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RESEARCH PAPER

Design and development of a sustainable chocolate de-bubbling machine to reduce food waste and support biodiversity-friendly cacao processing

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[Published: October 10, 2025]

ABSTRACT

In today's drive for sustainable development, innovative food processing technologies are vital not only for enhancing productivity but also for supporting biodiversity conservation and minimizing environmental impacts. This study presents the design and development of a chocolate de-bubbling machine that uses vibratory technology to remove air bubbles during the chocolate molding process. Beyond improving product quality, the machine contributes to environmental sustainability by reducing food waste, lowering energy consumption compared to traditional industrial alternatives, and utilizing locally available, durable materials. By supporting smallholder cacao processors, the device encourages sustainable cacao production systems that are often linked with agroforestry practices promoting biodiversity. Guided by the Input-Process-Output framework, the research involved needs analysis, design, fabrication, testing, and evaluation. Results revealed high acceptability ratings among end-users and professionals, with a grand mean of 4.6, confirming its effectiveness, user-friendliness, portability, and reliability. This study highlights the role of eco-innovations in promoting responsible production and consumption while contributing to biodiversity-friendly agricultural practices and environmental sustainability.

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INTRODUCTION

Cacao is a crop of high ecological and economic value, often cultivated in agroforestry systems that support biodiversity and environmental sustainability. In the Philippines, cacao production provides livelihoods for smallholder farmers while contributing to the conservation of forest ecosystems when grown under shade trees. However, challenges in post-harvest processing, particularly the presence of air bubbles in molded chocolate, lead to food waste, reduced product quality, and economic losses. Traditional methods of bubble removal, such as manual tapping of molds, are inefficient and labor-intensive.

Food processing innovations that address these inefficiencies can play a dual role: improving food quality and reducing environmental impacts. In line with the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land), there is a need for technologies that are both effective and environmentally sustainable.

This study introduces the design and development of a chocolate de-bubbling machine that integrates vibratory technology to improve product quality while promoting environmental benefits. The device, constructed from locally available and durable materials, reduces waste by ensuring fewer defective products and lowers energy consumption compared to industrial alternatives. Furthermore, by empowering local processors, it supports sustainable cacao value chains, which contribute to biodiversity conservation in agroforestry landscapes.

The implications of this research extend beyond food processing efficiency. By aligning with biosciences and sustainability principles, the innovation contributes to waste reduction, responsible resource use, and enhanced livelihoods for cacao farmers. In doing so, it emphasizes the critical link between technological advancement, environmental stewardship, and biodiversity-friendly agricultural practices. This study aims to design and develop a chocolate de-bubbling machine as an eco-innovation that enhances food processing efficiency while promoting environmental sustainability.

Specifically, it seeks to:

1. Determine the materials and specifications to be used for the fabrication of a chocolate de-bubbling machine utilizing locally available and durable components to minimize environmental footprint;

2. Design and fabricate a chocolate de-bubbling machine that reduces food waste by improving the quality of molded chocolate; and

3. Evaluate the developed machine in terms of effectiveness, reliability, user-friendliness, portability, acceptability, and environmental contribution, particularly its role in supporting sustainable cacao processing and biodiversity-friendly practices.

MATERIALS AND METHODS

Research design

This study used the product design and development method of research to create a design chocolate vibrator that was guided by the Input-Process-Output framework.

The input component incorporated needs analysis, observations, interviews, and a review literature for existing chocolate bubbling machine in the market. The process component followed the product development method, beginning with design and ending with testing and evaluation. The developed and ready-to-use chocolate vibrator is the output component. Finally, the feedback includes information about the evaluators' reactions to the developed device, which serves as the foundation for future improvements

Locale of the study

This study was conducted in Lasam, a municipality located in the province of Cagayan, Philippines.

Lasam is situated in the northeastern part of Luzon, characterized by its rich agricultural landscape and vibrant local economy. The town is known for its close-knit community and cultural heritage, which includes various local agricultural products.

The area is accessible via major roadways, making it a suitable location for research and development activities. The municipality enjoys a tropical climate, which is conducive to agriculture, particularly in the cultivation of cacao, the primary ingredient in chocolate production.The locale is particularly relevant to this study as it serves as both a testing ground and a potential site for the implementation of the chocolate de-bubbling machine. By focusing on a community that actively engages in chocolate production, the research aims to address specific challenges faced by local producers, such as air bubble formation during processing.

Respondents and sampling technique

The respondents in this study were the local processors as the end users while technical personnels like teachers of different schools, TESDA personnels, chocolate processors as the professionals. The researchers used the non probability sampling specifically judgemental sampling because we selected certain individuals or group of people who will give us more information on our study.

Analysis of the data

This section details the statistical treatment used to analyze the evaluators' responses regarding the designed and developed chocolate de-bubbling machine. The evaluators included end-users and professionals from Allacapan, Magsaysay, Lasam, and the Cagayan State University Lasam Campus processing center. Responses from both groups were collected and coded according to the established scale, where a numerical value of 1 indicates "Strongly Disagree" and a value of 5 indicates "Strongly Agree." This coding facilitates quantitative analysis of qualitative opinions.
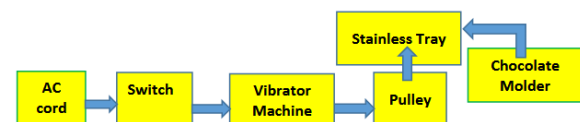
RESULTS AND DISCUSSION

Design features of the device
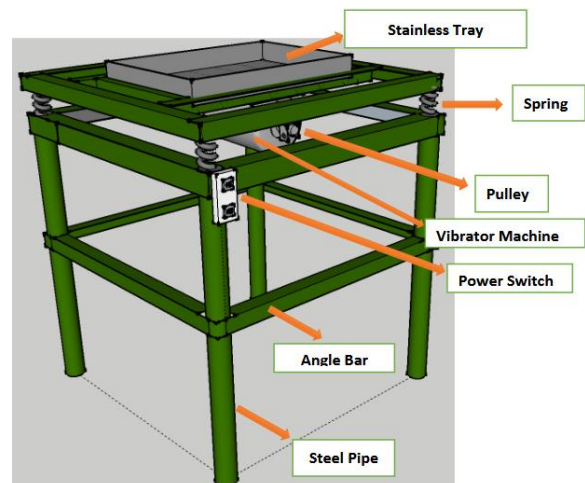
Fig. 1. Isometric view of the chocolate bubbling machine with illustration

Block diagram and system operation

Fig. 2. Shows the block diagram and its flow of operation

Actual view of the device

Fig. 3. Actual view of the chocolate bubbling machine

Assessment of the product

The data gathered shows the attitude of the respondent if the device effectiveness in vibrating molded chocolate. Eleven professionals (73%) rated strongly agree and four (27%) rated agree, with a computed mean of 4.7. This shows the device designed was effective in vibrating molded chocolate.

Table 1. The designed device was effective in vibrating molded chocolate (Professional)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0		0
Disagree	2	0		0
Neutral	3	0		0
Agree	4	4	27%	16
Strongly agree	5	11	73%	55
			100 %	Computed mean=4.7

Table 2. The chocolate bubbling machine and leveler are very reliable in terms of removing bubbles of molded chocolates (Professional)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	0	0	0
Agree	4	4	27%	16
Strongly agree	5	11	73%	55
			100%	Computed mean=4.7

Table 3. The device is user friendly (Professional)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	0	0	0
Agree	4	5	33%	20
Strongly agree	5	10	67%	50
			100%	Computed mean= 4.6

Table 4. The device was easy to move from one work place to another (Professional)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	2	13%	6
Agree	4	4	27%	16
Strongly agree	5	9	60%	45
			100%	Computed mean=4.46

Table 5. The price of the device is acceptable (Professional)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	0	0	0
Agree	4	4	27%	16
Strongly agree	5	11	73%	55
			100%	Computed mean =4.7

Table 6. The designed device was effective in vibrating molded chocolate (End-Users)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	0	0	0
Agree	4	1	7%	4
Strongly agree	5	14	93%	70
			100%	Computed mean =4.9

The data gathered shows the attitude of the respondent if the device effectiveness in vibrating molded chocolate. Eleven professionals (73%) rated strongly agree and four (27%) rated agree, with a computed mean of 4.7 (Table 1). This shows the device designed was effective in vibrating molded chocolate.

Table 7. The chocolate vibrator are very reliable in terms of removing bubbles of molded chocolates (End-Users)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	1	7%	3
Agree	4	4	27%	16
Strongly agree	5	10	66%	50
			100%	Computed mean =4.6

Table 8. The device is user friendly (End-Users)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	1	7%	3
Agree	4	0	0	0
Strongly agree	5	14	93 %	70
			100%	Computed mean=4.86

Table 9. The device was easy to move from one place to another (End-Users)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	3	20	9
Agree	4	2	13%	8
Strongly agree	5	10	67%	50
			100%	Computed mean =4.46

Table 10. The price of the device is acceptable (End-Users)

Options	Numerical value	Number of respondents	Percentage	Total
Strongly disagree	1	0	0	0
Disagree	2	0	0	0
Neutral	3	1	7%	3
Agree	4	3	20%	12
Strongly agree	5	11	73%	55
			100%	Computed mean =4.6

In Table 2 it shows that eleven (73%) of the professionals strongly agree and four (27%) of them agreed in terms of removing bubbles of molded chocolate with a mean of 4. This shows that the device is very reliable in terms of bubble remover.

The professionals response in Table 3 shows that the device is user friendly with a mean of 4.6, ten (67%) of them strongly agree and 5 of them (33%) answered agree. This affirms that the device is user-friendly.

The data gathered shows the attitude of the respondent if the device effective in vibrating molded chocolate. Fourteen (93%) End-Users rated strongly agree and one (7%) rated agree with computed mean of 4.9 (Table 4). This means that the device designed was effective.

The professionals response to the price of the device of being acceptable, Eleven (73%) of them strongly agree and four (27%) of them agree with a mean of 4.7 (Table 5). This shows that the price of the device is acceptable.

The data gathered shows the attitude of the respondent if the device effective in vibrating molded chocolate. Fourteen (93%) End-Users rated strongly agree and one (7%) rated agree with computed mean of 4.9 (Table 6). This means that the device designed was effective.

In Table 7 ten (66%) of the End-Users strongly agree, Four (27%)of the agree and one (7%) of them Neutral in terms of removing bubbles of molded chocolate with a mean of 4.6. This shows

that the device is very reliable in terms of bubble remover.

The End-Users response in table 8 that the device is user friendly with a mean of 4.86, which is fourteen (93%) of them strongly agree and one (7%) of them neutral. This affirms that the device is user-friendly (Table 8).

The data gathered shows the attitude of the respondent if the device was easy to move from one place to another. Ten (67%) End-Users rated strongly agree and two (13%) rated agree and Three (20%) neutral with computed mean of 4.46 (Table 9). This affirms that the chocolate vibrator is portable.

The End-Users response to the price of the device of being acceptable 11 (73%) of them stongly agree, three (20%) of them agree and one (7%) neutral, and with a mean of 4.6 (Table 10). This means that the price of the device was acceptable.

CONCLUSION

In consideration of the objectives of the study and the evaluation conducted, the following conclusions were drawn:

1. The chocolate de-bubbling machine was successfully designed and developed using locally available materials, reducing reliance on imported machinery and lowering environmental impact.
2. The device effectively eliminated air bubbles in molded chocolate, thereby reducing food waste and supporting more sustainable production practices.
3. Evaluations by end-users and professionals confirmed the machine's effectiveness, reliability, portability, and user-friendliness, while also highlighting its potential as an eco-friendly innovation.
4. By empowering local cacao processors, the machine contributes to the promotion of biodiversity-friendly agricultural systems, as sustainable cacao production is often linked with agroforestry practices that conserve forest ecosystems.

5. Overall, the study demonstrates that food processing innovations can simultaneously enhance product quality, improve efficiency, and support environmental sustainability goals, making them highly relevant to biodiversity and ecological conservation.

RECOMMENDATIONS

The following recommendations are offered to support future related research in improving the device:

1. Integration of renewable energy: Future designs of the chocolate de-bubbling machine may incorporate renewable energy sources, such as solar panels, to further minimize environmental impact and reduce dependence on non-renewable electricity.
2. Use of eco-friendly materials: Researchers and fabricators are encouraged to explore the use of biodegradable or recyclable materials in future versions of the machine to reduce waste and support circular economy principles.
3. Expansion of applications: The device may be adapted for use in other food products where air bubble removal is necessary, thereby contributing to reduced food waste across multiple food industries.
4. Environmental impact assessment: Future studies may include a life cycle assessment (LCA) of the machine to quantify its environmental footprint and ensure that its use supports biodiversity conservation and sustainable food systems
5. Capacity-building for local processors: Training programs should be developed for smallholder cacao farmers and processors on how to use and maintain the machine. This ensures that sustainable technologies are widely adopted, supporting biodiversity-friendly cacao farming practices.
6. Partnerships for sustainability: Collaboration with environmental organizations, local governments, and academic institutions is recommended to promote the use of eco-innovations like this machine, linking food processing efficiency with biodiversity conservation and rural development.

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