Rediseño de una trilladora para la agricultura a pequeña escala en Córdoba, Colombia.

Redesign of an indigenous rice thresher for small farms in Córdoba, Colombia.

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Resumen:

Introducción: La agricultura colombiana aún presenta un bajo nivel de mecanización, lo cual es principalmente resultado de la falta de financiamiento, especialmente para la agricultura a pequeña escala. Esto ha llevado a la fabricación artesanal de maquinaria agrícola utilizando recursos locales copiando otros diseños. Esta maquinaria generalmente tiene baja eficiencia y confiabilidad. En el artículo, se lleva a cabo el rediseño de un trillador de arroz indígena que estaba fuera de uso debido a su baja eficiencia y las significativas pérdidas de arroz durante su operación.
Objetivo: La investigación tiene como objetivo rediseñar un trillador de arroz casero, mejorando significativamente su desempeño, con un bajo costo de fabricación mediante el aprovechamiento máximo de sus componentes y la reconstrucción utilizando recursos e infraestructura local.
Metodología: Para el rediseño, se aplicó la metodología de cinco pasos propuesta por Mullineux. Se analizaron y rediseñaron todos los mecanismos de la máquina, y se reingenierizaron por completo.
Resultados: Se introdujo un nuevo diseño de dientes de trilla llamados "dientes de trilla en peine", muy simples de producir, ensamblar y reemplazar. El trillador rediseñado se implementó y evaluó, logrando la misma productividad que el trillador original, reduciendo las pérdidas de arroz en dos tercios. Además, los resultados de la evaluación en campo fueron coherentes con los resultados de investigaciones anteriores.
Conclusiones: Los resultados muestran que es beneficioso para la agricultura a pequeña escala en Colombia fabricar maquinaria agrícola adaptada a sus necesidades específicas, fabricada localmente con sus recursos, pero aplicando métodos de ingeniería adecuados para garantizar que el rendimiento de las máquinas sea satisfactorio

Palabras clave: Máquinas agrícolas; rediseño; trilladora de arroz; mecanización en pequeñas fincas.

Abstract.

Introduction: Colombian agriculture still has a low level of mechanization, which is primarily a result of the lack of financing, especially for small-scale farming. This has led to the artisanal manufacturing of agricultural machinery using local resources by copying other designs. This machinery generally has low efficiency and reliability. In the paper, the redesign of an indigenous rice thresher which was out of use due to its low efficiency and the significant rice losses during its operation is carried out.

Goal: The research is aimed at redesigning a homemade rice thresher, significantly improving its performance, with a low manufacturing cost through the maximum utilization of its components and reconstruction using local resources and infrastructure.
Methodology: For the redesign, the five-step methodology proposed by Mullineux was applied. All the machine's mechanisms were analyzed and redesigned, and completely re-engineered.
Results: A new design for threshing teeth called "comb threshing teeth" was introduced, very simple to produce, assemble and replace. The redesigned thresher was implemented and evaluated, achieving the same productivity as the original thresher, reducing rice losses by two-thirds. Also, the field assessment results were coherent with the results of the former research works.
Conclussions: The results show that it is beneficial for small-scale agriculture in Colombia to manufacture agricultural machinery adapted to its specific needs, manufactured locally with its resources, but applying appropriate engineering methods to ensure that the performance of the machines is satisfactory.

Keywords:

Agricultural machines; redesign; rice thresher; small farm mechanization

I. Introduction.

Agricultural mechanization is one of the main factors of agricultural development and plays a crucial role in increasing productivity and reducing rural poverty [1]. It is much more advanced in large-scale agriculture, which has the financial capacity to cover its high costs. However, since there is predominantly small-scale agriculture in developing countries, the approach of only large-scale mechanization is highly beneficial and is being surpassed. However, appropriate national strategies for the productive and economic scale of agricultural machinery [2] on small farms are only beginning to be developed [3]

There are two major scales in Colombian agriculture: large-scale commercial agriculture, which uses a significant amount of chemical and weed control products and fertilizers and a massive machinery application, and low-input smallholder agriculture, whit the use of few resources, traditional crop landraces, and low machinery application, resulting in lower agricultural yields [4]. Only half of the farming production units in Colombia report diesel consumption, evidencing a low mechanization level [5], which is one of the leading causes of low productivity in Colombian agriculture [6]. The importance of establishing policies that allow the intensive use of machinery to be increasingly extended to small producers despite the high costs has been clearly defined [4].

In developing countries, farmers often resort to manufacturing their machinery through reverse engineering in local workshops to avoid the high cost of mechanization; also, the use of obsolete equipment is frequent. However, such indigenous machinery typically exhibits lower productivity, poorer performance, and less reliability than industrial-produced machinery [7]. However, properly redesigning the machinery can significantly improve the performance of indigenous or obsolete equipment. [8], [9]. Therefore, adequate methodology, reliable data collection procedure, and considering the farmer's opinions are essentials for successfully redesigning results [10].

The low utilization of machinery in Colombian rice farming is one factor that most affect its competitiveness since only 27% of the producers have their machinery [11], so renting with high costs predominates [12]. The machinery is generally obsolete with over 20 years of use [13]. The increase in mechanization is a critical factor for the sustainability of small farms in Colombia[14] and specifically for post-conflict agricultural policy[15], for which alternative solutions are needed due to the difficulty in obtaining financing to purchase it [16].

Contrary to current trends in agricultural machinery, which involve massive incorporation of informatization [17], the use of autonomous vehicles [18], and the commercialization of high-tech machinery with integrated technology, this research focuses on contributing to demonstrate that it is reasonable for small-scale Colombian agriculture to manufacture its machinery under local conditions instead of resorting to costly investments in machines designed and manufactured for a different production scale, which is achieved through the redesign and reconstruction of a rice thresher machine and could be a contribution to solve the need of innovation in Colombian small farms [19].

II. Methods.

The redesign of machinery is a specific activity carried out to improve the capabilities of machines already in operation and make them more competitive. However, achieving a successful redesign faces difficulties, such as requiring expertise for the new design engineers to fully understand the machine because the information available is generally geometrical and topological, and there is a lack of proper knowledge about performance, capabilities, and design constraints. Also, significant work is needed to understand the prior design decisions and retrace the engineering reasoning and decision-making processes during any previous design/redesign process. [20]. Agricultural machinery design has a high level of uncertainty due to the diversity of field conditions in which it will operate, and redesigning to improve its performance is frequent and needed.

Therefore, selecting the appropriate methodology to apply is crucial for the success of a redesign. However, a significant difficulty is a lack of information about the criteria and constraints followed for their design and how well they have performed their functions in operation. For example, the structures functional analysis method is applied to equipment redesign aims to gain a more profound knowledge of the current mode of operation as a starting point to upgrade work [21]. This methodology has been successfully applied in the redesign of agricultural machinery, ensuring the coherence between the physical configuration of the machine and its intended functions [8], and it will use in this study as the first step of the rice thresher redesign.

Most existing supportive tools for mechanical design are poor at work with problems where the design knowledge is incomplete and continually changes [22]. Since most design decisions involve considering some restrictions, the constraint-based redesign process helps improve and optimize existing products [23]. This approach to constraint-based redesign allows for enhancing the performance, efficiency, and functionality of existing products or systems while considering the limitations and constraints that influence their design. Finally, it helps ensure that the final design meets the established requirements and maximizes desired outcomes [24]. The methodology followed is shown in (Fig. 1).

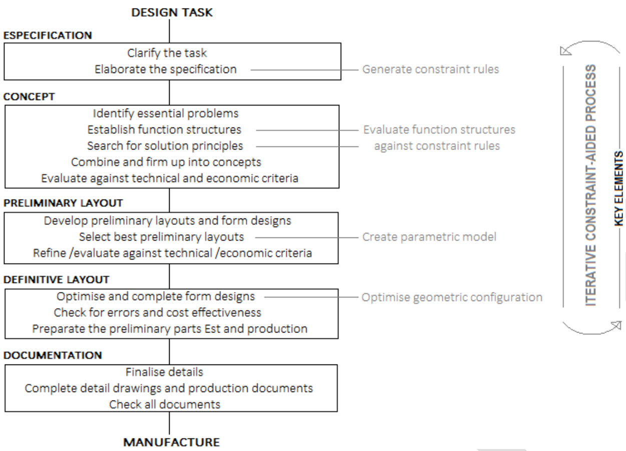


Figure 1 Methodology. Source: [22]

III. Results and Discussion

A. *Design specification establishment*

Grain Thresher is used for threshing grains such as cereals, frequently combined with cleaning the product by removing other plant residues and impurities. Threshers can be stationary, processing harvested and previously dried grains, or combine harvesters, which perform the task in a single operation [25]. The mechanisms of a thresher have five functions: Cutting, Feeding, Threshing, Separating, and Cleaning [26], which are carried out throughout four functional units: feed device, threshing device, and cleaning unit.

B. *Redesigned thresher*

The redesigned threshing was indigenous manufacturing and did not have a cutting unit attached, as shown in Fig. 2.

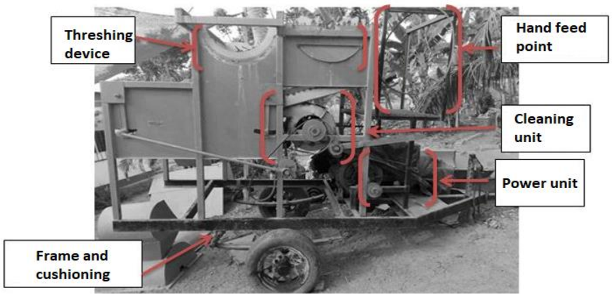


Figure 2 Redesigned threshing.[27]

The farmers discarded the threshing machine because of its low efficiency, low productivity, and significant rice losses, resulting in the deterioration of its components.

The power unit of the machine is a single-cylinder Jindong diesel engine with 18 kW at 2000 rpm. It is connected to a 38 mm transmission shaft through a flexible disc coupling.

According to the mechanical drive dimensional analysis, the engine power is consumed 15% by the cleaning unit (fans and sieves) and 80% by the threshing device (threshing and rollers). The power drive is V-belts, where the first transmission goes to the ventilation unit and the threshing rollers and sieve. During the machine exploitation, the engine overheating, and frequent stops occur during operation. There were also frequent belt failures; hence the drive system had to be carefully analyzed in the redesign process.

The cleaning unit of the machine has two in-line centrifugal fans with 42,5 m3/s airflow operating at 1200 rpm and a sieve measuring 0,94 m in length and 1,2 m width. The sieve comprises a galvanized mesh classifier with a clearance of 12 mm and an inclined plane of 35° (see Fig. 3).

Figure 3 Cleaning unit. [27]

In the cleaning unit's diagnosis was evidence of significant rice loos because of falls outside the screen, and the fans expelled another portion along with the spike particles. There is also a collision between the lower part of the screen and the front of the fans, causing vibrations and damage to the sheets that make up the screen and the blower.

The feeding mechanism for the ears of stalks of rice is through a hopper on the upper cover of the cleaning roller, fed handly by an operator doing arduous work resulting in significant grain losses.

The threshing device has two rotors built by two discs over one axis and four bars joined to the discs, with 15 fingers 12,7 mm diameter and 75 mm height each (see Fig. 4). The diagnosis of the threshing unit evidenced excessive crushing of the husks and a return of the spikes through the feeding hopper, resulting in significant rice losses and loss of quality in the commercial rice.

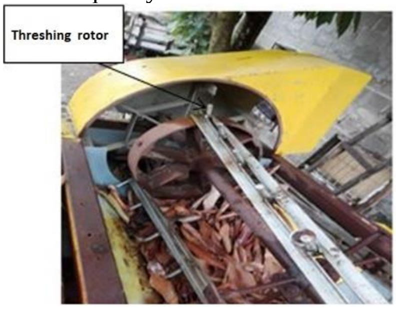


Figure 4 Threshing rotor. [27]

The frame of the thresher is shown in (Fig. 5). It is a base supporting the engine and a structure made of 50,8 mm square tubes that hold the components and mechanisms. Its dimensions are 2 m in height, 3 m length, and 1,5 m width. The machine's casings are 3,175 mm thick sheets bolted to the structure. The thresher is suspended on two leaf springs and two wheels and is towed. The frame has vibrations, and the transportation is complicated because of the excessive height, which creates imbalance and affects the damping system.

Figure 5 Frame. [27]

C. Thresher performance assessment

Five paddy rice batches of 100 kg were processed for the thresher performance assessment. Previously a sample was hand hackneyed and weighed; the average composition was 85 % grain and 15 % rice straw and husk. The average results of hand and machine trash are shown in Table 1.

Table 1 Results of thresher performance assessment.

	Paddy rice, kg	Time, min	Rice content, kg	Clean rice, kg	Loss, kg	Straw and husk, kg
Hand	100	175	84,2	68,2 (81%)	16,0	15,8
Machine	100	5,6	83,9	27,3 (32,5 %)	56,6	16,1

The results confirmed why farmers had discarded the use of the thresher and continued to hand thresh, despite it being an arduous task with low productivity of around 30 kg/h. The loss of over 55 % of the grains is an unacceptable outcome.

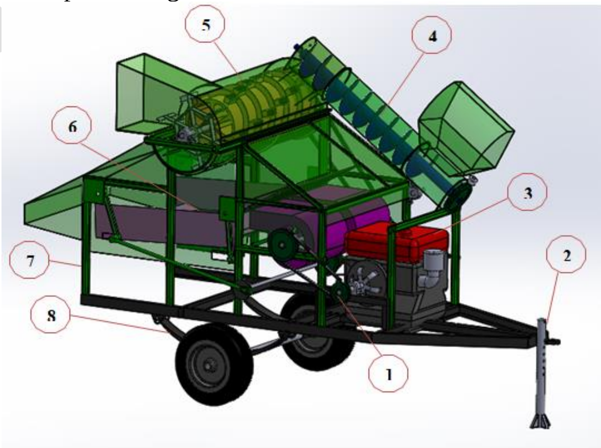
D. Redesign specifications

Since the redesigned thresher lacked technical documentation and its production capacity had not been established. A survey was conducted among rice producers to estimate it to complement the results shown in Table 1. The thresher production capacity for the redesign was set at 750 kg per hour.

The main challenge of redesigning the thresher is to achieve 80 % grain recovery from the paddy rice, equivalent to the manual threshing process. Additionally, the machine's ergonomics must be improved, ensuring its economic feasibility and maximizing the possible reuse of its components.

E. Conceptual design

The 18 kW diesel engine and the main drive is reused for the redesign, which will be the baseline power for designing the mechanisms. The chassis and the complete structure will be reused, although the height will be increased to improve stability during transportation. A feeding conveyor will be incorporated to allow a single operator to carry out this task and humanize the work. The threshing rotor must also be completely redesigned to improve machine efficiency. (Fig. 6) shows the thresher conceptual design.



1. Mian drive. 2. Chassis with tow bar. 2. Diesel engine. 4. Feed conveyor. 5. Threshing roller. 6. Cleaning unit. 7. Support structure. 8. Undercarriage

Figure 6 Conceptual design.

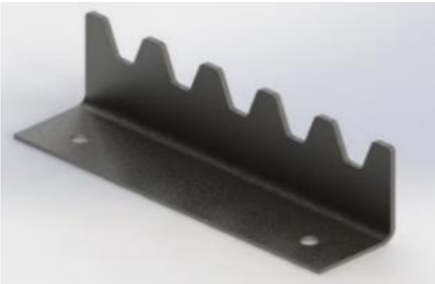
F. Mechanisms redesign

The threshing rotor was entirely redesigned, the entire feeding unit was redesigned, incorporating an auger conveyor and resizing it to improve ergonomics, and the cleaning unit was redesigned.

The redesign of the rotor was the main modification in the thresher. Due to space constraints installing a feeding roller was impossible. Therefore, the rotor had to be as efficient as possible. A bar-type rotor was chosen to fulfill these requirements best [28].

The force required to detach a rice panicle ranges between 2 and 3 N [29]. Knowing that the average mass of a rice panicle is 0.1417 g [30], there are around 7057 rice panicles in a paddy rice kg. The rotor speed (nr) is 800 rpm according to the current belt drive, and the hourly machine capacity is 750 kg/h, processing approximately 0.15 kg/rev, approximately 113 panicles/rev. Considering the need for 3 N to detach a rice panicle. Then, the peripherical force (fmin) needed in the rotor can is calculated by multiplying force by the number of panicles resulting in 170 kg.

According to the assessment of the belt drives, approximately 50% of the engine power is driven to the threshing rotor, so the inner power in the rotor is 9 kW. It should also be considered that the maximum force in the threshing rotor should not be much higher than the minimum force, as it can affect the product quality and



increase. The torque (Tr) needed in the rotor y is calculated as: (see equation 1)

$$Tr = 9550 \cdot \frac{N}{nr} = 9550 \cdot \frac{18}{800} = 515 \text{ Nm} \quad (1)$$

The rotor diameter is calculated as follows: (see equation 2).

$$Rd = \frac{Tr}{2 \cdot Fmin} = \frac{515}{2 \cdot 1700} = 0.37 \text{ m} \quad (2)$$

The threshing rotor configuration is a cylinder with four lines of threshing teeth and a helical plate to push threshed rice (see Figure 7)

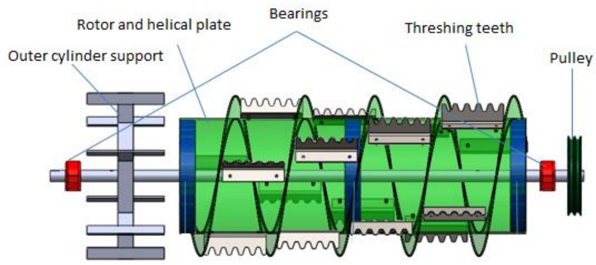


Figure 7 Threshing rotor design

The following equation determines the height of the threshing teeth: (see equation 3).

hd = Rcil - Rd -t = 445 – 370 – 3 = 72 mm (3)

Where:

Rcil – Radius of the rotor container, 445 mm.

t – Clearance for milling threshing. Around the average height of a panicle. 3 mm [31].

The distance between fingers in a threshing roller (Se) is determined according to the thickness of the the rice processed spikes [31]. Therefore, according to the capacity of the machine, this separation is calculated as follows (see equation 4).:

Se = Te + t = 25 + 3 = 28 mm (4)

Where:

Te – Paddy rice spikes thickness. The average value is 25 mm.

There are different types of teeth for rice threshing; the most common one is the fixed or removable spikes or fingers on the rotor. Also, knife bar, rectangular bar, and rasp bar [32], [33]. The redesigned thresher used fixed welded fingers frequently failed due to wear or fracture, similar to those reported in the specialized literature for similar machines [28]. These failures affected the operation and efficiency of the thresher, requiring repair work for their replacement. The most resistant types of teeth have inadequate manufacturing for their production with the available technologies in rural areas, so a new kind of tooth called "comb tooth" was designed for highly resistant and durable, easy to assemble and disassemble while ensuring good threshing.

The comb threshing teeth were designed from an angular profile, as seen in (Fig.), bolted to the rotor

Figure 8 Threshing teeth comb.

G Cleaning unit redesign

In the cleaning unit redesign, the screening area and the dimensions of sieve were verified. Also, the fan speeds were established to solve the problems caused by the airflow velocity.

The prior sieve has a 30° inclination, which results in a high sliding speed of the particles over it, reducing the effective sieving area and decreasing the production because of the waste of un-sifted product [34]. According to the diameter of a rice panicle, which is approximately 2.5 mm, and following the recommendations of [34] of a range of inclinations between 20 and 26° for particles with an average size of 2 mm to 3 mm, an angle of 26° is established.

The cleaning area or screening surface (S), is the required surface to separate impurities from the Paddy rice flow without retention or clogging, is determined by (see equation 5)

$$S = \frac{T_P}{B * f_c} * f_{op} \quad ,m2 \quad = 0.23 \text{ m2} \quad (5)$$

Where

TP - Theoretical weight to sieving (ton/h). It was established at 750 t/h

B - Basic sieve capacity (ton/m2·h).

fc - Correction factors (see equation 6)

fop = Operation factors (dimensionless) = 1.4

$$f_c = f_d * f_r * f_s * f_e * f_a * f_m * f_l * f_p * f_i * f_0 = 0.27 \quad (6)$$

Where:
fd - bulk specific gravity factor

$$f_d = \frac{\rho_a}{1,6} = \frac{0,760\ \mathrm{ton/m^3}}{1,6\ \mathrm{ton/m^3}} = 0.475$$

ρa – paddy rice density, 760 kg/m3

fr - rejection factor = 0.92
fs - half-size factor = 0.6
fe - performance factor = 1
fa - wet screening factor = 1.3
fm - mesh opening factor = 1
fl - laxity factor = 1
fp - cloth position factor = 1
fi - Incline factor = 1
fo - free area factor = 0.8

As the screening area of the original machine is 1.1 m^2 and is larger than the required area, its dimensions are kept unchanged

The fans are centrifugal (see Figure 4) at 1700 rpm, with a working area of 2 m2 operating at 1700 rpm, and an airflow of 50 m³/min (qvo). Far to the recommended airflow for paddy rice cleaning ranges from 27 m³/min to 38 m³/min [35]. To meet the recommendations and avoid excessive paddy rice loss the fan speed was reduced. The airflow was set at 34 m^3/min (qv), the belt drive was redesigned, and the new speed (n) was calculated as: (see equation 7)

$$n = n_0 * \frac{q_v}{q_{vo}} = 1070\ \mathrm{rpm} \tag{7}$$

Since the thresher´s feeding of the machine was done through a hopper located on top of the roller, one operator had to climb onto a platform on the machine's support, while the other operator picked up the sheaves from the ground and handed them, causing grain losses during transport from the ground, also the need of two people for operate it. Therefore, a conveyor auger was introduced.

H. Structure redesign

The thresher´s support structure is formed by 10 mm U-shaped steel ASTM A36 profiles and a 50 mm square tube structure, which supports the components of the threshing unit and the cleaning unit. During transportation, overturning and destabilization of the structure occur due to excessive height. Therefore, the support was modified to relocate the center of gravity closer to the ground. The configuration of structure is shown in Fig. 9.

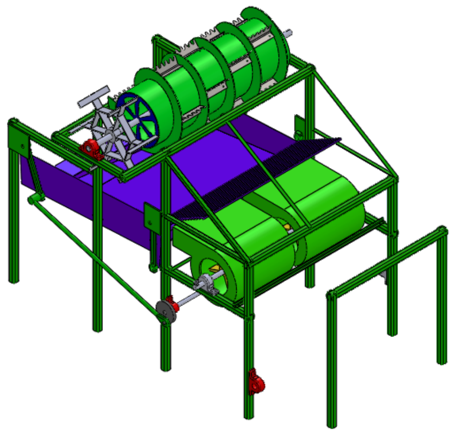


Figure 9 Structure configuration

Finite element models were developed for the structure and the thresher chassis strength verification. The resulting forces from the operation of the systems and their weight were applied. Fig. 10 shows the analysis results for the structure, evidencing the stresses not over 3 MPa, ensuring its strength and the welding. In the case of the chassis (see Fig. 11), the stresses are significantly higher, reaching up to 168 MPa but still lower than the allowable material stress of 250 MPa.

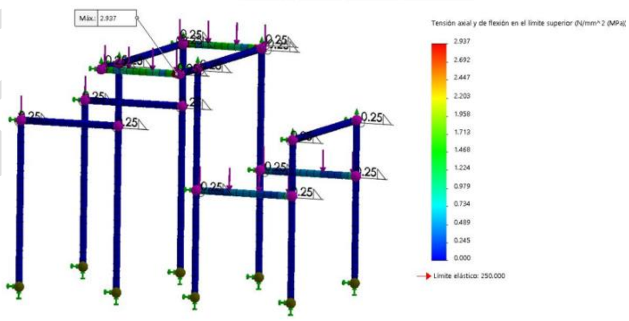


Figure 10 Structure finite elements models results.

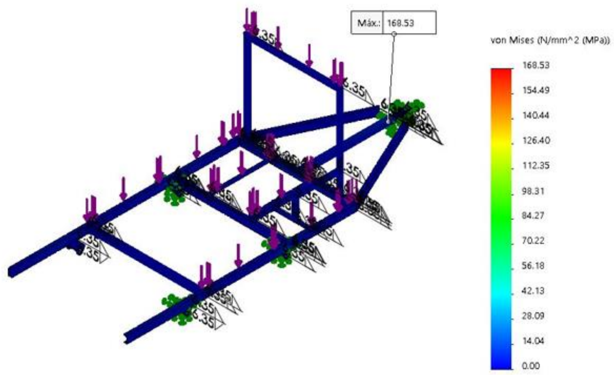


Figure 11 Chassis finite elements models results.

IV Redesign results assessment

In Fig. 12, the model and the redesigned actual thresher are shown.

Figure 12 Redesigned thresher. [27]

The same manual and prior thresher assessments procedure were followed for the redesigned thresher performance assessment processing. Five 100 kg batches of Six month old rice with five days of cutting were threshed. The average results of the hand, prior, and redesigned thresher are shown in Fig. 13. The redesigned thresher has almost the same productivity as the prior one, while the loos went down significantly, and the cleaned rice increased by almost three times which is very important for farmers. Additionally, its operation was more stable and with only one person in abetter work conditions.

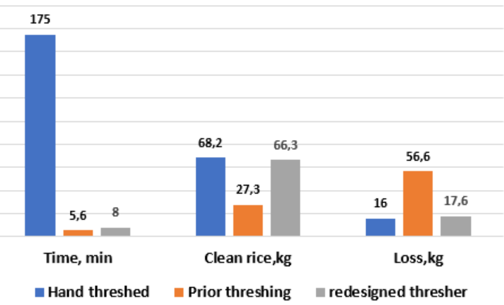


Figure 13 The average results of the hand, prior, and redesigned thresher

The performance of the redesigned thresher was also evaluated in ten field tests, during which the machine was operated continuously for one hour. The clean rice in each tests and the different residues were carefully weighed. The average results are shown in the table 2.

Table 2 Results of redesigned thresher productive assessment.

Component	Peso(kg)	%
Straw and husk, kg	152	20
Other waste	58	7,6
Unthreshed paddy rice	49	6,4
Clean rice	502	66
Total paddy rice Processed	761	100

To evaluate the performance of the thresher, the loss rate (Lr) and impurity rate (Ir) were selected [36], [37]. The grain loss pertains to the grains that are included in the mixture discharged from the threshing device, while the loss rate relates to the reduction in grain mass from the total input grain mass.

$$\text{Lr} = \frac{\text{Unthreshed paddy rice}}{\text{Clean rice+Unthreshed paddy rice}} \cdot 100\ \% \tag{8}$$

$$\text{Ir} = \frac{\text{Total paddy rice processed} - \text{Clean rice} - \text{Unthreshed paddy rice}}{\text{Total paddy rice Processed}} \cdot 100\ \% \tag{9}$$

The L2 value of 9,7 & is higher than the value of 5,16 for similar rotor speed through of simulations reported by [36]. The result of 34.1% for Ir is also close to the range reported by () of between 35 to 41% with 803 rpm rotor speed [37]. However, the difference is to small, which, given that they are different machines with different parameters and threshing mechanisms, as well as different rice varieties, is an acceptable range that validates the new design. The results also evidenced the fulfillment of the initial requirements established for the redesign. The hourly processing capacity of paddy rice achieved in the field evaluation was 761 kg/h, whereas the required capacity was 750 kg/h. Additionally, the grain losses, excluding damaged grains, were 9.8%, nearly half of the established value of 20%.

The total cost of redesigning and rebuilding the thresher was 1.100 USD, while the cost of a new one of a similar capacity in the Colombian market is between 8.000 to 11.00USD. (https://faretty.co/tienda/piladoras-trilladoras-de-arroz/trilladora-de-arroz-y-cereales/).

3. Conclusions.

The redesign and reconstruction of agricultural machines is a satisfactory alternative for small farmers as it enables them to reach similar productivity to commercial machines which significantly lower cost while also humanizing the work process.

In the case study, a disused thresher was successfully redesigned because of its low productivity due to high rice losses and low reliability. By utilizing a significant portion of its components and local manufacturing facilities, the reconstruction cost was more than five times lower than acquiring a similar machine from the market.

The machine achieves a similar efficiency to manual threshing, cleaning around 90% of the grain contained in the paddy rice in less time and with low demand for the workforce.

The new design of the comb threshing teeth, introduced in the redesign, has been validated and achieves performance values close to those recorded in the literature for similar machines. Due to its simplicity in fabrication, installation, and replacement and its increased robustness and resilience compared to traditional welded fingers, this design proves to be a significant contribution to constructing threshers using resources and technology available in rural areas when it deteriorates.

This research contributes to implementing a structured methodology for mechanical redesign tailored to agricultural machinery, which is highly relevant for small-scale Colombian agriculture because of the lack of resources for significant investments in mechanization and often constructs indigenous machines empirically without thorough engineering work, low productivity, and substantial losses. The considerable improvement of the indigenous thresher performance from the former thresher and manual threshing in the case study demonstrates the importance of developing local engineering capacity.

4. CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Demóstenes José Durango Álvarez: Investigación, Metodología, Validación, Recursos. **Juan José Cabello Eras**: Conceptualización, Análisis formal, Escritura – Borrador original. **Valery José Lancheros Suarez**: Investigación, Metodología.

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