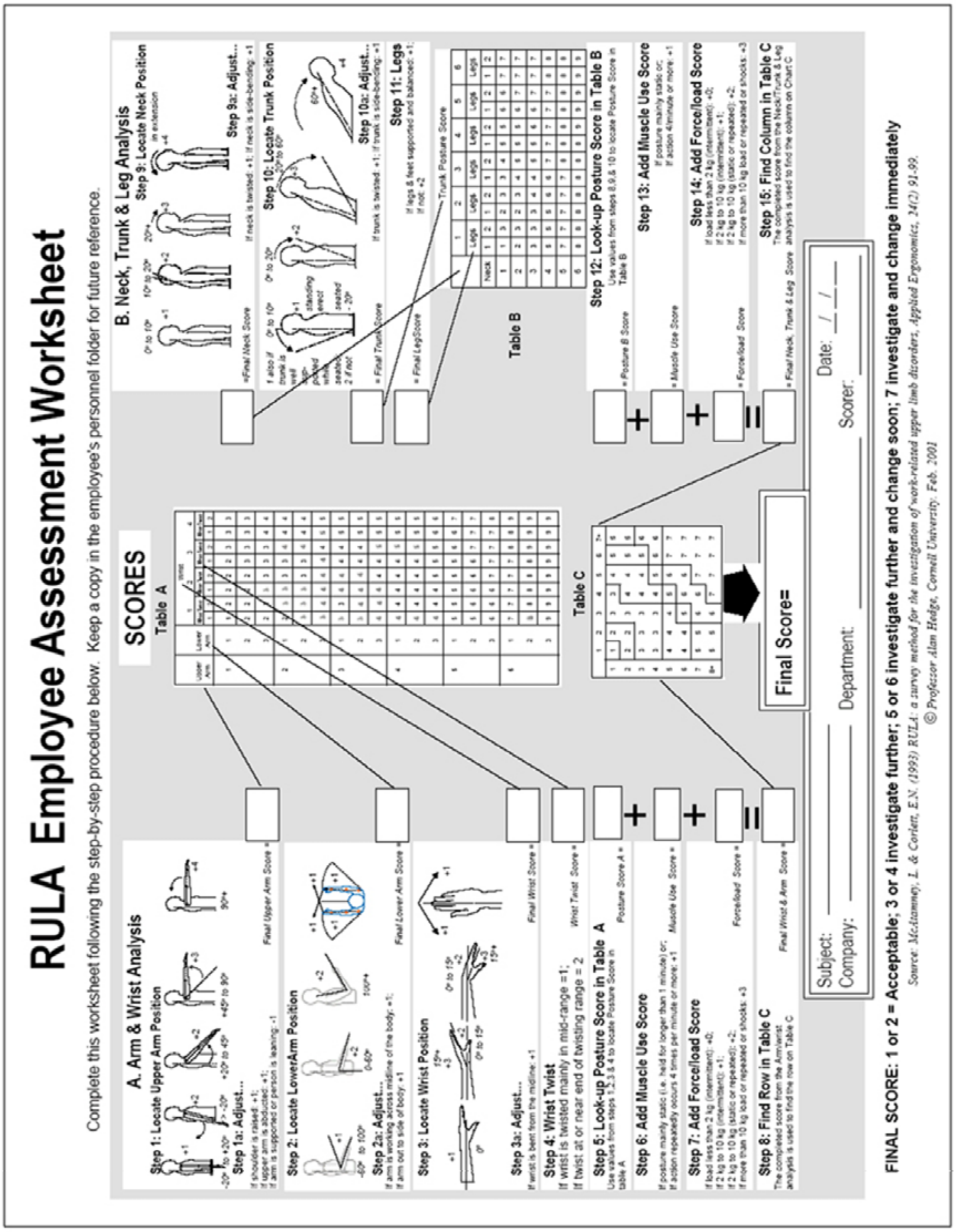
Total for Work pace ________

Stress

Q1	Q2	Q3	Q4
1	4	9	16

Total for Stress ________

Appendix 2: RULA Self Employee Assessment worksheet



Appendix 3: Category-Requirement Relationship Rating Sheet

Category- Requirement Relationship Rating

Name ____

Background ____

Contact No.____

A pineapple peeling solution has to be purchased for small labour intensive processing units which appropriately meets their requirement. These units run throughout the day and face various issues like power crisis, space constraints, capital resource limitations, etc. There are basically four possible categories of peeling solutions i.e. small hand tools, hand powered machines, semi-automated machines and fully automated machines. All the requirements are generally associated with these solution categories. Rate how strongly or weakly these requirements are related to these solution categories. Rate the category- requirement association between 1to 7. With "7"being the strongest and "1" being the weakest.

Sr. No.	Categories of food processing machine / Users' Requirements	Small hand tool like solution	Hand powered solutions	Semi-Automated solutions	Fully automated solutions
1	Lower Cost				
2	Lower wastage of raw material				
3	Better Portability				
4	Higher productivity				
5	Better peeling effectiveness (diff. sizes)				
6	Uniform quality of output				
7	Lesser repair and maintenance				
8	Higher aesthetic appeal				
9	Power-independent operation				
10	Less Space occupying				
11	Better safety of workers(accident / injuries)				
12	Better Adaptability of workers(familiarity to technology)				
13	Better comfort of workers				
14	Multipurpose utility				

Appendix 4: Priority assessment questionnaire

Priority assessment questionnaire

This questionnaire is the part of ongoing research in equipment design for small scale industries and the information provided here is to be solely used for the academic purpose.

Name of Entrepreneur:____

Name of Unit:____________________________________

Number of workers:____

Processing capacity:_______________________

Products

manufactured:____

____

Problems Faced in processing:_______________________________________

____

What you find are the difficult tasks in pineapple processing:_______________________

Present peeling technique:_______________________________________

Do you feel peeling is a difficult task?

Not at all						Very much
1	2	3	4	5	6	7

How much does the peeling process affect production capability of the unit?

Not at all						Very much
1	2	3	4	5	6	7

A new M/c has to be developed for pineapple peeling and this survey is to understand the different priorities of the entrepreneurs. All the questions below are to be answered in this context only.

Sr. no.	Questions	Responses						
1EA	Would you prefer M/c which peels fast but cannot peel different shapes and size of pineapple effectively?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
1EB*	Would you prefer M/c which peels quite fast but also removes some amount of flesh while peeling that is greater than present M/c?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
2WA*	Would you prefer M/c which has very high output also a high wastage	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7

2WB*	Would you prefer M/c which has moderate output and amount of waste is more than present technique	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
3PA*	Would you prefer a machine which cant peel significantly fast	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
3PB	How important productivity in selecting a new M/c	Not Important at all						Very Important
		1	2	3	4	5	6	7
3PC	How significant is very high productivity for you (say1000 Pc/Hr)?	Not significant at all						Vey Significant
		1	2	3	4	5	6	7
4RA*	Would you prefer M/c that needs regular maintenance for better performance?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
4RB*	Would you prefer a machine having periodical wear, tear but high peeling rate?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
5SA*	Would you buy equipment that is as per all expectations but might have risk in operating?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
5SB*	Would you buy M/c if there is some probability of injuries during operations?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
6EA*	Would you prefer M/c which meets all expectations but slightly difficult to use, in terms of effort?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
6EB*	Would you prefer M/c which is less repetitive and fast but requires higher force than present technique?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
7AA*	Would you prefer M/c which requires time or training for getting familiar with?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
7AB	Would you prefer machine which requires time or training for understanding and operation if it is really fast once operations starts?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
8CA*	Would you spend more than your estimate if the machine is as per expectation?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
8CB*	Would you buy M/c if it is above your expectation but the cost is extremely high?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
9EA*	How is the present power situation in your area wrt your unit's requirements?	Very Bad						Very good
		1	2	3	4	5	6	7

9EB*	W.r.t prevailing power condition, how much would you prefer an electric power driven machine?	Not important at all						Very important
		1	2	3	4	5	6	7
10MA	Would you spend more than your estimate if the equipment has multiple utility?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
10MB	Would you go for a big & costly M/c if it can peel some other fruits as well?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
11PA*	Would you buy M/c which is as per expectation but has to be almost permanently fixed?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
11PB	Would you prefer M/c which is somewhat lower on expectation but easy to take any where	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
12SA*	Would you prefer a machine which occupies more space compared to present M/c or tool?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
12SB*	Would you accommodate M/c which is as per your expectation but bigger in size?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
13QA*	Is roughly peeled output acceptable for the majority of items which you prepare?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
13QB*	Would you prefer M/c that peels fast but has some juice spills and crushed output?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
14AA*	Would you buy a machine which doesn't have very appealing look but performs well?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7
14AB	Would you like a machine which looks very nice but has moderate performance?	Definitely Not						Definitely Yes
		1	2	3	4	5	6	7

Appendix 5: NASA Task Load Index

NASA Task Load Index

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

Name	Task	Date

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

Very Low — Very High

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

Very Low — Very High

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

Very Low — Very High

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

Perfect — Failure

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

Very Low — Very High

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

Very Low — Very High

Appendix 6: Buyer specific equipment details

Hand powered machine

Space requirement (l*b*h):
450 * 350* 500 mm (to be fixed on some table)

Weight : 5 kg

Cost: 5500/-

Material: Contacting parts of stainless steel 304

Easy to fit and use blade with 3 diameter(105, 95, 85 mm) to peel and cut the pineapple

Capacity: 75-100 pc/hr

Appendix 7: Product Efficacy Assessment sheet

Assessment of products' efficacy in fulfilling the entrepreneurs' key requirements

This questionnaire is the part of ongoing research in equipment design for small scale industries and the information provided here is to be solely used for the academic purpose.

Name: ____

Unit: ____

This questionnaire has to be completed on the basis of product models, which have been demonstrated with all necessary details i.e. general working, cost, material, dimension, weight, some specific information pertaining the model, etc. The objective of the study is to compare the old model with new models to establish its efficacy in fulfilling different requirements with respect to criteria mentioned below.

1. How would you rate the following features of the given product, considering work period for a whole day?

		Very Bad	Bad	Somewhat Bad		Somewhat Good	Good	Very Good
1	Peeling effectiveness (different diameter)	1	2	3	4	5	6	7
2	Lower/ acceptable material wastage	1	2	3	4	5	6	7
3	High Productivity (output rate)	1	2	3	4	5	6	7
4	less frequent repair and maintenance	1	2	3	4	5	6	7
5	safe operation	1	2	3	4	5	6	7
6	Easy/ comfortable operation	1	2	3	4	5	6	7
7	Ease of understanding and operating	1	2	3	4	5	6	7
8	Lower cost	1	2	3	4	5	6	7
9	Non electric operation	1	2	3	4	5	6	7
10	multipurpose use possibility	1	2	3	4	5	6	7
11	Ease of carrying and moving	1	2	3	4	5	6	7
12	Less space occupying	1	2	3	4	5	6	7
13	Uniform quality of output	1	2	3	4	5	6	7
14	Looks of the product	1	2	3	4	5	6	7

Unit:____

2. Rate the model for its appropriateness in fulfilling various requirements with respect to following considerations.

		Most inappropriate		Might be inappropriate		Might be appropriate		Most appropriate
1	Consideration for Effective peeling of varying shapes and sizes of fruit	1	2	3	4	5	6	7
2	Consideration for wastage reduction	1	2	3	4	5	6	7
3	Consideration for faster peeling irrespective of quantity	1	2	3	4	5	6	7
4	Consideration for reducing frequency of repair and maintenance	1	2	3	4	5	6	7
5	Consideration for operational safety	1	2	3	4	5	6	7
6	Consideration for user comfort	1	2	3	4	5	6	7
7	Consideration for ease of understanding and use without any training or skill	1	2	3	4	5	6	7
8	Consideration for cost of equipment	1	2	3	4	5	6	7
9	Consideration for existing power supply	1	2	3	4	5	6	7
10	Consideration for multipurpose use	1	2	3	4	5	6	7
11	Consideration for ease of carrying and moving	1	2	3	4	5	6	7
12	Consideration for space requirement for installing and using	1	2	3	4	5	6	7
13	Consideration for quality of output in terms of lesser damage and smooth finished output	1	2	3	4	5	6	7
14	Consideration for aesthetic appeal of product	1	2	3	4	5	6	7

Appendix 8: Details regarding different Categories of peeling solution

Hand operated small tool

Space requirement: negligible

Weight: 100- 200 gm

Cost: 100 -500/-

Material: Stainless steel and plastic

Capacity: 20- 25 pc/hr

Hand operated small tool

Space requirement(Dia. * L): 84 * 240 mm

Weight: 200 -300 gms

Cost: 1913/-

Material: Stainless steel and plastic

Capacity: 30- 40 pc/hr

Hand powered Solution

Space requirement (l*b*h):
505 * 295* 550 mm

Weight : 5 kg

Cost: 5500/-

Material: Contacting parts of stainless steel 304

Capacity: 75-100 pc/hr

Semi automated machine

Space requirement (l*b*h): 1100*265*920 mm

Weight: 200 kg

Power: 1.5- 4 kW

Cost: 307,550/-

Material: Contacting parts of stainless steel 304

Capacity: 360-600 pc/hr

Semi automated machine

Space requirement (l*b*h): 700*762.5*1725 mm

Weight: 200 kg

Power: 1.5- 2 kW

Cost: 307,550/- (approx.)

Material: Contacting parts of stainless steel 304

Capacity: 360-600 pc/hr

Semi automated machine

Space requirement (l*b*h): 1500*700*1900 mm

Weight: 150 kg

Power: 1.5 kW

Cost: 1,200,000/-

Material: Contacting parts of stainless steel 304

Capacity: 400-600 pc/hr

Thickness of peel that can be removed: 2- 6 mm (adjustable)

Automated Pineapple Processing Line

Space requirement (l*b*h): magnificent

Weight: more than 200 kg

Power: 10- 15 kW

Cost: 30,500,000/-

Capacity: 800 –1000 pc/hr

Appendix 9: Product Category preference assessment sheet

Assessment of Entrepreneurs' preferences of the product categories

Unit:____

Part 1

1. For these given models what would be your order of preference?(1- 4 in descending order)

   ____

   ____

2. What are the most important and attractive attributes which made you make the most preferred choice?

   ____

3. What is the most undesirable attribute that made you make the least preference?

   ____

Part-2

4. How would rate these four products as per suitability to your context of use:

		Most Inappropriate						Most Appropriate
1	Model 1	1	2	3	4	5	6	7
2	Model 2	1	2	3	4	5	6	7
3	Model 3	1	2	3	4	5	6	7
4	Model 4	1	2	3	4	5	6	7

5. What would be your likeliness if you have to buy one:

		Most unlikely						Most likely
1	Model 1	1	2	3	4	5	6	7
2	Model 2	1	2	3	4	5	6	7
3	Model 3	1	2	3	4	5	6	7
4	Model 4	1	2	3	4	5	6	7

6. Which model will be most acceptable to you? Rate them:

		Most unacceptable						Most acceptable
1	Model 1	1	2	3	4	5	6	7
2	Model 2	1	2	3	4	5	6	7
3	Model 3	1	2	3	4	5	6	7
4	Model 4	1	2	3	4	5	6	7

Appendix 10: List of Publications

Journal papers, Conference papers and Abstracts published, under review in connection to the thesis work

1. Prakash Kumar, and Debkumar Chakrabarti, QFD based methodology to decide upon contextually appropriate solution category with specific reference to pineapple peeling equipment design, ICORD 2015, January 2015 (Springer).

2. Prakash Kumar, and Debkumar Chakrabarti, Ergonomic evaluation of manually operated pineapple peeling machine, HWWE 2014- Guwahati, December 2014 (Mc Graw Hill).

3. Prakash Kumar, and Debkumar Chakrabarti, Thaneswer Patel and Anirban Chowdhuri, Occupational health related issues and ergonomic risk factors associated with pineapple peeling activity among the small fruit processing unit workers, International Journal of Industrial Ergonomics (under final review).

4. Prakash Kumar, and Debkumar Chakrabarti, Design development of a pineapple eye removing device, HWWE 2011- Chennai, January 2012.

5. Prakash Kumar, and Debkumar Chakrabarti, Extending the life cycle of under-utilized urban scrap through sustainable Design Approach, ICORD 2011, January 2011.

6. Prakash Kumar, and Debkumar Chakrabarti, User Centered design input in Mechanical Engineering and Design: Ergonomics relevance, HWWE 2009 - Kolkata, December 2009.

7. Thaneswar Patel, Sanjog. J, Prakash Kumar and Sougata Karmakar, Isometric muscular strength data of Indian agricultural workers for equipment design: Critical analysis,Agricultural engineering international CIGR Journal, Vol 16, June 2014.

8. Thaneswar Patel, Sanjog. J, Prakash Kumar and Sougata Karmakar, Analytical Study of Isometric Muscular Strength of Agricultural Workers: Indian Perspective,Ergo-2013 Ergonomics for Rural Development, December 2013.

9. Sangeeta Pandit, Prakash Kumar, and Debkumar Chakrabarti, Ergonomic Problems Prevalent in Handloom Units of North East India, International Journal of Scientific and Research Publications, Volume 3, Issue 1, January 2013.

9 Prakash Kumar, and Debkumar Chakrabarti, "Design intervention to enhance productivity of the workers engaged in manual peeling of pineapple at small industrial units", National Seminar on 'Ergonomics for Enhanced Productivity' Tamilnadu Agricultural University, February 2013(abstract).

10 Prakash Kumar, and Debkumar Chakrabarti, "Ergonomic Risk Assessment in small scale pineapple processing units of North East", Indian science congress, Indian science congress, Kolkata, January 2013(abstract).

11 Prakash Kumar, and Debkumar Chakrabarti, "Ergonomic investigation of the practices adopted for pineapple pealing in small scale fruit processing units of North east", at Humanizing work and work environment (HWWE) Conference, Pant Nagar, December 2012(abstract).

12 Prakash Kumar, and Debkumar Chakrabarti , "Occupational health related issues in pineapple processing industries of North east India", International Conference on Molecules to Systems Physiology, Kolkata 2011(abstract).