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Design and fabrication of a sugarcane abrasive peeling machine

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Abstract

Sugarcane peeling is an integral process in the production of fresh sugarcane juice. Conventional methods involve manual peeling using a fruit peeler knife, which result in considerable sugarcane loss and limited production capacity. Therefore, the objective of this research is to design and fabricate a sugarcane abrasive peeling machine to overcome these challenges. The proposed machine utilizes a rotating metallic wire brush to achieve surface abrasion, and it consists of essential components such as the main frame, power supply unit, transmission unit, and metallic wire brush unit. The study primarily focuses on investigating the influence of wire brush speed on the abrasive area. Three different speeds were examined: 650, 750, and 850 RPM. The results demonstrate that the optimal condition for sugarcane peeling is achieved at a wire brush speed of 850 RPM. This speed effectively removes 60.99%, 92.99%, and 97.38% of the total surface area during the first, second, and third rounds of the abrasive process, respectively. In continuous operation testing, the machine demonstrates an average capacity of 122.44 kg/h, with the total flesh loss rate of 4.52% by weight. Notably, this abrasive peeling method yields a juice extraction rate 29.4% higher than the traditional manual method, while preserving the desired color and taste characteristics of fresh sugarcane juice, as observed in the traditional manual peeling process. Furthermore, the overall operational competence of the machine received a score of 4.6 on a 5-point scale rating. The estimated break-even point is 6,929 kg/year, which corresponds to a period of 0.60 years. This indicates the time required to recover the initial investment. Furthermore, the projected return period is 0.03 years for a production volume of 120,000 kg/year.

Keywords: Sugarcane juice, Abrasive peeling machine, Sugarcane flesh loss

1. Introduction

The fresh sugarcane juice has remained immensely popular throughout the years, owing to its significant consumer demand. Furthermore, this refreshing beverage is readily available for purchase, both at general stores and through roadside stalls positioned along highways. [1] Therefore, there are continually increasing sugar cane juice producers for both retail and wholesale distribution, which producers range from the household level Agricultural Community Enterprise Group or large factories, etc. [1-3].

The production process of sugarcane juice begins with the peeling of sugarcane using a fruit peeler knife, followed by washing, cleaning, squeezing, filtering, and bottling. It has been observed that nearly every step of the process still relies on manual labor, except for the use of a machine-assisted juicer for the squeezing stage. Data from industry producers indicate that the bottlenecks in the production process are primarily associated with the peeling stage, which continues to rely on manual labor with a knife. This process is time-consuming, with a peeling capacity of 75 kg/h. Operators often sustain injuries from knife cuts, leading to fatigue and an inability to work continuously throughout the day due to the exertion required for peeling. Furthermore, it has been found that the amount of sugarcane juice obtained from the aforementioned production process is relatively low, approximately 40% by weight of the cane before peeling. This low yield can be attributed to the loss of sugarcane flesh that remains attached to the peeled husk and inefficiencies in the sugarcane juicer [3-6].

Previous research conducted by [4] explored and developed a continuous feed sugarcane peeling machine based on the principles of husk removal and surface abrasion using a curved blade for the peeling process. The findings revealed that at a speed of 1080 rpm, the machine effectively peeled the surface, resulting in a 91.06% weight removal of the sugarcane surface. The peeling process exhibited an efficiency rate of 19.01% by weight of the cane before peeling, with a working rate of 115.86 kg/h. Additionally, a study by [5] focused on a sugarcane peeling machine that utilized two roller holders to hold two peeling blades, rotating in opposite directions for husk removal. The study found that at a speed of 1380 rpm, the machine achieved a peeling capacity of 43.83 kg/h, with a loss rate of 2.59% of the sugarcane weight. The operating cost was estimated at 0.466 baht/kg, with a payback period of four years when working for 1600 h/yr. It is evident that these two research works differ in their operational principles and have relatively moderate operational

efficiency, with a certain loss of sugarcane flesh during the peeling process. Based on the literature review, it is evident that these previous studies have different working principles, moderate working efficiency, and certain losses of sugarcane flesh during peeling. Therefore, this research aims to overcome these limitations and develop an improved sugarcane peel abrasion machine that can enhance juice extraction efficiency, minimize sugarcane flesh loss, and improve overall working capacity. The proposed of this research is to designed and fabricate, and tested to validate its performance and feasibility

2. Materials and methods

2.1 Sugarcane preparing

This research employed the Suphanburi 50 sugarcane variety as the experimental sample. A random sample of 5 stalks was selected to measure the average central diameter at three positions: root, middle, and tip. The measured average central diameter values were 33.1 mm, 31.55 mm, and 29.35 mm, respectively. Furthermore, a random sample of 30 sugarcane stalks was selected and divided into segments measuring 100 mm in length for testing the factors affecting machine performance.

2.2 A study on the suitability of blade types for sugarcane peel removal

The objective of the comparative study was to evaluate the effectiveness of different blade types in removing sugarcane peel while minimizing damage or bruising to the sugarcane flesh. In Figure 1, the three blade types, namely knife blade, radial brushing with abrasive stones, and longitudinal brushing with brass brushes, were selected for the investigation. The study aimed to compare the potential of each blade type in achieving successful peel removal without causing harm or deformation to the sugarcane flesh.

Figure 1 The blade types; a) Knife blade, b) Wrie brush and c) Abrasive stone.

2.3 A study on the factors affecting the performance of a sugarcane abrasive peeling machines.

After designing and fabricating the sugarcane abrasive machine, a brush-type blade incorporating brass wire was chosen due to its optimal performance in removing sugarcane peel. In this study, the effect of brush rotation speed was investigated at three levels: 650, 750, and 850 rpm. The sugarcane peels were subjected to abrasive action for 1, 2, and 3 cycles. The evaluation of the study focused on the peel removal efficiency, expressed as the percentage of peel removed, and the peel removal time. In Figure 2, the peel remaining on the total surface area using the abrasive machine during the first, second, and third rounds is shown, respectively.

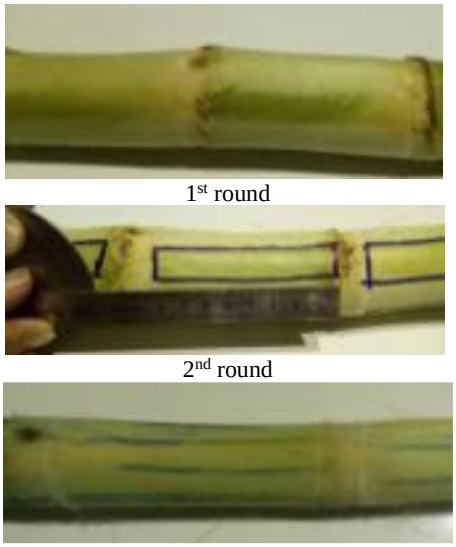

Figure 2 The peel remaining on the total surface area using the abrasive machine during the first, second, and third rounds

Upon determining the suitable operational parameters, the sugarcane abrasive machine was implemented on-site at the community-based enterprise and integrated farming community of Ban Noan Can in Wiang Sa-at Subdistrict, Phayakkhaphum Phisai District, Maha Sarakham Province. A team of five personnel was assigned to operate the machine. Following the operation, they were asked to evaluate the machine's usability and satisfaction level by assigning a rating score of 1 to 5.

3. Results and Discussion

3.1 The comparative study of blade types affecting sugar cane peel removal

The results of the study on sugarcane surface brushing techniques for juice extraction revealed three different approaches: knife blade, radial brushing using abrasive stones, and longitudinal brushing using brass brushes. In the testing phase, it was found that only two techniques, namely the use of abrasive stones and brass brushes, were effective in removing the sugarcane peel. Among the two techniques, the brass brush method yielded better results. Based on these findings, an innovative design and development of a sugarcane surface brushing machine was conducted, incorporating a simple and efficient rolling mechanism. The Suphanburi 50 sugarcane variety was selected for the study due to its non-specific characteristics. Table 1 presents the blade type details of the sugarcane peel brushing mechanism, utilizing a set of rollers and employing brass brushes for the brushing process is mostly suitable.

Table 1 The results of a comparative study of different blade types that are suitable for removing sugarcane peel

Principal work of blade type	Result	Illustration
Knife blade: Wooden-handled knives were utilized in the peeling process, employing a dual-knife configuration to scrape or remove the peel radially from the sugarcane stalk.	The sugarcane husk exhibits fissures and ruptured fibers, along with evident bruising of the cane flesh.	
Wrie brush: Two sets of brushes, rotating in opposite directions, will be utilized to abrade the peel of the sugarcane stalk along its longitudinal axis.	The wire brush exhibits the ability to completely remove sugarcane peel, resulting in a smooth surface without any observed cracks or flesh bruising.	
Abrasive stone: During the polishing process, two abrasive stones will be used to abrade the peel along the length of the sugarcane stalk.	The abrasive stones partially remove sugarcane peel, resulting in minor surface cracks and slight flesh bruising.	

3.2 The result of the design and fabrication of a sugarcane abrasive machine

The results of the design and fabrication of the sugarcane abrasive machine for peeling (Figure 3) are as follows:

- Structural Integrity: The machine was constructed with a robust and durable main frame, ensuring its stability and longevity during operation. This design feature contributes to the machine's reliability and ability to withstand the rigors of the peeling process.
- Brushing Mechanism: The use of two sets of brushes, including metallic two wire brushes, proved to be effective in removing the sugarcane peel. The descending order installation of brushes with different diameters (200 and 150 mm) further optimized the peeling performance.
- Operator Convenience: The machine was designed to be user-friendly, allowing easy control of the sugarcane feeder and guiding the sugarcane shells to make contact with the rotating brush. This design consideration ensures smooth operation and facilitates the peeling process.

The steps involved in the operation of the sugarcane abrasive machine for peeling are as follows:

- When the machine is turned on, the motor provides power to drive the belt.
- The set of brushes starts rotating.
- The sugarcane stalk to be peeled is fed into the brush set.
- Hold the sugarcane stalk and slowly push it into the brush set.
- The rotating brushes will peel the sugarcane stalk along its length.
- Push the sugarcane stalk further into the brush set and rotate it to ensure thorough peeling.
- Once the sugarcane is clean, remove it from the machine, indicating the end of the peeling process.

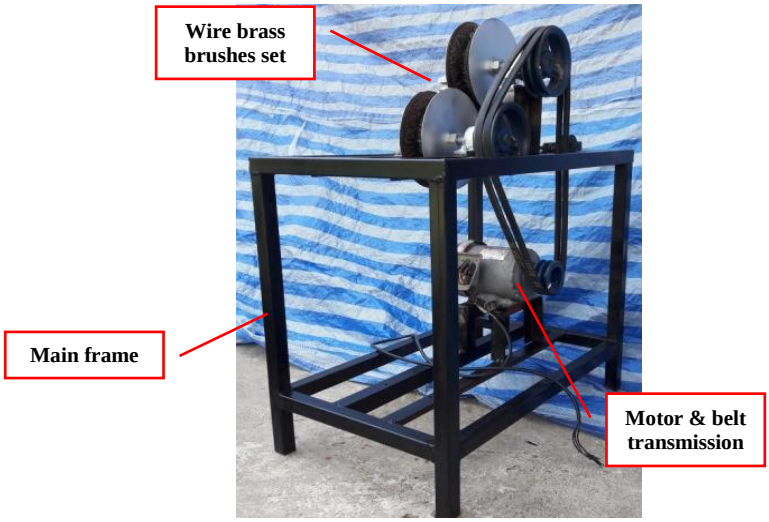

Figure 3 Illustrates a sugarcane abrasive machine.

3.3 Performance testing of the sugarcane abrasive machine

The result of the testing optimal rotational speed of the sugarcane abrasive machine for complete peel removal was tested at three different speed levels: 650, 750, and 850 rpm. According to Table 2, the results indicate that at a rotational speed of 850 rpm, the average peeling time was 34.63 s, and there was an average flesh loss of 4.52%.

Table 2 The results of peeling capacity and flesh loss at different rotation speeds of wire brushes.

Wire brushes speed (rpm)	Stalk	Flesh loss (%)	Time (s/stalk)
650	1	8.78	50.25
	2	2.49	53.43
	3	3.34	50.72
average		**4.87**	**51.47**
750	1	3.85	42.94
	2	4.53	40.94
	3	4.89	43.05
average		**4.42**	**42.31**
850	1	4.10	34.06
	2	4.27	35.03
	3	5.18	34.79
average		**4.52**	**34.63**

Based on the test results regarding the impact of brush wire speed, it was determined that the rotational speed of 850 rpm was suitable for operational adjustments. Consequently, a subsequent test was conducted to compare the peeling cycle at three different instances. According to Table 3, it was observed that at this speed, the abrasive process effectively removed 60.99%, 92.99%, and 97.38% of the total surface area during the first, second, and third rounds, respectively.

Table 3 The results of sugarcane peel removal using a brush speed of 850 rpm in the sugarcane abrasive machine.

No. Stalk	Total peel area	Sugarcane peel removal (%)		
		Round 1	Round 2	Round 3
1	392.69	66.82	87.85	96.21
2	399.76	61.01	88.19	95.29
3	384.37	62.71	89.36	95.64
4	486.94	38.73	95.62	97.67
5	471.23	37.3	94.53	98.08
6	472.96	49.11	95.25	97.80
7	591.71	77.25	96.12	99.24
8	564.23	78.2	94.82	97.87
9	573.65	77.75	95.15	98.58
Average		60.99	92.99	97.38
Standard deviation		16.11	3.44	1.35

Based on the conducted performance testing of the sugarcane abrasive machine designed for peeling, it was observed that the machine exhibited the capability to effectively peel curved sugarcane stalks. Specifically, a curved sugarcane stalk measuring 1.30 m in length, weighing 880.94 g, and possessing a curvature radius of 11 degrees, was successfully processed using the machine.

The machine was operated at a constant rotational speed of 850 rpm, and the peeling process for the aforementioned curved sugarcane stalk was accomplished within a time frame of approximately 1.64 min. This outcome signifies the machine's efficient performance in peeling curved sugarcane stalks, thereby showcasing its ability to handle varied shapes and sizes of sugarcane during the peeling operation.

In Figure 4, The demonstrated capability of the sugarcane abrasive machine to effectively process curved sugarcane stalks highlights its versatility and efficacy in accommodating the inherent curvature and diverse dimensions of sugarcane during the peeling process.

Figure 4 Efficient peeling of curved sugarcane stalks with the sugarcane abrasion machine.

This research study entailed deploying the sugarcane abrasive machine to a cohort of 5 farmers for empirical testing and eliciting their evaluations of usability. The evaluations were conducted using a 5-point rating scale for each aspect. The results indicated that the overall operational competence received a score of 4.6, machine usage and control received a score of 4.4, peeling efficiency received a score of 4.6, peeling capacity received a score of 5, machine maintenance and repair received a score of 4.5, construction materials received a score of 5, minimization of sugarcane flesh loss during peeling received a score of 5, and sugarcane juice taste received a score of 5. In Figure 5 showcases the machine being used by the farmer.

Moreover, in this study, farmers conducted a comprehensive comparison between various methods of preparing peeled sugarcane for juice extraction, specifically employing the sugarcane abrasive machine and the traditional knife peeling technique. The results demonstrated a substantial 29.4% increase in juice yield when utilizing the machine, while simultaneously maintaining the original color and taste characteristics observed during the manual peeling process.

Overall, the developed sugarcane abrasive peeling machine in this paper has demonstrated high efficiency in peel removal and a reliable system, with an impressive rate of 97.38%. This rate surpasses the findings of previous studies conducted by [3] [4] and [5], who reported rates of 55.6% and 91.06%, 96.5% respectively. Additionally, the peeling capacity of the machine remains consistent and comparable, showing no significant differences [6], [7], [8]. The successful performance of the machine in peeling sugarcane and achieving desired results can be attributed to its structural integrity, effective brushing mechanism, and operator convenience.

Figure 5 The actual operation of a sugarcane abrasive machine by a farmer.

The payback period and break-even point were evaluated under the following conditions: the initial investment in the machinery amounts to 15,000 baht, with one worker operating the machine for 6 hours per day. The production capacity is set at 100 kg per hour, and the machine operates for 200 d/yr. The remuneration for peeling sugarcane is set at 1 baht/kg. Additional details can be found in Table 4.

The analysis indicates that the break-even point is estimated at 6,929 kg/yr. This signifies the threshold at which the investment cost is recouped. Additionally, a return period of 120,000 kg/yr is projected.

Table 4 The payback period and break-even point of the sugarcane abrasive machine

Cost estimation conditions	amount	unit
Initial investment (P)	15,000	baht
Service life (N)	7	year
Salvage value (S) 10% of P	1,500	baht/year
Maintenance and repair expenses (R&M), 15% of P	2,250	baht/year
Labor costs (320 baht/ man-day, 200 day/year)	64,000	baht/year
Electricity costs (5 baht/h)	6,600	baht/year
Peeling capacity: 100 kg/h (opening time 6 h/day)	120,000	kg/year
Depreciation expense: D = (P-S)/N	1,929	baht/year
Interest expense: I, interest rate (i) 4% per year I = ((P+S)/2) x (i)	825	baht/year
Fixed costs: Fc = D+I	2,754	baht/year
Machine utilization cost (Ac), Ac = (Fc/A) + (1/Ct) x (R&M + F + O + Lo)	0.60	baht/kg
Revenue	1.00	baht/kg
Break-even point at 6,920 kg/year will have a payback period.	0.60	year
Payback point at 120,000 kg/year	0.03	year

4. Conclusions

The sugarcane abrasive machine is comprised of essential components, namely the main frame, power supply unit, transmission unit, and metallic wire brush unit. Specifically designed for abrasive sugarcane peeling, the metallic wire brush unit is equipped with two brushes. These brushes, made of brass, are arranged in descending order of diameter, with one measuring 200 mm and the other 150 mm. During operation, a single worker is responsible for controlling the sugarcane feeder and guiding the sugarcane shells to come into contact with the rotating brush, thereby facilitating the efficient removal of the sugarcane peel.

To conduct the testing, the machine was operated at a rotational speed of 850 rpm for the brushing set, using the Suphanburi 50 sugarcane variety. The sugarcane stalks used in the experiments were set to a length of 800 mm, with an average diameter of 30.67 mm. The efficiency of the machine was evaluated, resulting in an average efficiency of 99.23% in terms of sugarcane peel removal. Additionally, the analysis indicated a total flesh loss rate of 4.52%. On average, each segment of sugarcane required approximately 34.06 s of brushing time, resulting in a processing rate of 122.44 kg/h.

Furthermore, the overall operational competence of the machine received a score of 4.6 on a 5-point scale rating. The estimated break-even point is 6,929 kg/yr. This corresponds to a period of 0.60 yr, indicating the time required to recover the initial investment. The projected return period for a production volume of 120,000 kg/yr is 0.03 yr.

5. Acknowledgements

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6. References

[1] Chinnasaen T, Thinkum P, Chanachai S, Jungpol P, Vanit M, Riabroy K. Consumption behaviors on sugarcane juice of consumers in Khon Kaen province. Khon Kaen agriculture journal SUPPL. 2023:1.

[2] Numaoy raimaijon Co., Ltd. Production process and products [Internet]. n.d. [cited 2023 Dec 20] Available from: https://www.raimaijon.com/th/product/

[3] Dankhunthod A, Yodsing P, Karisuk S, Leetrakool A, Duangsuphan A. Development of sugarcane exfoliating machine. Industrial Technology Journal. 2022;7(1).

[4] Prueangam P. Development of a continuous feed sugarcane polishing machine. Department of Agricultural Engineering, Faculty of Engineering, Kasetsart University. 2016.

[5] Chaiyapong S, Manthamkarn V. Design and testing of a sugarcane peeling machine for the production of fresh sugarcane juice. 4th Annual Conference of the Thai Agricultural Engineering Association, March 13-14, 2003. At KU Home, Kasetsart University, Bangkhen Campus, Bangkok. 2003:122.

[6] Asim M, Hisyamudin NN, and Masrol SR. Sugarcane bark/skin peeling machine [Internet]. 2014. [cited 2023 Dec 20] Available from: https://www.semanticscholar.org/paper/Sugarcane-bark-skin-peeling-machine-Asim-Hisyamudin/9b729fd219ef6efed1a-1bc12f75bb1b6d0a7e0b2

[7] Tagare VS, Patil VB, Talaskar SP, Wadar SD. Design and manufacturing of sugarcane peeling machine. International Journal of Advanced Scientific and Technical Research. 2013;3(3);70-83.

[8] Xinfeng G. Design of sugarcane peeling machine. Advance Journal of Food Science and Technology. 2015;7(6):398-400.