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Development of continuous pre-milling treater for pre-milling treatment of pulses

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Abstract
Pulses are essential sources of dietary protein and other essential nutrients, making them a crucial component of human nutrition worldwide. Pre-milling treatment is a vital step in pulse processing, as it enhances the milling efficiency, reduces energy consumption, and improves the overall quality of the end product. This research paper presents the development of a continuous pre-milling treater specifically designed for the pre-milling treatment of pulses. The treater employs innovative mechanisms to achieve efficient and uniform conditioning of pulses, leading to enhanced milling outcomes. The paper discusses the design, working principles, benefits, and potential applications of the developed treater, emphasizing its contribution to improving the pulse processing industry for its continuous operation for improved recovery in pulse milling for commercial purposes adoption.

Keywords: Pulse, pre milling treatment, microwave, continuous pre milling treater

Introduction

Pulses are a rich source of dietary protein, fiber, vitamins, and minerals. As an integral part of diets worldwide, their processing holds significant importance in providing nutritious food products. Pre-milling treatment, a critical stage in pulse processing, involves the conditioning of pulses to achieve optimal moisture content, texture, and structure for efficient milling. Traditional pre-milling treatments involve soaking and drying pulses, which can be time-consuming and may result in inconsistent conditioning. This paper introduces a continuous pre-milling treater designed to address these limitations and enhance the pulse processing efficiency. However, with the advent of organized large-scale milling systems, most small-scale processors are thrown out of their profession since their product is inferior in quality and produces lower yields due to their pre milling treatment operations. For this reason, the dhal available in the market comes entirely from large-scale mills with existing batch types and time-consuming pre milling treatments. Therefore, no such small capacity and continuous type pre milling treater or any short type pre milling treatments are available for small-scale industry and agro-processing complex in processing areas of our country.

Design and Development

The continuous pre-milling treater is designed to ensure uniform conditioning of pulses through precise control of moisture and heat. The treater comprises a conveyor system that feeds pulses onto a vibrating bed. Steam is injected at controlled intervals to achieve the desired moisture content. The treater's design allows for adjustable residence times, ensuring that different types of pulses can be treated optimally. A PLC-based control system monitors and adjusts parameters such as steam flow, conveyor speed, and residence time to maintain consistent conditions.

Design considerations of continuous pre milling treater

Microwave energy requirement for treatment

The microwave energy requirement for treatment was calculated using the developed treater per hour output capacity of treating pulse grains.

Working area for treatment chamber

For easy handling of the treater, the length of the treatment chamber of the continuous pre milling treater was considered 0.6 m. The domestic microwave oven has a width of around 0.30 m. Therefore, the dimensions of the treatment chamber were taken for two domestic microwave oven dimensions; hence it was fixed as 0.6 m in length and 0.30 m (same as microwave oven width) width, and the height was 0.30 m (also the same as microwave oven) and according to that the total treating area 0.18 m^2 was calculated.

Mass density of pre-treated pulse grains

Assuming that the single grain layer was passed in all trials through the treatment chamber during the whole treatment process. The mass density of pre-treated pulse grains was calculated for the entire range of conveyor belt speed. The surface area of grains was calculated as 0.15 m^2 (Length 0.60 m × Width 0.25 m) at the conveyor belt's minimum speed, showing its reading was 12 with a corresponding treatment time of 2 min. Similarly, the surface area of grains was calculated as 0.075 m^2 (Length 0.30 m × Width 0.25 m) at the maximum speed of the conveyor belt showing its reading was 93 with a corresponding treatment time was 15 s. The weight of pulse grains was receded as 260 g per sample holder of emery roll dehuller. So, mass density was calculated as a minimum of 1733.33 g/m^2 and a maximum of 3466.67 g/m^2. This was important for the load on the conveyor belt for smooth running in the treatment chamber for pre milling treatment of selected pulse grains.

Output Capacity (kg/h)

The output capacity was calculated based on a kilogram of the treated pulse grains obtained from the treatment chamber in an hour. The output capacity varies with varying treatment times. Hence, it was calculated for the optimized treatment time, and it was approx. 10 kg/h.

Development of major components of continuous pre milling treater

While designing and developing the continuous pre milling treater, the primary importance was given to ease of fabrication, use of locally obtainable material, the minimum price of fabrication, the comfort of assembling and dismantling for repair and examination were duly considered. The following major components of the treater were developed:

1. Treatment section
2. Frame
3. Microwave system
4. Conveyor system
5. Driving mechanism
6. Controlling unit

Treatment Section

Fabrication of the treatment section was the most critical part of the actual work. The success of this research problem was directly dependent on the successful operation of this section. The fabrication of this section started with the design consideration of the chamber. The extensive literature survey helped in understanding the working of microwaves. The microwave energy used to pre-treat pulse grains works only when the energy in intense form impinges on the pulse grains in a closed metallic chamber. No continuous pre milling treaters are available commercially, but the comprehensive design of such treaters could not be found even after a detailed search.

The treatment section includes a close treatment chamber, electronic components to generate microwave energy, and a cover for the protection of electronic components. The ideal metal for making food processing machinery is stainless steel because of its inert character and negligible corrosion. Therefore, the stainless steel (SS 304) food grade metal of 1.5 mm thickness was selected for constructing the treatment section. The treatment section includes two major components as treatment chamber and cover.

Treatment chamber

The domestic microwave oven was taken as a reference for the design of the microwave treatment chamber. The dimension of the treatment chamber as 0.6 m in length, 0.3 m in width, and 0.3 m in height was selected. Suppressions were provided to reduce the leakage of microwave radiation from both the side inlet and outlet of the treatment chamber. The treatment chamber's detailed drawing and developed design are shown in Fig. 1 and Fig. 2. The treatment chamber included different components like a waveguide to transfer microwave energy from the magnetron to the treatment chamber, suppression to reduce the microwave energy from the inlet and outlet, and exhaust for the moist air outlet.

Suppression

The dimension of suppression was kept as 0.75 m in length on the inlet side and 0.40 m in length on the outlet side, 0.30 m in width, and 0.03 m in height. The height of suppression was decided based on the material to be passed, and radiation leakage was less through this section. The single layer of selected pulse grain was placed on the conveyor belt and pass-through suppression of the treatment chamber. According to this condition, the height of suppression was decided because, after the pre milling treatment process, the material can come out with a conveyor belt from the treater. The suppression was welded at 0.07 m above the bottom of the treatment chamber with arc welding. The silicon carbide (absorbing material) bricks were also used to absorb the left-out microwave energy from suppressing the inlet and outlet of the treatment chamber. Each side bricks of 0.05 m thick were placed on the top of suppression in a single layer. The silicon carbide brick size was 0.15 × 0.05 × 0.05 m.

Waveguide

A waveguide is an electromagnetic feed line. It is used to feed the microwaves directly to the treatment chamber, and it may comprise a rectangular or cylindrical metal tube or pipe. A square waveguide (0.14 m × 0.14 m) was fitted by SPS Solutions, Ludhiana (Punjab). The dimension of this domestic oven waveguide match with 2450 MHz frequency. A total of two waveguides were used to develop the continuous pre milling treater. Both waveguides were fixed on top of the treatment chamber at equal distances along 0.6 m length. The center-to-center distance between each waveguide was 0.30 m. To fix the waveguide (0.14 × 0.14 m), square holes were made with laser cutting. The waveguides were joined with the help of spot welding.

Exhaust for moist air

One exhaust was provided in the treatment chamber to remove moist air from the continuous pre milling treatment process. A circular metal grid of 0.10 m diameter was made on the top of the treatment chamber. The diameter of the hole in the circular metal grid was 101.6 mm. The holes in the grids are small compared with the wavelength of the microwaves; hence the grids act just like metal plates, and only moist air can pass through this exhaust. The moist exhaust air from the treatment chamber was drawn by a PVC elbow and an exhaust fan. PVC pipe was made of 0.10 m diameter. Plate 3.9 shows the PVC elbow for exhausting the moist air. The exhaust fan was fixed at the top of the electronic chamber above the treatment chamber to suck the moist air from the treatment chamber.

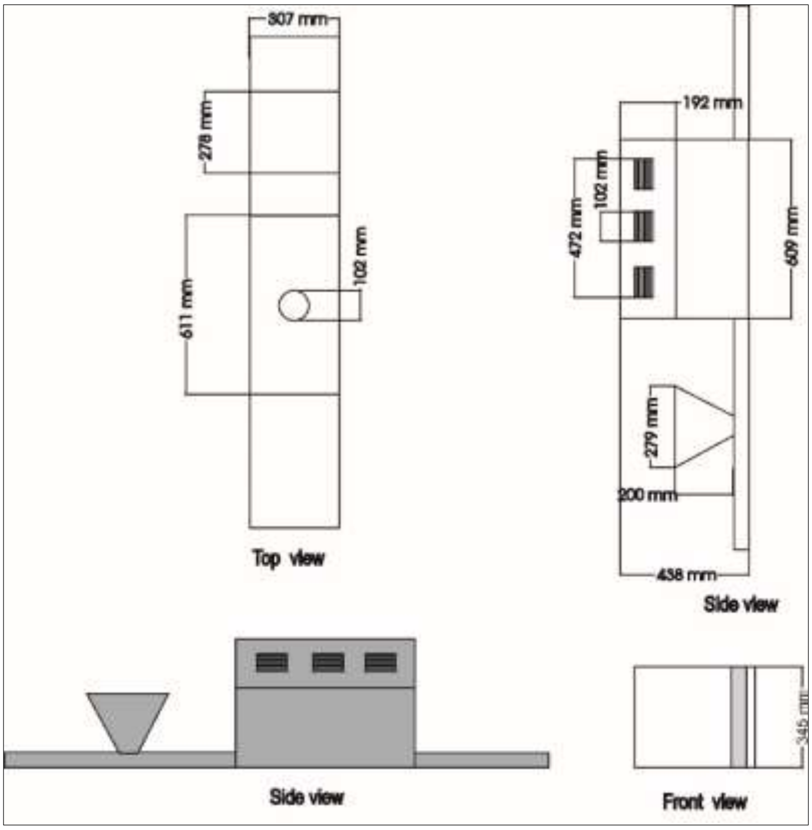

Fig 1: Detailed drawing of the treatment chamber

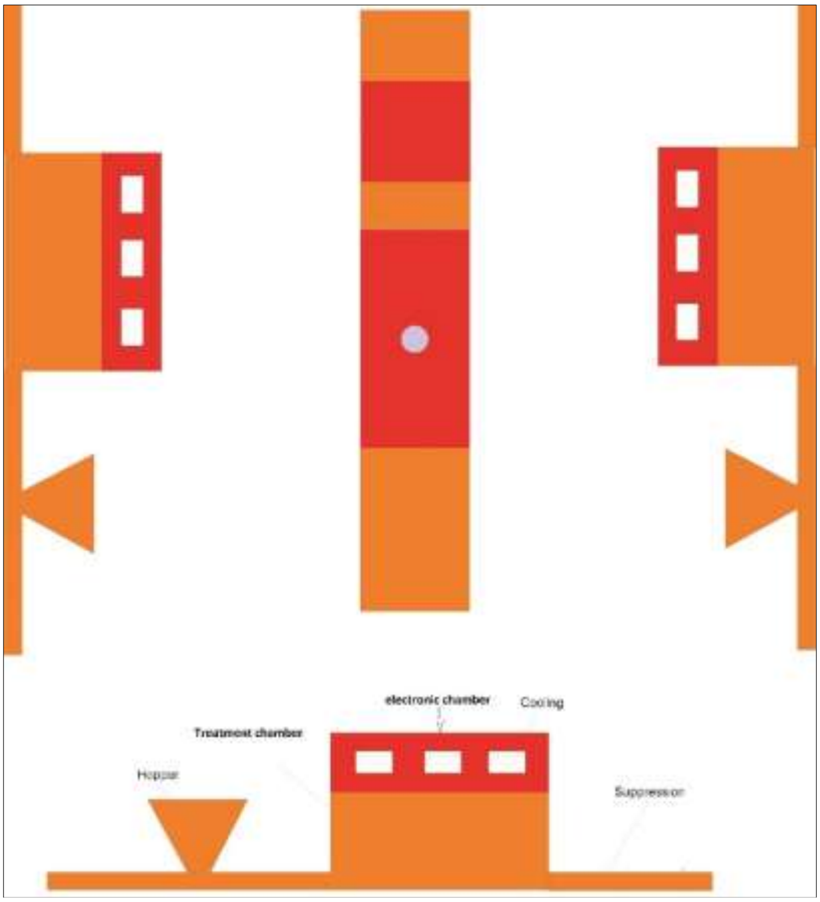

Fig 2: Developed design of treatment chamber

Electronic chamber

Above the treatment chamber, the top electronic chamber was made from a 1.5 mm SS 304 metal sheet. The electronic chamber has the same rectangular box type with one lower side removable. The electronic chamber dimensions were kept the same as the treatment chamber 0.6 m in length, 0.30 m in width, and 0.30 m in height. At the top of the electronic chamber, one circular hole with 0.10 m was provided to pass the moist exhaust air through the elbow. Ventilation was provided for the hot air outlet on both sides of the electronic chamber along 0.6 m length. On each side, three ventilation windows were provided. The dimension of the ventilation window was 0.10 x 0.10 m. The ventilation was made with the help of laser cutting. The lower side of the electronic chamber was joined with the treatment chamber by bolts.

Frame

The structural frame was made of MS sheet and supported by iron square bars to support the central treatment chamber, control panel, and driving mechanism. The frame was 1.80 m in length and 0.40 m in width, and the height above the ground was 0.60 m. The frame constructed of an iron square bar was supported by eight legs (Fig. 3). For the smooth movement of the treater's joint, eight caster wheels of 0.05 m diameter were fitted below all eight legs. The caster wheels were fixed with the frame by arc welding. All the structural components of the frame were joined with arc welding.

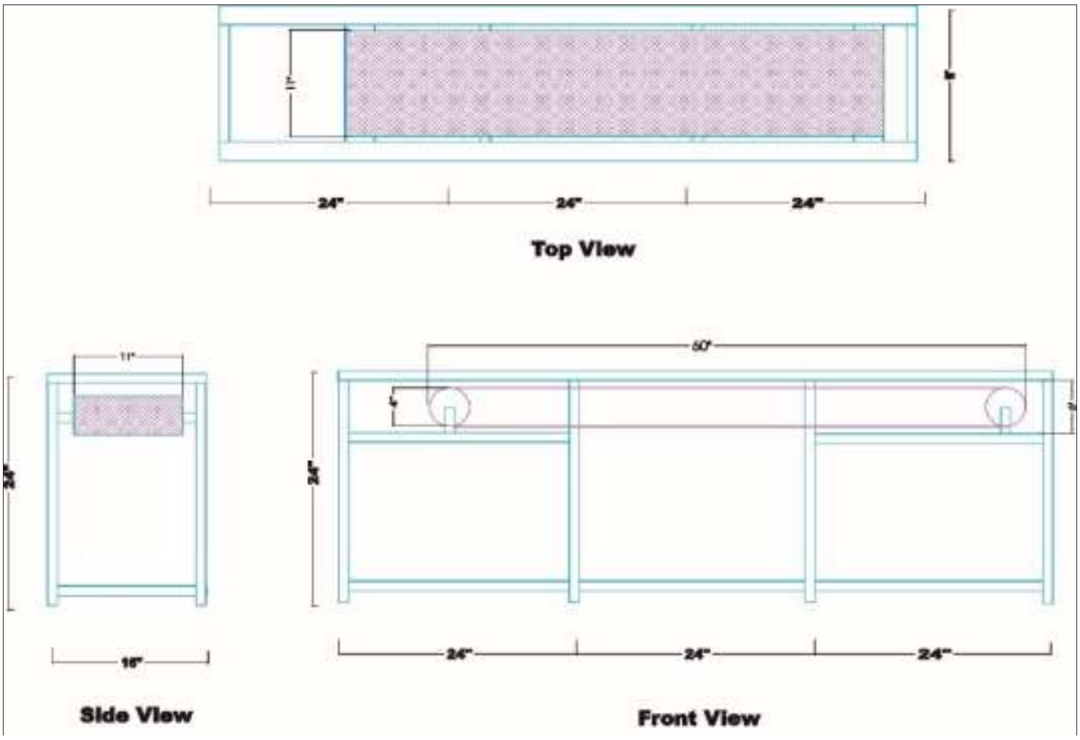

Fig 3: Detail drawing of the frame

Collection outlet opening

The rectangle-type collection outlet opening was made at the end of the frame to collect treated grains. The dimension of the collection outlet opening was 0.20 m in length and 0.13 m in width 0.08 m in tapered height.

Microwave system

A microwave system includes four essential parts: magnetron, transformer, high voltage capacitor with diode, and cooling fan. All parts of the microwave system were attached to the electronic chamber.

Conveyor System

Selection of conveyor system

Heating microwave energy is non-uniform because of the random dispersal of waves within the chamber (Li *et al*, 2011) [23]. Manickavasagan *et al.* (2006) [24] described the sinusoidal wave design consequences in growing hot and cold spots in the microwave heating cavities. Atong *et al.* (2006) [25] enhanced the dispersal of microwaves by using manifold microwave generators, and the movement of the belt in the continuous operation added to the uniform dispersal. Therefore, the conveyor system was made with an endless belt, two roller shafts mounted on the frame, and a driving mechanism.

Belt

The PTFE (Polytetrafluoroethylene) Teflon mesh belt was used to convey cleaned and graded selected pulses in the continuous pre milling treater's treatment chamber. The dimension of the belt was 3 m in length, 0.28 m in width, and 0.001 m in thickness with a 4 x 4 mesh size. The endless belt was made by jointing both ends (male and female) with the thin nylon wire. Teflon has low surface energy, which makes it the least wettable and is the leading cause of its non-stick character of Teflon (Bhandari and Howes, 1992). The high-temperature resistance and solid non-stick behaviour make Teflon the choicest material in high and low-temperature food processing processes. Rajkumar *et al.* (2007) [26] also used a Teflon belt in the continuous foam mat dryer.

Roller shaft

Two conveyor roller shafts were mounted on the frame, supported by four pedestals. The conveyor roller shaft was made of an MS iron rod. The roller dimensions were 0.12 m in diameter and 0.305 m in length. The detailed drawing of the roller shaft is given in Fig. 4. Out of these two-roller shafts, one roller was fixed in fixed type pedestal bearing and one roller was fixed in adjustable type pedestal bearing. The adjustable bearing was used to adjust the belt length. The size of the internal diameter of all the pedestal bearings is 0.025 m. The Roller shaft and pedestal bearing were connected with the help of an MS solid shaft of 0.025 m in diameter and 0.20 m in length. Half of the MS solid shaft was inserted into the roller by drilling the hole. All fixed type pedestal bearings were fixed on the frame with the help of a nut and bolt. The bearing housing was made around the adjustable bearing to provide smooth sliding forward and backward movement with the help of a threaded bolt. The remaining adjustable bearings were fixed on the frame with the help of arc welding after completing the bearing housing.

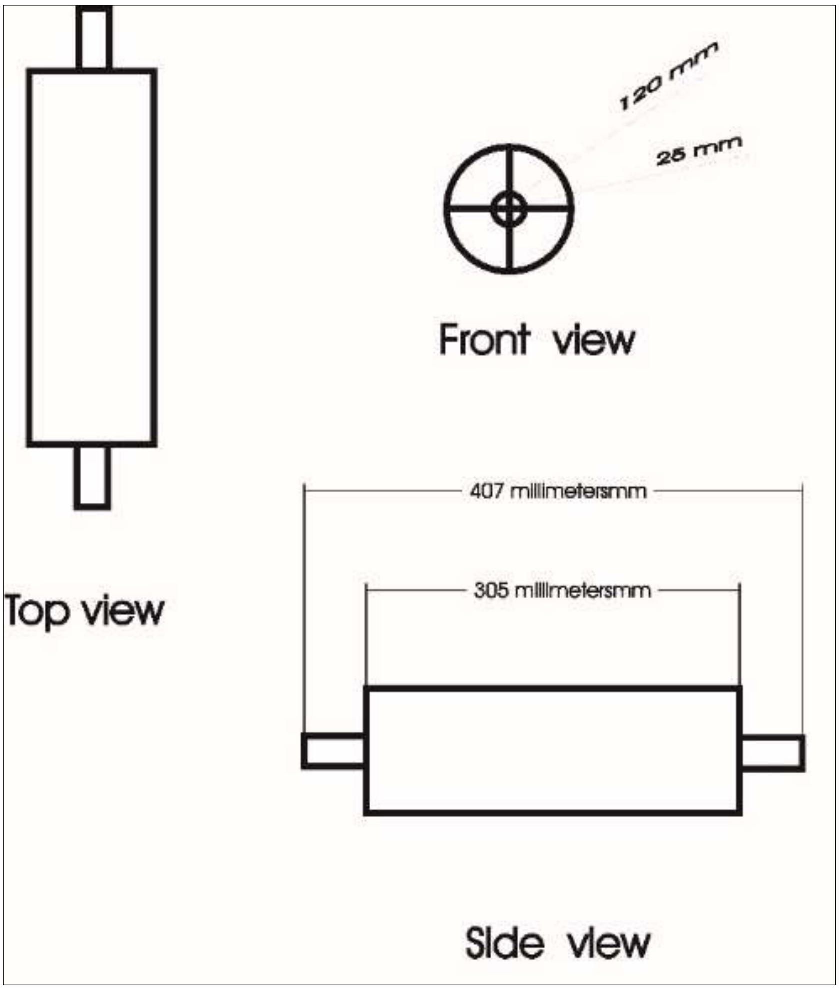

Fig 4: Detail drawing of the roller shaft

Driving mechanism

According to the preliminary microwave treatment study on selected pulse grains, it was observed that in a single microwave radiation generator (microwave oven), the treatment time ranges between 1 to 3 minutes for five different combinations. Hence, the maximum residence time for the material within the treatment section was 2 minutes due to its double microwave generators. The length of the treatment section was 0.60 m, and the lowest speed to attain the required residence time was computed as 5 mm/s. This speed of the belt represents extreme slow speed. To achieve this very slow-speed stepper motor with a microcontroller was selected.

Stepper motor holder

The Stepper motor was fixed on a motor holder with four L and Key nuts at the center. The Stepper motor holder was made from an MS round plate, and it was fixed on the frame with a nut and bolt. It was adjusted with the help of moving the plate up and down by losing the nut bolt. The diameter and thickness of the motor holder were 0.10 m and 0.005 inch, respectively. The developed stepper motor holder and its detailed drawing is shown on Fig. 5.

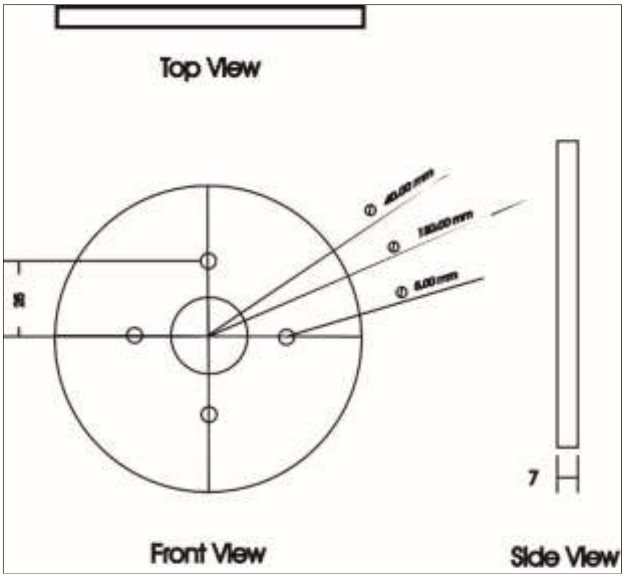

Fig 5: Detailed drawing of stepper motor holder

Conclusion

Pulses are fed onto the vibrating bed of the treater, where they spread evenly in a thin layer. Steam is introduced at intervals to prevent over-condensation and maintain optimal moisture content. The vibrating action of the bed ensures even distribution of steam and prevents clumping. The treater's modular design allows for easy customization based on pulse type, desired moisture content, and throughput requirements. The continuous pre-milling treater offers several benefits over traditional methods. The precise control of moisture content leads to improved milling efficiency, reducing energy consumption and increasing yield. Additionally, the uniform conditioning achieved by the treater enhances the consistency and quality of the end product, making it suitable for producing high-value products like pulse flours for food and beverage applications. The treater's continuous operation also results in time savings and reduced labor requirements. The development of a continuous pre-milling treater represents a significant advancement in pulse processing technology. By addressing the limitations of traditional pre-milling treatment methods, the treater improves milling efficiency, reduces energy consumption, and enhances the quality of the final product. This research opens avenues for further exploration in pulse processing optimization and underscores the importance of continuous processing solutions in the food industry. While this paper introduces a promising solution for continuous pre-milling treatment of pulses, further research can focus on optimizing the treater's parameters for different pulse varieties, investigating its scalability, and evaluating its economic viability in large-scale processing facilities. Additionally, the potential integration of sensor technologies for real-time monitoring and control could enhance the treater's performance and adaptability to varying conditions. The continuous pre-milling treater developed in this research paper demonstrates its potential to revolutionize the pulse processing industry. By providing efficient, uniform, and controlled pre-milling treatment, the treater contributes to increased efficiency, reduced waste, and improved product quality. Its implementation can lead to a more sustainable and nutritious food production landscape, ultimately benefiting both producers and consumers alike.

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