Vol. 17, no. 1, pp. 59-68, enero-junio 2018
Revista UIS Ingenierías
Página de la revista: revistas.uis.edu.co/index.php/revistauisingenierias

Design of a cutting tool for oil-palm bunches

Diseño de una herramienta de corte para racimos de palma aceitera

Lina Parra-Ruiz[1], Jorge Quintero-Medina[2], Fernanda Maradei[3]

[1]Escuela de Diseño Industrial, Universidad Industrial de Santander, Colombia. Email: linaparrapr@gmail.com
[2] Escuela de Diseño Industrial, Universidad Industrial de Santander, Colombia. Email: jleonardo.qm@gmail.com
[3] Escuela de Diseño Industrial, Universidad Industrial de Santander, Colombia. Email: mafermar@uis.edu.co

RECEIVED: October 27, 2016. ACCEPTED: May 27, 2017. FINAL VERSION: October 5, 2017.

ABSTRACT

The aim of this article is to design a Cutting System for Oil-palm fruit bunches to reduce both the low back stress in workers and the damage received by the bunches when impacting the soil. The Oil palm has gained importance around the world because its efficiency in terms of productivity and resources consumption. However this palm can reach 20 meters high with a leaf crown that make difficult to have access to the fruit bunches. Bunches can weigh between 20 and 25 kg, in consequence, workers have to adopt uncomfortable postures that force the body and develop musculoskeletal disorders especially the low back pain. The process of design starts by a field analysis that allows to determinate the way in which workers use tools like Malaysian knife, and the postures that they normally adopt to develop this task. This information was taken to create alternatives and concepts, which were modelled in CAD software and tested through a finite element analysis. The low back stress is reduced trough taking the mass centre of the tool out of the body; this is possible with a new support that carried the cutting tool while workers only manoeuvre to give direction. To reduce the impact energy, it was performed panels around the palm, which offer an elastic deformation, those can adopt the form of a wheelbarrow to make easy its transportation. Through this system workers are able to cut the bunches without perform inappropriate body postures and at the same time, as the mass centre is out of the operator's body there is no reaction over lumbar discs. Otherwise, as panels produce an elastic deformation while bunch's collide this increase the time for fruit bunches to reach the soil, for that the deceleration enhance and in this way the collision force is reduced.

KEYWORDS: Ergonomics; low back stress; fruit damage; human simulation.

RESUMEN

El objetivo de este artículo es diseñar un sistema de corte para racimos de fruta de palma de aceite para reducir tanto el estrés lumbar en los trabajadores como el daño recibido por los racimos al impactar el suelo. La palma de aceite ha ganado importancia en todo el mundo debido a su eficiencia en términos de productividad y consumo de recursos. Sin embargo, esta palma puede alcanzar los 20 metros de altura con una corona de hojas que dificultan el acceso a los racimos de frutas. Los racimos pueden pesar entre 20 y 25 kg, en consecuencia, los trabajadores tienen que adoptar posturas incómodas que fuerzan al cuerpo y desarrollan trastornos musculoesqueléticos, especialmente el dolor lumbar. El proceso de diseño comienza con un análisis de campo que permite determinar la forma en que los trabajadores usan herramientas como el cuchillo malasio y las posturas que normalmente adoptan para desarrollar esta tarea. Esta información se tomó para crear alternativas y conceptos, que se modelaron en software de CAD y se probaron a través de un análisis de elementos finitos. El estrés de la espalda baja se reduce al retirar el centro de masa de la herramienta del cuerpo; esto es posible con un nuevo soporte que lleva la herramienta de corte, mientras que los trabajadores solo maniobran para dar dirección. Para reducir la energía de impacto, se realizaron paneles alrededor de la palma, que

ISSN Impreso: 1657 - 4583, En Línea: 2145 - 8456

ofrecen una deformación elástica, que pueden adoptar la forma de una carretilla para facilitar su transporte. A través de este sistema, los trabajadores pueden cortar los racimos sin realizar posturas corporales inapropiadas y, al mismo tiempo, como el centro de masa está fuera del cuerpo del operador, no hay reacción sobre los discos lumbares. De lo contrario, como los paneles producen una deformación elástica mientras chocan los racimos, esto aumenta el tiempo para que los racimos de fruta lleguen al suelo, por lo que la desaceleración mejora y de esta manera se reduce la fuerza de colisión.

PALABRAS CLAVE: Ergonomía; tensión de espalda baja; daño a la fruta; simulación humana.

1. INTRODUCTION

The oil palm is one of the main products harvested and exported in Colombia, is a perennial tree that produces between three and four bunches each crop, whose weight is roughly from 20 to 25 kilograms and it has to be harvested three times a year during 25 years of palm life. Its applications have a range of variety from cleaning implements to dietary fats with high energy content[1]. The Oil extracted is considered the raw material that used less energy and chemicals during its farming process and at the same time, it is the most productive in terms of oil amount per hectare sown[1].

The anatomy of oil palm restricts the harvest labour, due to positions of bunches and limited access to get it. These are in the upper part of the palm at 20 m height and is supported by a crown of leaves with a radius of 3 m, additionally the leaves and bunches have thorns [2]. The conventional tool used to harvest is the Malayan stick, which has a blade in the distal end of a long bar with more than 3 m length. The tool allows to remove the leaves close to the fruit. Afterwards, the branch that holds the bunch is cut and the later falls down to ground, this produce damage on the fruit like wounds and bruises[3].

The technological review shows that there are no other tools for harvest activity in the palm oil sector. In addition, the ergonomics analysis shows that farmers adopt force postures and repetitive movements that increase operator workload resulting in the low back and upper limbs pain[4]. Romero (2000) identifies a series of risk factors such as handing heavy, awkward postures and poor safety standards; the last risk is responsible for 80% of the accidents[5]. These accidents have a serious economic impact on a business; in one of palm-oil plantations of the eastern llanos basin of Colombia, the total cost in e year was estimated at $134 million due to direct and indirect cost[5].

Thus, this sets the great challenge of finding responses to the current situation to improve the labours conditions. Therefore this work is aimed to designer a tool that would support the palm-oil extraction process that will reduce injuries to farmers.

2. MATERIAL AND METHODS

2.1. Direct observation

For the design of the cutting system it was conducted a data recollection stage that began with a technical visit where the goal was to identify the conventionally tools used and understand the process for bunch recollection. The observation was conducted in a farm located in the

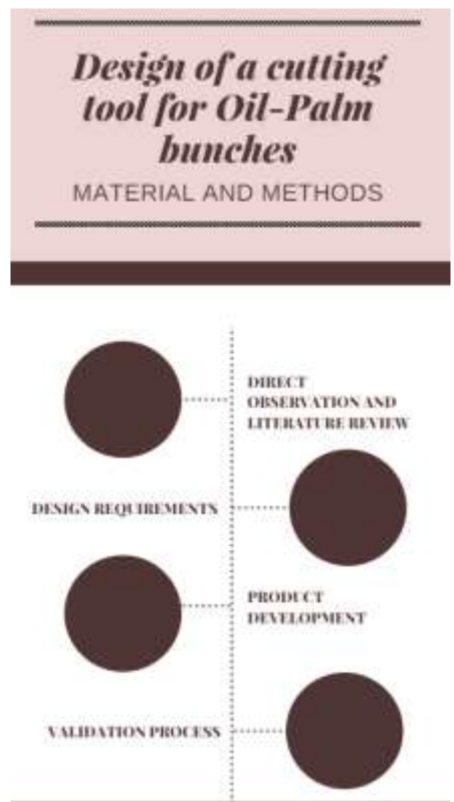


Figure 1. The design processes. **Resource**. Author.

township of San Rafael (Santander), the goal of the visit was to understand, how the peasants harvest oil-palm. This was followed by an interview with farmers to learn about the activities and tools used, additionally the study was made an analysis of load charges by human model simulation (Jack and process simulate human, Siemens PLM software); these was evaluated through OWAS[6] and NIOSH[7]. Finally, a literature and technologic review was made to determine criteria for design (see Figure 1).

2.2. Design requirements

Based on the observed and the literature found, the design attributes were established according to latent needs identified in the sector, include: a) desirables attributes that are the users expectation of product to achieve, b) the obligatory and c) standards, which are based on security norms. From these the design requirements were determined and classified in four categories: human, technical-productive, functional and formal-aesthetics. Likewise, these requirements were prioritized under relevance level, according its importance on tool development.

First of all are the functional requirements based on leaves and bunches cut, in a second place the technical-productive requirements as production cost and fabrication process, followed by human requirements focused on ergonomics parameters and accidents prevention as well as human factors.

2.3. Product development

In the product development stage, the alternatives were proposed and are screened according to the tool main function. In this way, it were assessment and preselected three alternatives, according to requirements fulfilment percent, which were based on the relevance level previously established.

The final alternative selected is carried out to details design, thus at this stage was developed the mechanism required for operation and dimensions. In the same way, it was used an Ashby methodology to select the materials, taking into account the mechanical strain that they will endure. This methodology consists of four phases, the first is translation where the functions, limits and aims that a material must satisfy, this information is the base for the second step, in which the materials that no fulfill the requirements established were discard, in this way the selected materials are organized in descending order where the first place is occupied by the one which present better properties (ranking). Finally a research of support information is done with the purpose to determinate physics-mechanical and physics-chemical additional properties that designer must know[8].

Finally the tool's static analysis was made with the materials selected and verified by Solidworks software to prevent design fault.

3. RESULTS

3.1. Recollection data stage

The technical visit was in Meseta San Rafael road Bucaramanga-Barrancabermeja, had 30 hectares and working between three and four people in bunches harvesting activity. The farm is located in a region constantly affected by change weather, this impact negatively the cutting and recollection bunches task due the difficult access that field present.

The operators use Malaya stick and knife to carry out the tasks, those tools do not present grips to prevent a hand slipping while the cut is done, at the same time the blade is not welded to telescopic pole, because this have to be removed for a constant sharpening.

For the pruning and cutting bunches process, the direct observation found the following steps: First, workers have to remove the leave located right below the bunch and whose brings support, to do this, the worker put the knife on the leave's based and made a tangential cut, when this have been detach is necessary to chop in two or three parts and lay around the palm, in this way the accident rate is reduced for workers and animals used for transporting loads and at the same time, it will become into compost for the other plants. The next step is cut the branch, this makes the bunch falls down until collide with land, and then it is necessary to transport them from crop to recollection point, for this task usually it is used animal-drawn carts. The farmer thrust the knife into the bunch's stem and throw it to wheelbarrow or lift it with both hands (see Figure 2).

Figure 2. Harvesting oil-palm. **Resource.** Authors.

Finally, the study found that the farmers declared discomfort in low back and neck, although they considered it common due to their labours, likewise, harvesting has a high load on the back due to plant height and the applied tool and the weight of the bunches between 20 to 25 kilograms (see Figure 3).

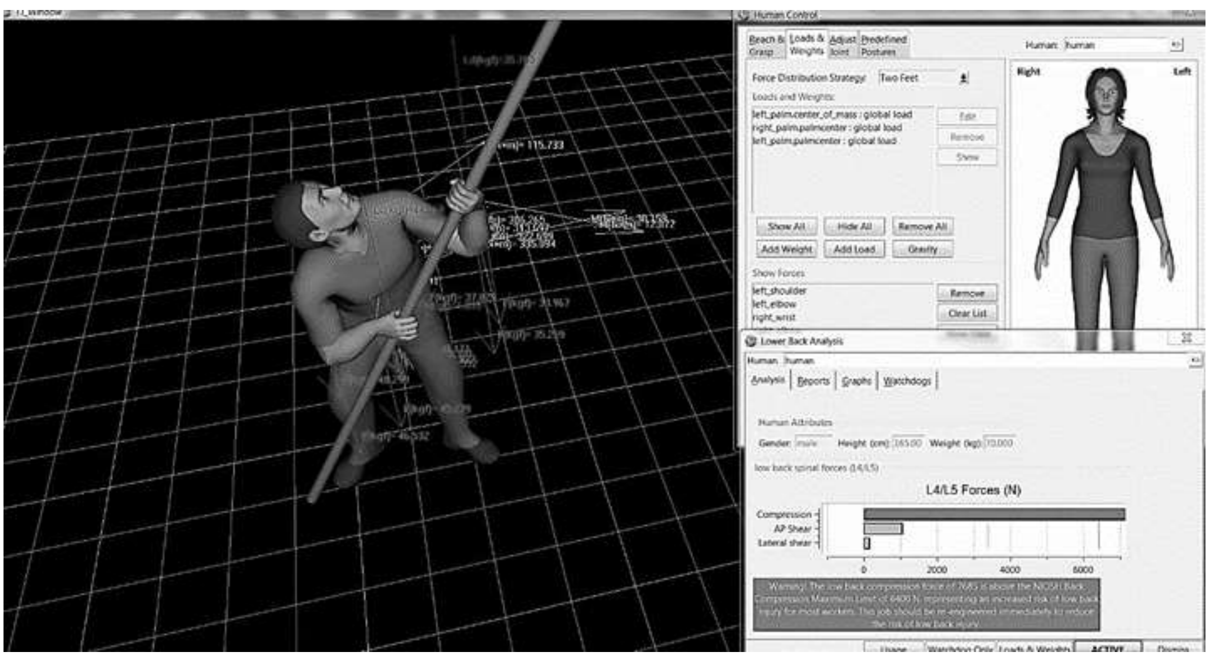


Figure 3. NIOSH with Malayan Stick. **Resource.** Authors.

3.2. Requirements

Based on the information found in the recollection data stage, the design attributes were established and classified in desirables, obligators and standards, in other words, the attributes that hope the product accomplish, those ones that must have and those that cannot change respectively.

In this way, the design requirements is set for each attribute, thus the importance was according to number of times that appear in the list (frequency), also some attributes may have had the same requirement, consequently it is produced an increase of the importance of the specific requirement that appear more than once. Desirables attributes have a punctuation of one (1), obligatory three (3) and two (2) for standards, therefore, each requirement's partial points are determined for the attribute's sum.

Finally if the requirement were established as an obligatory and a standard attribute it will have a partial punctuation of five.

The requirements were classified in human, technical productive and formal aesthetic. The point sums of each category are a percent of total punctuation, as well as requirements' importance level in order to assess each alternative (see table 1).

3.3. Alternatives evaluation

During the design stage of this project, 42 alternatives were made based on the attributes. First, those were assessment the functional requirements, taking into account the system ability to cut leaves and bunches and were preselected 30 alternatives. At the end of this phase, 18 possible solutions were selected, due to technique productive requirements associated to production cost and viability. After that human requirements in terms of ergonomics and accident rate reduction left three alternatives (Figure 4). Finally, it is determined the requirements fulfill percent for each proposed design, from this analysis, the alternative selected is alternative 3 due to accomplish in higher percent the majority of the requirements presented.

3.4. Detail Design

Based on final alternative the functional needs were determined, for which some mechanism are proposed as it is showed on the table 2.

Table 1. Hierarchy of requirements.

		Frequency	Partial points	Total	% Total
Human requirements	Cutting system weights less than 3 kgf	3	6	31	42,47
	The system's grip allows an elevation of 80° in relation with tool's axis.	2	4		
	Maximum vibration level 2 m/s^2	2	5		
	The handle has a length of 12,5 cm.	2	5		
	The system has a handle of 4 cm de diameter.	2	5		
	The handle has a friction coefficient between 0,5 and 1.	2	5		
	Frequency of maintenance one time per week.	1	1		
Technical productive requirements	60% recyclable.	1	1	16	21,92
	The materials have a security factor of 2.	3	6		
	The system uses less than 989.41 W for its operation.	1	1		
	The system generates under 0,911 kgf CO_2 during its use.	2	4		
	14 KW of energy is required for the manufacture.	1	1		
	The system resists a weight minimum of 25kgf.	1	2		
	Reduce bunch's collision force in 20%.	4	7		
Functional requirements	Allow pruning and cutting the bunch.	1	1	14	19,18
	Allow seeing the branch that will be cut.	1	1		
	The maximum dimensions for the system are 60x60x50 cm if the operator has to carry it.	1	3		
	Exact cut	1	2		
	The angle edge is greater than 100° and radius of curvature minimum of 2mm.	2	5		
formal aesthetic	The angle edge is greater than 100° and radius of curvature minimum of 2mm.	2	5	7	9,59
	System use language by means of universal signs and color codes.	1	1		
	The system is Modular	1	1		
				73	**100,00**

Table 2. Mechanics proposed.

Needs	Solution
Locate the blade on the bunch.	Elevation mechanism of the bar from 0° to 80°.
Routed the tool.	Routed mechanism.
Buffer the reaction force during the cut.	Compression spring to absorb the force.
Transport the tool.	Wheels in the three support points.
Buffer the vibrations by uneven ground.	Compression spring as buffer.
Make the cut.	Rail on the guide of the bar to move the blade in longitudinal direction.

Resource. Authors.

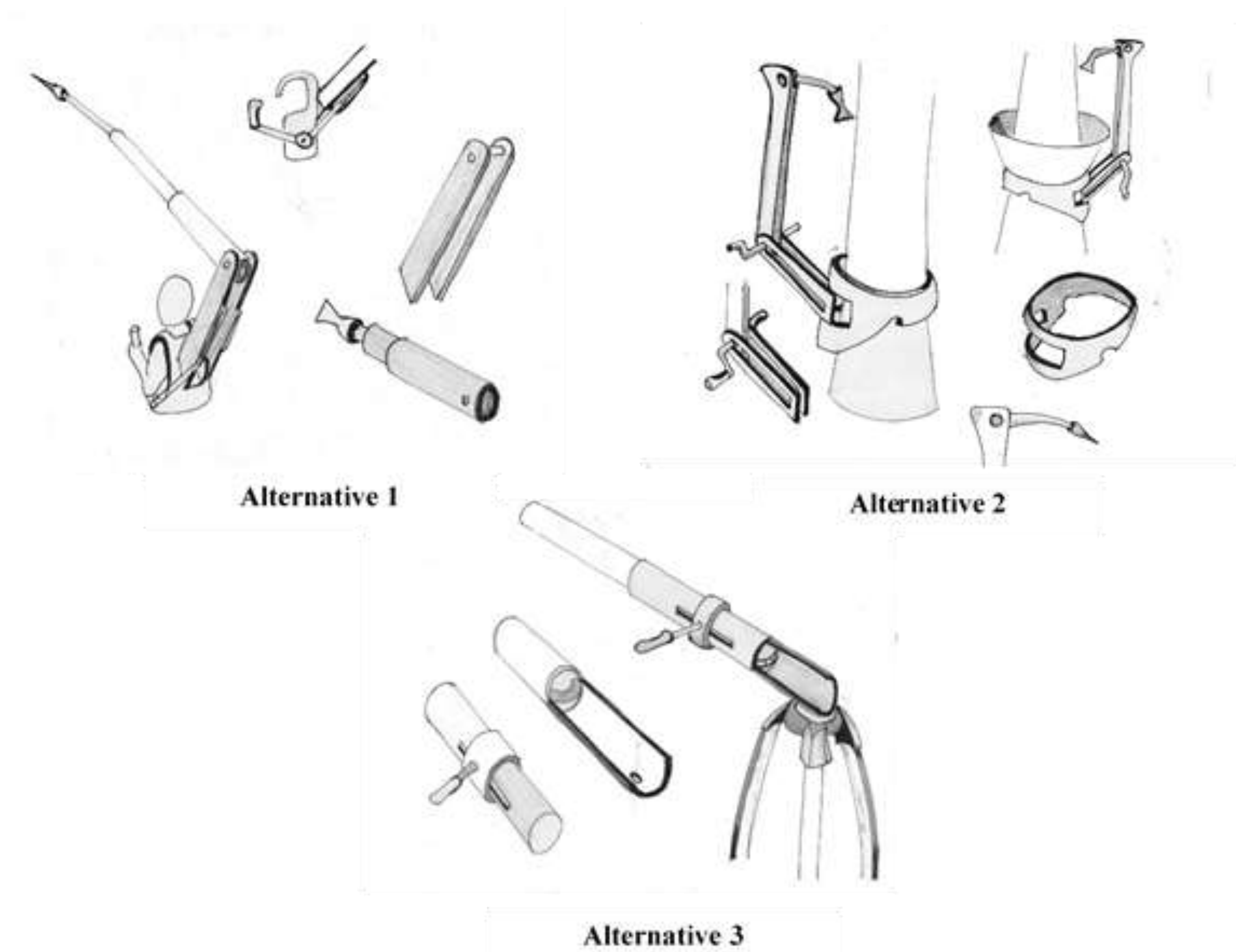


Figure 4. Alternatives preselected. **Resource.** Authors.

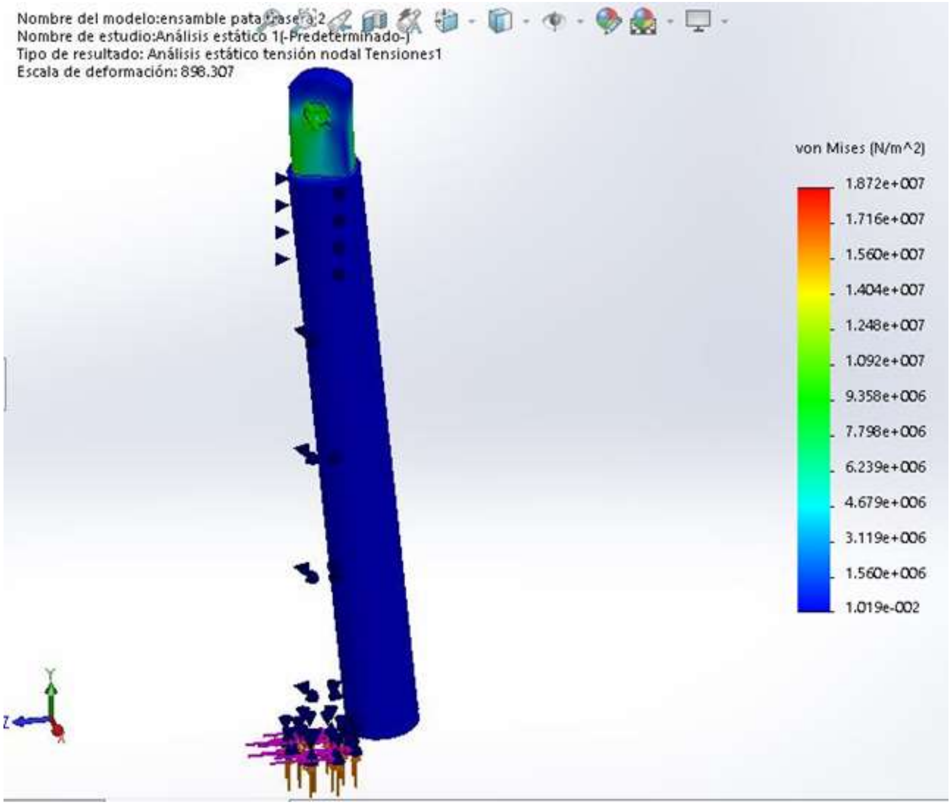
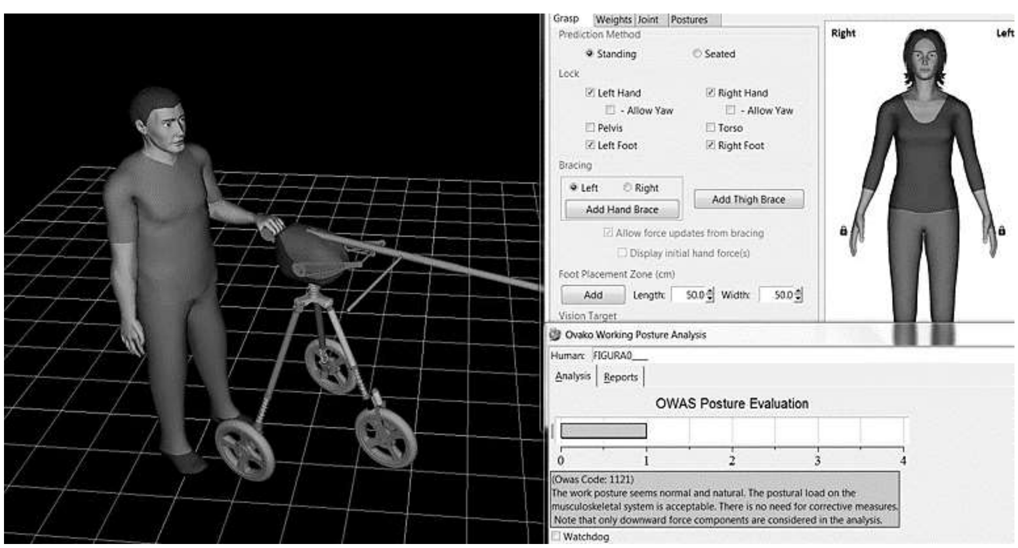


Figure 5. Static analyst validated through Solidworks. **Resource.** Authors.

The tools dimensions are based on anthropometric dimensions of a masculine population between 30-39 years old, where the radial height and biacromial width were taken into account according to the 50 percentile to prevent adduction and abduction shoulder postures, while it was used a percentile 5 for arm length to place the second handle the nearest distance from user's body with the aim of keep a neutral trunk posture.

Also, is established the material for each tool's piece. A static analysis is made to specify thickness' material and avoid failure due to wear or outside forces. The result obtained by static analysis were validate through simulation software called Solidworks (Figure 5) to determined possibility of material fractures, in this way the pieces which presented possible fails were formally modify or the material previously stablish was change.



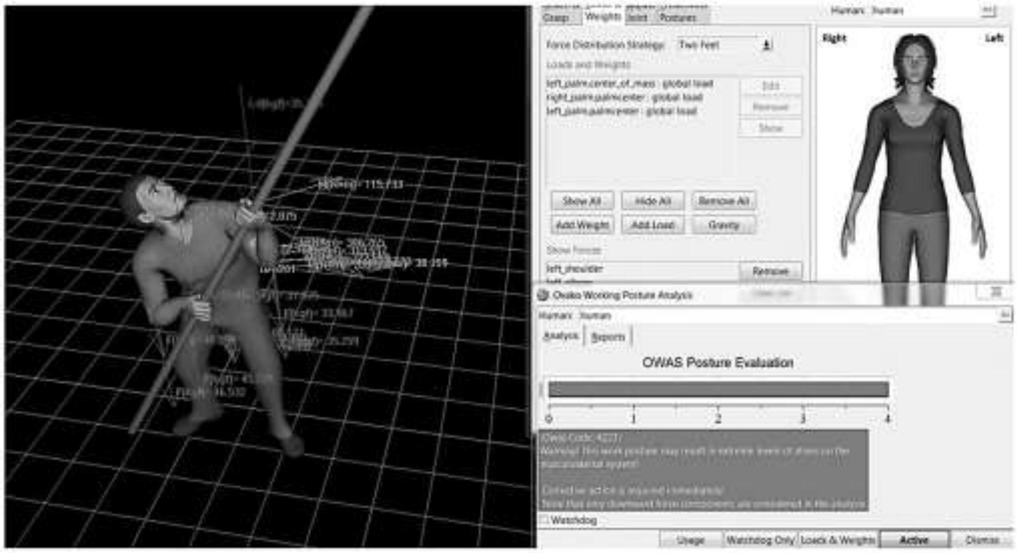


Figure 6. Postural comparison between new product (left side) and traditional tool (right side). **Resource.** Authors.

3.5. Cutting Tool

The tool purposed has a 3 points base whose bring support to telescopic bar, composed by two members of 2, 3 or 6 meters length, each one depends of the palm's height that is planning to be harvest. Additionally the tool can be transport inside the crop, there is no need to be carry off due to it has all-rounder wheels and at the same time, present a shock-absorbed to reduce the vibrations generated by uneven ground.

For the cutting task, the operator has to perform force in direction to the ground, this will activate the knife elevation mechanism, when the cut is executed the user can slides the bar trough a rail allowing to reach the bunch stem and placed the knife in the right point. For other part, the shaft under the body allow the tool a 360° radius of action to make easy reaching the palms planted around.

Likewise, a postural assessment was conducted to identify load joint by OWAS where this method considered the posture of arms, back, legs and the load. The figure 6 shows that when the new product is used, the postural risk is very low (score 1), on the contrary, when the traditional tool is used, the score is 4; very high.

4. DISCUSSION

The purpose of this study was to design a tool that would support the palm-oil extraction process that will reduce injuries to farmers. In this sense, it was found that the literature review agree with the situation observed on field, where conventional tools as Malaya stick and knife are used. However motorized tool are present in the market, this tools focus on enhance the productivity and efficient cut while patents found were mechanism that reduce the vibrations generated for motors and different knife forms to decrease the reaction forces produced by the cut.

In this connection, the motorized tools reduce the effort that person made when perform the harvesting task, nevertheless the motor weight and fuel have to be carry off in operators' back during their work hours, at the same time it is not a solution of getting access to tall bunches and continue with the conventional system of a long bar to get them.

However, the direct observation shows a high load on the back. That compression force was 7685 N above the NIOSH recommended back compression (3400 N) representing an increased risk of low back injury for most workers[7]. Similarly, the study also shows a postural risk very high when the farmers harvest; the work posture may result in extreme levels of stress on the musculoskeletal system[6]. These working conditions increase the possibility of musculoskeletal disorders which had already evident for other authors[2, 9, 10]. According to Burnett and al (2001), the kind of tools used by peasants may impact on the workload,[11] thought must therefore be given to applying reliable ergonomic principles more effectively to the way in which workplaces are designed and work is organised.

Based on this, with the use of the cutting tool proposed, the farmer keeps a neutral posture because this prevent back flexion and extension, also peasants does not bear up the weight of bunch and tool, it just rests where it is put (on the new product). At the same time the wheels transform the way in which operators move around the field and how the tool is transported inside the crop; although the operators have to push the tool, the force done for theirs no overcome the limit recommended for Snook and Ciriello in 1991 contemplating frequency, height push and distance, this characteristic allow the users handle the total tool's weight without development musculoskeletal disorders. Additionally the shock absorbers reduce the vibration generated for the uneven ground and the reaction forces when the cut is done. The telescopic bar is conforming by two pieces of two, three or six meters each one allowing reach palms from two (2) to 12 meters height, thus the weight carried off is no above the limit.

5. REFERENCIAS

[1] G. La Rotta Amaya and G. J. Tobón Quintero, "Efectos sociales del cultivo de palma de aceite: Condiciones laborales, seguridad social y educacion en los trabajadores palmeros de Cumaral," Bogota D.C., Trabajo de grado 2010.

[2] Y. G. Ng *et al.*, "Risk factors of musculoskeletal disorders among oil palm fruit harvesters during early harvesting stage," *Annals of agriculture and environmental medicine*, vol. 22, no. 2, pp. 285-291, 2015.

[3] N. G. Yee Guan, S. B. Mohd Tamrin, S. Yusoff Irwan, M. Ippei, and H. Zailina, "Ergonomics observation: Harvesting Task at Oil Palm plantation," *Journal of occupation health*, vol. 55, pp. 405 - 414, 2013.

[4] L. Garzon Castañeda, "Trastornos musculo-esqueléticos y la relacion con la carga posturas asociadas a la labor de cosechero de palma aceitera en una plantación del Meta, Colombia 2015," 2015.

[5] J. A. Romero. La Salud Ocupacional En las plantas de beneficio de Palma de aceite. *PALMAS*. 8. 2000

[6] P. Kivi and M. Mantilla. Analysis and improvement of work postures in the building industry: application of the computerised OWAS method. *Applied ergonomics*. 43. 1991 [Online] Available: https://www.ncbi.nlm.nih.gov/pubmed/15676798

[7] T. R. Walters, V. Putz-Anderson, A. Garg, and L. J. Fine. Revised NIOSH equation for the design and evaluation of manual lifting task. *Ergonomics*. 749, 1993. [Online] Available: https://www.ncbi.nlm.nih.gov/pubmed/8339717

[8] M. Ashby, *Materials Selection in Mechanical Design*. ELSEVIER, 2005.

[9] J. G. Grzywacz *et al.* Work organization and musculoskeletal health: Clinical findings from immigrant Latino poultry processing and other manual workers. *Journal of Occupational and Environmental Medince*. 1001, 2012. [Online] Available: https://www.ncbi.nlm.nih.gov/pubmed/22821071

[10] P. P, M. S, G. DE, C. AB, and C. JP. The influence of skill and low back pain on trunk
postures and low back loads of shearers. *Ergonomics*. 73. 2010.

[11] C. Burnett, N. Lalich, L. MacDonald, and T. Alterman.bWorker Health by Industry and Occupation. *Statistics Bol*. 2001.