Design and experimentation of a corn pericarp peeling machine

Soto Dominguez Kenyuri Carlos*, Peña Rojas Miguel Ángel, Porras Salvador Alex Davida, Quispe Cabana Roberto Belarmino

(Department of Mechanical Engineering, Universidad Continental, Huancayo, Perú, 120101)

Abstract: Corn plays a fundamental role in the diet of diverse cultures and has nutritional benefits, being a rich source of carbohydrates, fiber, vitamins and minerals, in addition to containing antioxidants with health properties. In places like Peru and Latin America, where corn production and commercialization are significant for various culinary uses (patasca, tamales, humitas, among others), there is a need to industrialize the peeling process to speed up production and advance technologically, overcoming the manual method disadvantages. Therefore, this research aimed to design and manufacture a precooked corn peeling machine based on the friction of corn with a rough surface, through the incorporation of adjustable paddles and constant flow of clean water to remove impurities, in order to obtain larger quantities of peeled corn production, being able to supply the local market. To design the machine, the VDI 2221 methodology was applied, which included the creation of a list of requirements and a function structure. The state of the art corn shelling technology was evaluated using techniques such as the black box, white box and morphological matrix approach to analyze solution options. Design aspects such as shaft diameter, vane strength, cylinder volume, drive belt selection, number of belts and bearing choice were considered. Finally, manufacturing materials were selected. The design of the corn peeling machine was obtained. In addition, data on peeling speed and amount of corn peeling were found through washing tests using different corn grains. It was found that the optimum time is 7 minutes, which considerably improves the artisanal method, which requires more time and physical effort by the producer and for the manufacture of the machine, non-polluting materials will be used for corn, such as stainless steel AISI 304, which does not corrode in contact with water. It was concluded that, with the design of a corn pericarp peeling machine gave a 96.3% efficiency in the peeling process, which shows that it is possible to peel corn for health care, also for use in different gastronomic dishes. In addition, the manufacture of the machine is possible since the materials used can be easily found in the local market and have low costs.

Keywords: ccorn, peeling, nixtamalization, pericarp, husk, mycotoxins

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1 Introduction

Zea Mays L. is a gramineae plant, food grain or cereal, commonly known as maize or corn in Perú (Riego, 2023) and also known as corn in Mexico. It can be said that this cereal is abundant in vitamins, which has led to an increase in its production and consumption. (Ministerio De Desarrollo Agrario Y Riego, 2023).Corn cultivation in Peru has a high production, due to its geographical location and the important role it plays in the food industry (García Mendoza, 2017).

Corn is prone to mycotoxin contamination, particularly aflatoxins and fumonisins. Ingestion of cereals containing these mycotoxins has been linked to

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* **Corresponding author: Soto Dominguez Kenyuri Carlos,** Universidad continental (UCCI), Mechanical Engineering Department, Huancayo campus, 120101, Huancayo, Perú. Email: 75047328@continental.edu.pe.

various diseases. For example, aflatoxins have been associated with the development of liver cancer, stunted growth and weight loss. (Bogantes-Ledezma, et al, 2004).On the other hand, fumonisins have been linked to an increased risk of esophageal cancer, immunosuppression and developmental abnormalities of the nervous system (Ochoa et al., 2016).

Nixtamalization, a method perfected by ancient Native American cultures, is used as one of the techniques to eliminate toxins present in corn. This method involves boiling the corn kernels in an alkaline solution, such as lime or ash, and then removing the pericarp. Subsequently, the corn undergoes a second cooking that causes the kernel to swell, resulting in the final product known as "mote" (Johana et al., 2016). Where the second peeling process requires a lot of energy from the farmer or the individual who carries out the process, generating high physical effort and obtaining little production in a prolonged period of time (Medina, 2018). Therefore, in production improvement in terms of resource savings objectives are effectively achieved in industrial processes, while non-industrial processes, although appearing to be equally effective, may be perceived as more complicated (Medina, 2018). In certain rural areas of Peru, the lack of access to the technology needed to peel corn efficiently can be a challenge in these non-industrial processes. This, in turn, restricts the ability of local farmers and producers to compete in the marketplace (Chávez et al., 2022).

Given the main problem in the corn shelling process, which involves cooking corn kernels in water with a 1:2 ratio and adding lime in the range of 1% to 5% on a corn basis, along with moderate heating to boiling, followed by a cooking period of 15 to 20 minutes; this whole process is carried out for the purpose of removing the husk from the kernel (Cuaran, 2013).

In order to identify the costs and benefits of the project that are relevant to its evaluation, it is necessary to define a baseline situation or situation without a study; the comparison of what happens with the project versus what would have happened without the study will define the relevant costs and benefits of the project. In which it is concluded that the total cost of production for obtaining peeled corn is 1.00$ Offering the customer a product of 1 ton at a value of 1.20(dollars) and generating a profit of 0.20 US cents per 1 ton f product sold. The design of the machine takes into account the 52 different varieties of corn. Mechanically, we seek efficiency in corn peeling without affecting its properties and characteristics for human consumption (Mamani, 2016). It has been demonstrated that when corn is subjected to alkaline products for the purpose of eliminating its husk, its capacity for agglutination and liquid absorption is increased (Obregón, 2018).

This study aimed to design and manufacture a precooked corn peeling machine to obtain clean corn suitable for the food industry.

2 Materials and Methods

To carry out the research, the methodology shown in Figure 1 will be used, which was adapted based on the German VDI 2221 standard.

This methodology will start with the development of a list of requirements and a role structure that includes both user and technical perspectives. Subsequently, analysis techniques such as black box and white box will be employed. Then, a morphological matrix will be applied to evaluate the different solution alternatives.

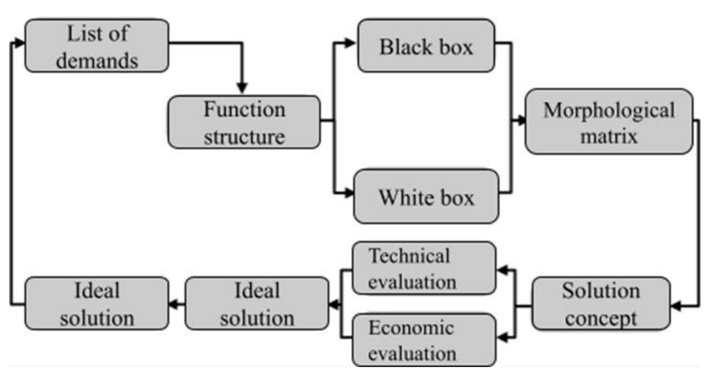


Figure 1 Adaptation of the VDI 2221 Methodology

2.1 List of requirements

Where the functions of the process are shown in which the demands of the user and designer are listed and detailed as shown in Table 1.

Table 1 List of requirements

D/R	Functions	Requirements	Requirement
R	Principal	Precooked corn kernels peeling with the capacity of 1 kg.	User
R	Production	The rotation and speed of the machine must guarantee the peeling of the corn.	Designer
R	Feeding	Filling of precooked corn will be easy.	User
R	Raw Materials	Precooked corn.	User
R	Operation	The operation of the machine will be very simple so that a specialized technician is not necessary.	Designer
R	Security	Thanks to the design we guarantee the operator's safety.	User
R	Quality	The quality of the corn kernels will not be affected during the shelling process.	User
R	Control	Thanks to the design, we can keep track of corn shelling.	User
D	Ergonomics	By design the operator will have no problems operating the systems.	User
R	Manufacturing	Existing materials on the market that guarantee feasibility will be sought.	Designer
D	Mounting	The equipment will be easy to assemble and install.	User
R	Maintenance	Due to our design, we will have easy access to be able to carry out its respective maintenance.	User

Where the following acronyms represent: **D:** Design; **R:** Requirements

2.2 Abstraction process

This choice symbolizes the opacity of the process shown in Table 2, focusing on the results without necessarily revealing the internal details of the corn pericarp peeling process.

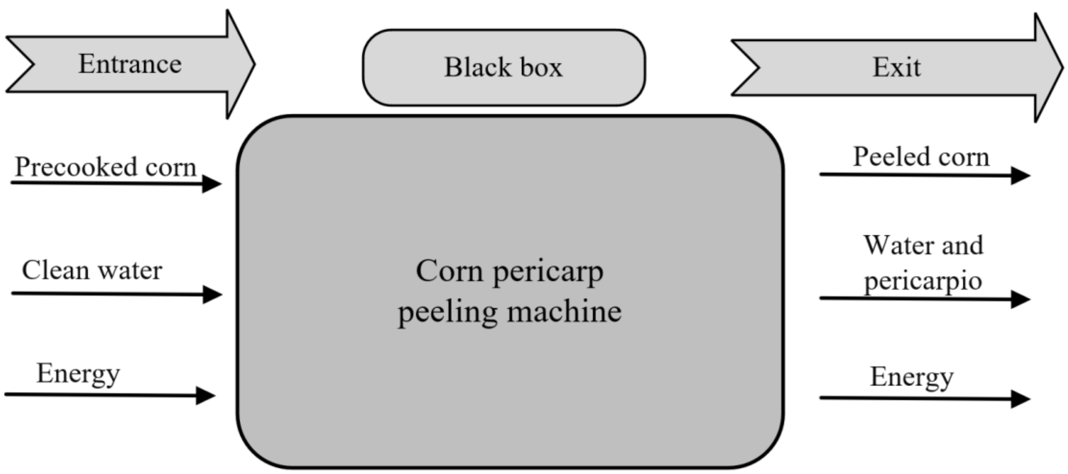


Figure 2 Black box

2.3 Sequence of operations

The corn peeling process starts with the manual introduction of corn into a machine equipped with a peeling mechanism. In this machine, there is a washing cylinder containing another inner cylinder with a rough surface that acts as a friction surface. When the paddles rotate, they drag the corn along this rough surface.

During this process, the used water is removed through a separate outlet at the bottom of the washing cylinder, allowing both the dirty water and the corn pericarp to be disposed of. Extraction of the peeled corn is carried out after the waste has been completely removed. The final product, i.e., the peeled corn, is removed manually using gates located on the internal peeling cylinder and on the washing cylinder. These gates are arranged in the same direction to facilitate the removal of the peeled corn.

2.4 Function structure

The presentation of this function structure in Figure 3. It is presented as an essential component to understand the underlying logic of the research methodology, where the process of operation of the machine is shown, where the process starts with the entry of corn with pericarp (husk), the entry of clean water and powered by electricity; The washing and peeling process requires the rotational movement of the paddles which will generate friction of the corn with the internal chamber to perform the peeling and finally we will have as a product the output of clean and peeled corn, also the pericarp (corn husk) and the dirty water.

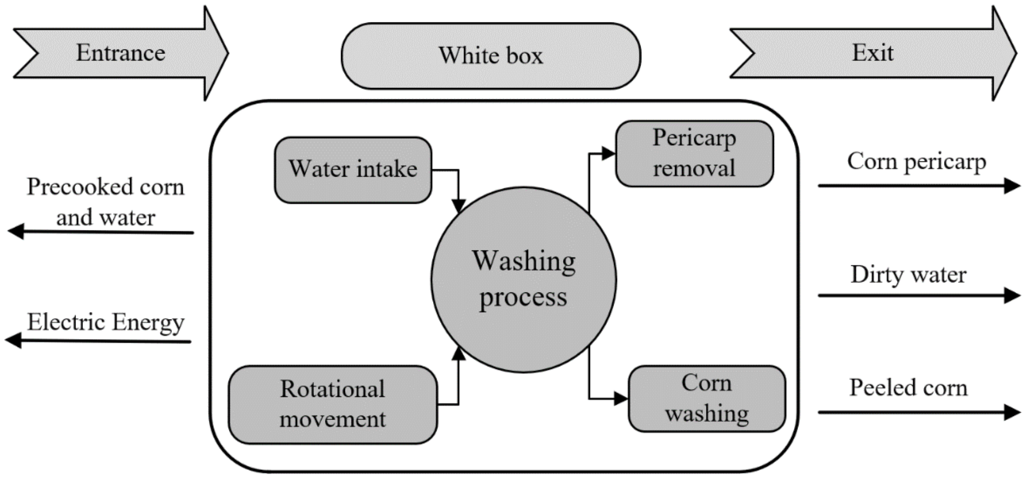


Figure 3 White box

2.5 Morphological matrix

Different components related to user and designer demands were systematically analyzed and organized as shown in Table 2.

Table 2 Morphological matrix

Partial functions	Function carriers		
	Solution 1	Solution 2	Solution 3
Drive	Manual	Electric	Mechanic
Electric power supply	Fuel	Single-phase alternating current	Three-phase alternating current
Transmission system	Pulleys	Gear	Chain
Rotational motion of the system	Three-phase engine	Combustion engine	single-phase engine
Corn feeding	Manual	Conveyor belt	Feeder hopper
Water intake	Constant direct Flow	Manual	Manual
Corn washing	U-container	Cylinder	trapezoidal
Pericarp removal	Pallets	Manual	Pallets
Control of the peeling process	Visual	Temperature	Graduation
Corn selection	Manual	Sieve	Manual
Water discharge	Duct	Manual	Gravity
Corn unloading	Manual	Gravity	Mechanic
Solution concepts	S.C.1	S.C.2	S.C.3

2.6 Technical evaluation

Table 3 Technical evaluation

Selection criteria	Importance	S.C. 1		S.C. 2		S.C. 3	
List of requirements	weight	rating	power	rating	power	rating	power
Function	9	4	36	4	36	5	45
Geometry	5	3	15	2	10	4	20
Maintenance	8	2	16	2	16	3	24
Security	9	3	27	2	18	4	36
Ergonomics	4	33	12	2	8	3	12
Energy	7	2	14	2	14	2	14
Manufacturing	7		0		0		0
Mounting	7		0		0		0
Quality	9		0		0		0
Transmission	5	4	20	4	20	4	20
Total valuation			140		122		170

2.7 Solution concepts

Solution 1: The concept solution 1 is evaluated, which starts with the manual entry of the corn, and then goes to the washing vat, which will have burners for cooking and removers for husking and cleaning the corn; the system will have a chain transmission; finally, it will go to the discharge outlet.

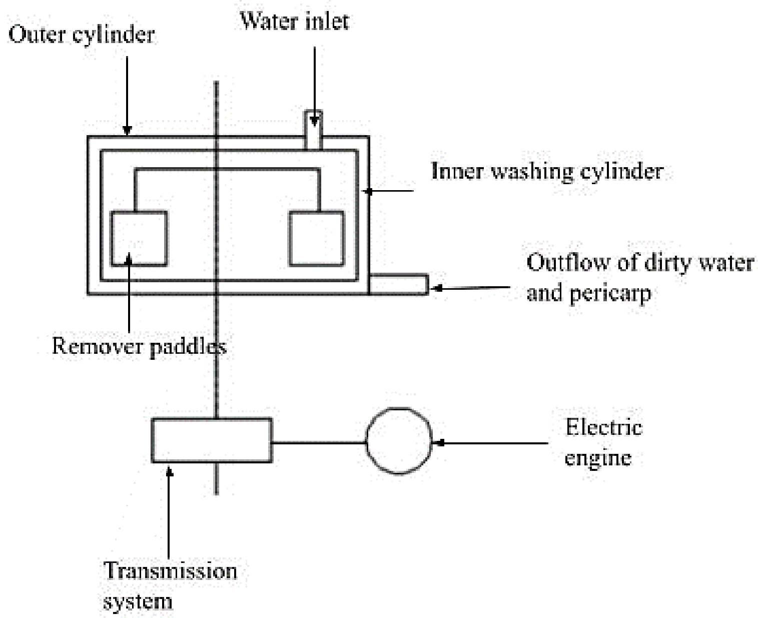


Figure 4 Concept of solution 1

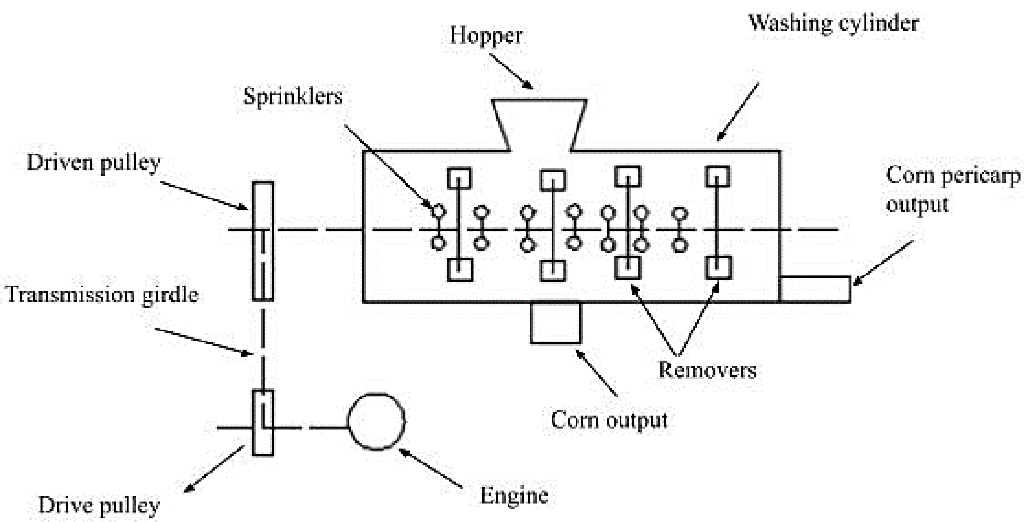


Figure 5 Solution concept 2

Solution 2: The concept solution 2 is evaluated in which it starts in the cooking chamber through combustion, passing through the exit duct to the feed hopper which is located on the rotating drum and has water sprinklers, to give the necessary rotation it will do so by means of a belt and pulleys and generate the rotation that will remove the corn and water.

Solution 3: The concept of solution 3 is evaluated, where we will have a high production capacity since we will be able to peel up to 5 kg of precooked corn, without losing quality during the process, the corn feeding will be manual, we will also be able to have an adequate control of the process, it will be a safe machine for the operator since it will be easy to operate so it will not require a specialized technician and the machine will be manufactured with existing materials in the environment to guarantee its manufacturing feasibility.

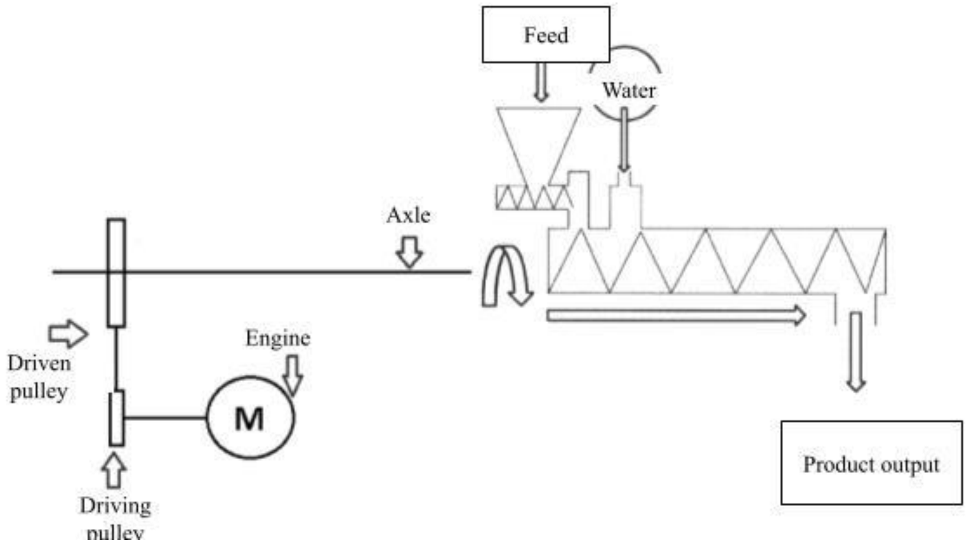


Figure 6 Solution concept 3

2.8 Economic evaluation

The economic evaluation shown in Table 4 shows the total cost for the manufacture of the machine, including the cost of the materials used, the cost of labor and indirect costs.

Table 4 Economic evaluation

Description	Amount in USD
Cost of material	$ 127.98
Labor cost	$ 40.36
Indirect cost	$ 31.81
Total	$ 200.06

3 Design considerations

3.1 Shaft diameter

For the calculation of the diameter, the loads that will be encountered in the machine must be taken into account (Budynas and Nisbett, 2000).

$$d=\left\{\frac{16n}{\pi}\left(\frac{2\left(Kf\times Ma\right)}{Se}+\frac{\left[3(kfs\times Tm)^{2}\right]^{\frac{1}{2}}}{Sut}\right)\right\}^{1/3} \quad (1)$$

where,

n = Design factor (1.5 no units);

Kf = Fatigue stress concentration factors (2.14 no units);

Ma = Maximum momentum (6.34 N m^{-1});

Se = Creep stress (40 Kpsi);

Kfs = Torsional stress concentration factors (3 no units);

Tm = Maximum torque (29.157 N m^{-1});

Sut = Ultimate stress (82.4 Kpsi).

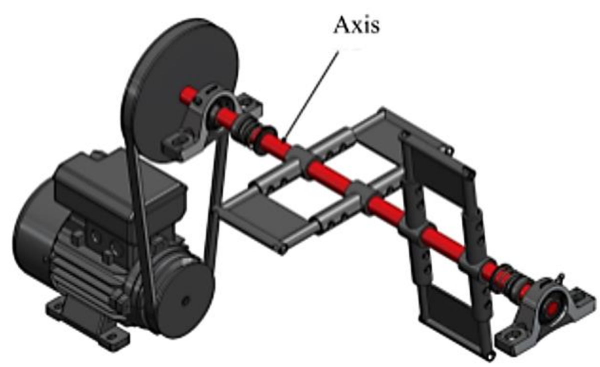


Figure 7 Shaft design

3.2 Strength of the vanes

The type of fluid is considered for the calculation of the force on the vanes (Mott, 2015).

$$Fr=\gamma*\left(\frac{H}{2}\right)*A \quad (2)$$

Fr=resistance factor

where,

γ = Specific gravity of the fluid (1000 kgf m^{-3});

H= Pressure distribution on a vertical wall (0.061m);

A = Contact wall area (0.0064 m^2).

3.3 Cylinder volume

$$Vc = \pi * r^2 * h \tag{3}$$

r:radius;

h: height.

$$Vr = \frac{1}{3} * Vc \tag{4}$$

where,

Vc = Container volume (0.022 m^3);

Vr = Volume occupied by the corn and water mixture at peeling point (0.0074 m^3).

3.4 Transmission band selection

The type of belt is selected according to the power, as the power is ½ hp a type A belt will be used.

3.5 Number of bands

$$Nb > \frac{Hd}{Ha} \tag{5}$$

where,

Nb= Number of bands. (1 band);

Hd= Design power (0.3825 hp);

Ha= Allowable power (0.5314 hp).

3.6 Bearing selection

Load capacity is *C10*, as shown in the following equaiton.

$$C10 = Fd * \left(\frac{Ld * nd * 60}{10^6} \right)^{1/2} \tag{6}$$

where,

C10= Load capacity (3.45 KN).

Fd= Desired strength (139.138 N).

Ld = Life time (rated life in hours). The rated life of a ball bearing is defined as the number of revolutions or hours at a constant speed before the failure criterion develops. (250000 Hours).

nd = Speed, speed of rotation of the stirring vanes (1200 rpm).

The shaft diameter and C10 are searched for in the catalog of SKF.

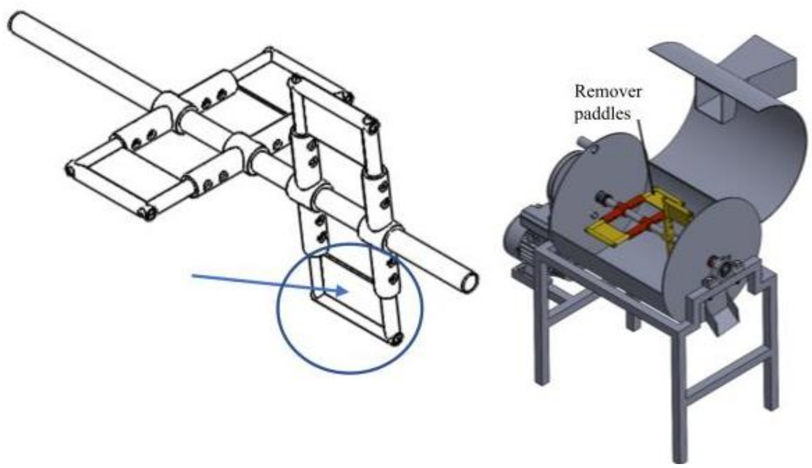


Figure 8 Pallet design

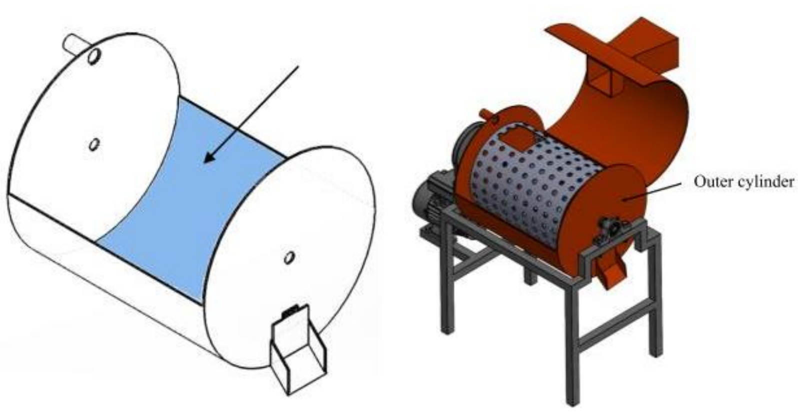


Figure 9 Volume of the outer cylinder

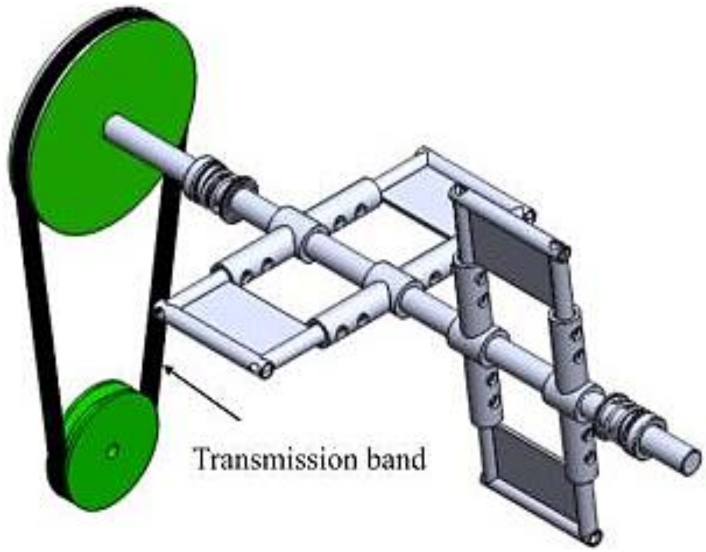


Figure 10 Transmission band

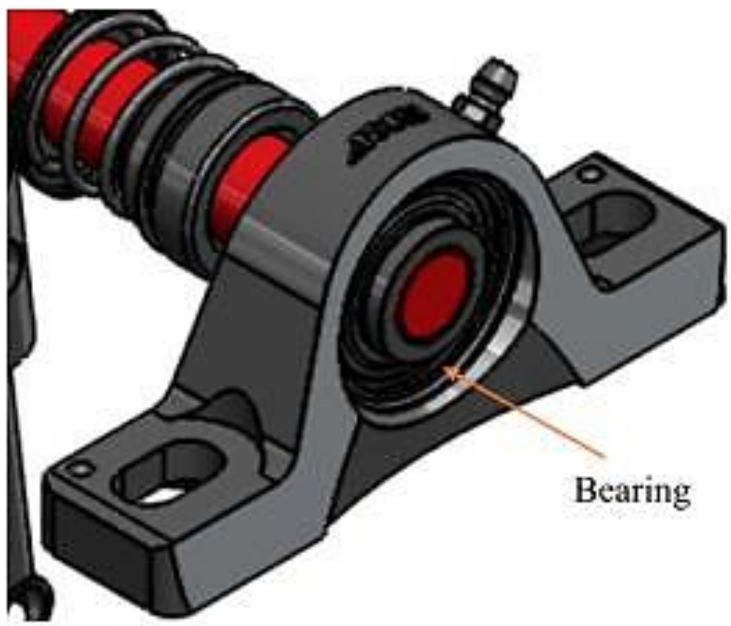


Figure 11 Bearing selection

4 Material selection and manufacturing

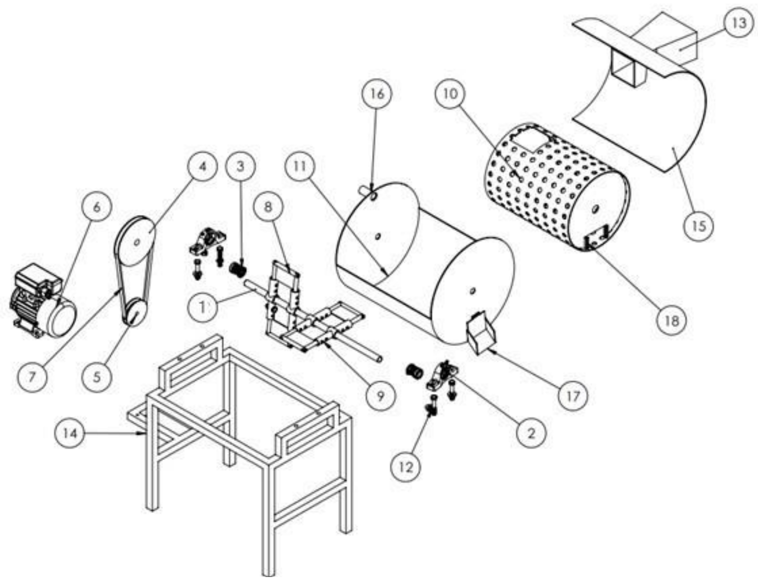
For the selection and construction of the machine based on the results of the mathematical model, AISI 304 stainless steel will be used, as it has a high resistance to corrosion (SISA, 2023). Which will be used in the manufacture of the inner cylinder, which It has a rough surface. surface; It will also be used in the manufacture of the outer cylinder, which will be responsible for storing corn and water.

The components that will perform the rotation work called remover paddles will also be made of AISI 304 stainless steel, because they will be in contact with the corn. For the manufacture of the structure that will support the cylinders, an AISI 1030 steel material will be selected, which is easily available in the market and has an accessible cost.

To obtain the speed of rotation of the drum where the peeling will take place, the speed of the motor indicated by the manufacturer is considered and the reduction will be given with the use of pulleys and the transmission ratio will be used.

5 Principle of operation

The feeding process of precooked corn, which will be done by pouring manually into the inner washing cylinder through a feeding door that will be arranged in the inner mesh cylinder, has the function of separating the final product and waste. The process of filling water to the washing chamber, with approximately half the volume of the outer cylinder, is the process of washing the corn that is done by turning the shaft, which has paddle removers and scrubbers, this has the particularity of being removable and adjustable for different varieties of corn. The transmission ratio will be achieved with the help of an electric motor and a transmission system with pulley and belt, which will rotate the shaft with the washing paddles at an optimum speed to ensure the washing. Also, there is the water discharge and exit of the peeled corn, which will be done through the gates of both the inner cylinder and the gate of the outer cylinder manually which are arranged in the same direction for removal.



Item	Name	Item	Name
1	Axis	10	Inner mesh cylinder
2	Bearing pedestal	11	Outer cylinder
3	Mechanical seal	12	Structure fastening bolts
4	Driven pulley	13	Hopper
5	Drive pulley	14	Structure
6	Engine	15	Viewing gate
7	Transmission girdle	16	Water inlet
8	Paddle Removers	17	Unblocking
9	Adjustable vane extension		

Figure 12 Explosion of the machine design and list of its parts

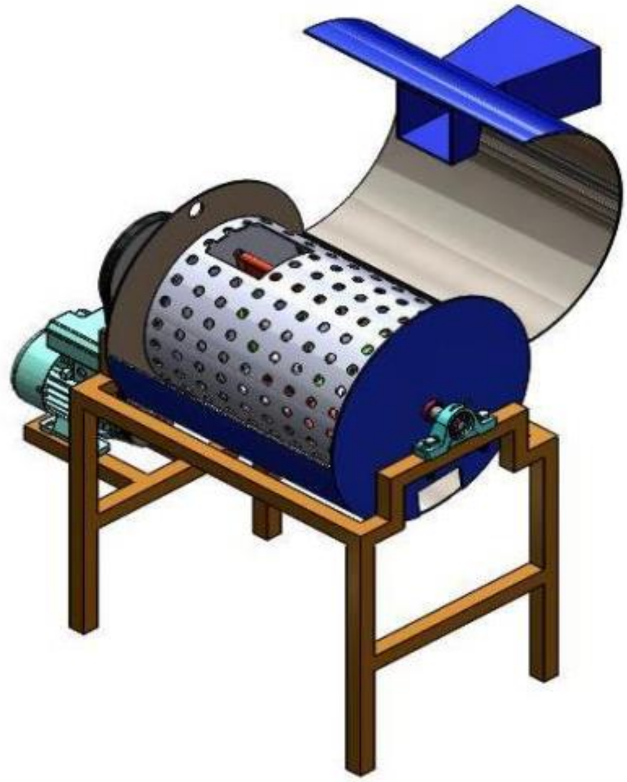


Figure 13 Machine design

6 Performance evaluation

For optimal shelling, the gear ratio was used to be able to reduce the speed.

The required speed will give us the optimal cleaning of the corn.

As shown in Figure 11, the efficiency of peeling efficiency is measured visually, comparing the precooked corn before feeding and at the final unloading where we will have the peeled corn free of pericarp.

Figure 14 The manufactured machine

7 Results

The results of the corn peeling experiment are shown by mentioning the efficiency with respect to peeling time. The transformation of corn without pericarp to the shelled stage is shown in Table 5.

The results of the selection of materials and dimensions for the prototyping of the machine, taking into account the production quantity of corn for peeling, are shown in Table 6.

Table 5 Corn peeling results

Peeling time(min)	Weight of precooked corn (kg)	Weight of husked corn(kg)	Efficiency %
3 min	5	0.070	98
7 min	5	0.185	96.3
10 min	5	0.300	94

Table 6 Results of materials and dimension

N°	Element	Material	Dimension
1	Axis	Steel AISI 304	0.31 Inches
2	Pallets	Steel AISI 304	0.6337 Newton
3	Cylinder	Steel AISI 304	0.0074 m^3
4	Transmission band	Polyurethane	1 of type A
5	Bearing	Steel	SKF 608
6	Structure	Steel AISI 1030	1 ½ inch x 1.5 mm

8 Discussion

To determine the density of the corn mixture and the proportions of water and lime, we took into account what was concluded in Cordero (2012), which mentions a favorable proportion for corn peeling.

With respect to the study carried out, it is considered that with our design proposal the corn is cleaner since clean water is constantly entering and water with corn pericarp (corn husk) is constantly leaving the plant.

The cooking time was based on the total time in which the pericarp was detached from the kernel. Pericarp detachment was determined subjectively by randomly selecting three kernels from each sample taken at 3, 7 and 10 minutes respectively; in the study by Cordero (2012) 15 minutes are required for shelling, where water and corn are kept in a single container, thus performing the turning for shelling.

When a vessel containing a fluid under pressure has closed ends, in addition to the circumferential forces, longitudinal forces act on the cylinder walls. This thrust is resisted by the longitudinal forces on the cylinder walls.

9 Conclusion

With the design, prototyping and pre-cooked corn peeling tests performed on the machine, we tested the peeling efficiency for 5 kg of pre-cooked corn in 7 minutes of work, giving us a 96.3% efficiency.

It was found that the speed for efficient corn shelling without affecting the physical shape of the corn is 179 rpm, taking into consideration the power of the ¼ hp electric motor.

The corn shelling process is beneficial for the mitigation of dietary health risks.

The materials used to manufacture the machine are readily available locally.

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