Multi-Fuel Dryer (A backyard and/or industrial type conventional multi-in-function dryer and oven for various kinds of dried or oven process goods/products) Intellectual Property Office Utility Model Registration no.2-2007000445

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Abstract
The increasing demand for efficient drying technologies has created the need for a locally manufactured, affordable, and versatile drying system capable of reducing post-harvest losses caused by unpredictable weather conditions. This study aimed to design, fabricate, and evaluate a Multi-fuel Dryer that can operate using various fuel sources, including wood, charcoal, sawdust, rice hull, coconut husk, recyclable paper, and liquefied petroleum gas (LPG). The developed technology was designed in different capacity variants ranging from 2–80 kg to meet household, agricultural, and commercial processing requirements. It also features a 2-in-1 dryer and oven system, allowing simultaneous drying and baking operations using a single heat source. The fabricated dryer was evaluated in terms of its structural composition, operational acceptability, drying efficiency, energy consumption, and economic viability. Evaluation results showed that the device obtained a Very Satisfactory rating for its structural composition (overall weighted mean = 3.56) and was rated Strongly Agree/Very Convenient in terms of operational acceptability (overall weighted mean = 3.79). Performance testing further demonstrated that the developed dryer significantly reduced drying time compared with conventional sun drying while maintaining reasonable energy consumption and operating costs. Cost analysis also confirmed its commercial viability across different capacity variants. The findings indicate that the developed Multi-fuel Dryer is a technically sound, energy-efficient, economically feasible, and user-acceptable technology that provides a practical alternative to conventional drying methods for agricultural, fishery, and household applications.

Keywords: Multi-fuel Dryer; Drying Technology; Multi-fuel Drying System; Dryer-Oven; Post-harvest Processing; Technology Development

1. Introduction

1.1 Situation Analysis

The Ilocos region is rich with commodities and blessed with seashore where people of all walks of life can have their fishing activity. Specifically, the Ilocos Norte is having nine towns along seashores. More than that, the other municipality are abundant and supplier of different commodities such as rice paddy/rice, corn, vegetables, root crops and others. However, during peak seasons of every commodity, there is an evident of wastage or losses due to improper management, stockage and preservation. It may also add-on the climate wherein there are places in Ilocos Norte that affected of Cagayan province climate's which is rainy season.

One of the affected area of the rainy season is the town of Adams (https://www.wunderground.com/history/daily/ph/adams/date/2024-4-4, which is the last part in the northern area and border of Ilocos Norte and Cagayan. Almost 20 years that the innovator is attached and married in this town and he observed their way of living. Farming is there main livelihood, second is fresh water fishing and for now the tourist spot such as the villagers garden and plants like in Baguio and Ifugao as well as fresh water, springs, falls and virgin forest which becoming in-demand as attraction for other people in visiting the place and of course this served as another way of Adams people's income. Tourist are staying for months in the staycation of the town because the place is like a little Baguio. However, the area is almost having a daily raining that's why their farm commodities were destroyed. Hence the innovator decided to design a village type drying equipment wherein it has a versatile used. Furthermore, this device is not only intended for drying farmer's and fishermen's commodities but also offered its possible features of drying and oven process those different food products in the urban area.

In addition, fabricated paddy rice mechanical dryers are not portable (https://www.philmech.gov.ph/?page=stories&action=storyFullView&recordID=2025233545 4PMcffba2e&storyCateg=RCEF&storyYear=2023&storyMonth=9). Manipulation and operating of this equipment are also laborious. Also, other mechanized fabricated portable devices are not multi-fuel and multi-in-function and mostly are made from other country wherein after sales service and parts are hard to locate or not available, in turn this device may put into junk. Thus, this new innovation is studied and presented.

On the other hand, post harvest of fish reach 38%, nearly 25 million tons of worlds fishing catch. The losses occur during numerous steps from catch to market. The lack of appropriate methods to preserve the catch on board results in heavy losses. (Post harvest fishery losses, report an International workshop at University of Rhode Island, 1998). Heavy losses of fish on board is due to microbial growth. Generally, fish harvested from the open ocean will be relatively free of human pathogens (with the exception of certain parasites) while those harvested from near shore salt water, fresh water and agriculture sources are at greater risk for contamination. Sources of micro-organism include general pollution resulting from human, animal and agricultural waste (Rasco et.al., 2001)

During ancient time, due to lack of technology in processing fish; ancestors discovered numerous manual process of preserving fish. One of the indispensable materials being discovered is salt (Espejo, 1998). Salting has no adverse effect on the value of fish protein. Bacterial growth can be significantly retarded by the presence of sufficient quantities

of common salt (Sodium chloride)(FAO, 1986). Other method of preserving fish is drying, much of the fish in rural areas of the tropics is preserve by sun drying. While the most sun drying is low, there are significant losses due to spoilage by dust, insect infestation, particularly when the fish are laid closed to the ground (James, 1983).

Mendoza, (1996) Reported during the Second National Fisheries workshop on policy Planning and Development at Puerto Azul, Ternate, Cavite that drying and smoking is one of the traditional and preservation technique which was inherited from our ancestors but due the abrupt changing of technology, drying and smoking are no longer concerned as preservative method instead it converted as one of the luxurious foods offered to hotels and special occasions.

With the drawbacks stated above, this innovation aims to have a market-driven drying equipment that made available in the whole country and offered after sales services. This multi-fuel dryer was innovated based on customized design offering variants (small: 2-3kg cap., medium:5-10 kg cap. and large scale 20-80kg cap.) that a certain small-scale welder can manufactured. This innovation is another breakthrough in the drying technology that offers great ideas and options to individuals who wants to venture in processing dried goods/products for their own consumption or additional livelihood.

1.2 Statement of Objectives

Generally, the study aimed to develop and evaluate a multi--fuel dryer. Specifically, it seeks to achieve the following;

1. To design and fabricate a multi--fuel dryer;
2. To evaluate the multi-fuel dryer in terms:
    - 2.1 structural composition;
    - 2.2 level of acceptability and convenience of operation;
    - 2.3 efficiency in terms of:
        - 2.3.1 energy consumption;
        - 2.3.2 drying time; and,
3. To determine the cost analysis of the variants of the device.

1.3 Place of the Study

This study details the development of a multi-fuel dryer which included fabrication, construction, and evaluation stages. The development was undertaken at the College of Industrial Technology, Mariano Marcos State University, Laoag Campus, City of Laoag, Ilocos Norte

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1.4 Definition of Terms

The following are the operational terms used in this study.

Development. This refers to the process of designing, fabricating, assembling and constructing the device.

Design. This refers to the innovative method of planning the fabrication and construction of the device. Specifically the blue print.

Fabrication. This refers to the act of grinding, cutting, welding, and shaping into form of a certain parts for the assembling and construction of the device.

Evaluate. This refers to the assessment of the structural composition, acceptability and operational convenience level, and, determination of the device efficiency and costing.

Structural Composition. This refers to the evaluation content which includes design, dimension, and materials.

Acceptability and convenience of operation. It refers to the level of acceptance and operation by the evaluators of the device.

Cost analysis. This refers to the costing of the possible ROI of the large scale of the device, cost analysis of the energy consumption of the large-scale of the device, and cost analysis of fabrication on small-scales variant of the device.

3. Methodology

3.1 Research Design

This study will employ a developmental and experimental research design to create the multi-fuel dryer and evaluate its performance compared. Moreover, the research and development approach aims to create a product or system and assess its effectiveness (Sugiyono, 2014; Domingo, 2023).

3.2 Development Process

Design and Fabrication of the device was based on the following figure :

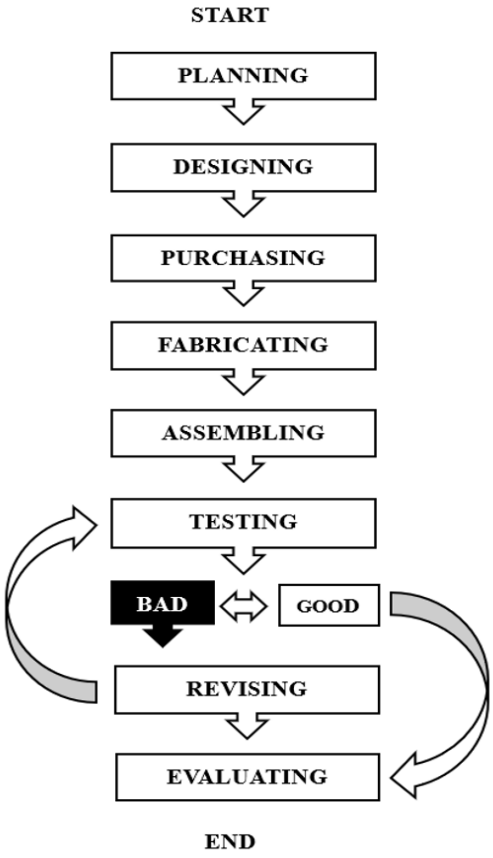

Fig. 1. Stages of Development

3.3 Respondent

Evaluators of the device are composed of 10 experts , 10 technology faculty and 10 food technology students, with a total of 30 respondents. The experts were those utilizing drying equipment , the technology faculty were composed of 5 food technology and 5 automotive technology faculty, and for the food technology students, they were randomly selected from third year and fourth year level.

3.4 ***Data Collection Methods***

The user feedback was conducted with the target respondents. Survey was conducted on the structural composition of the device, specifically its design, dimension, and materials used in the development stages. Acceptability and operational convenience were also conducted during the survey. The efficiency of the device was determined through energy consumption, and drying time. The energy consumption was determined through cycle of operation using different fuel source and products that being process, while the drying time, the difference of drying time between the device and the sun drying was observed. For the cost analysis, all the variants of the device comparison were presented in a table.

3.5 ***Data Analysis***

The study use descriptive statistics to summarize performance and environmental data (mean, standard deviation, percentages). It apply comparative analysis (e.g., paired t-tests) to evaluate the efficiency of the multi-fuel dryer.

3.6 ***Ethical Considerations***

During the conduct of the study, the researcher ensure safety protocols during testing and evaluation to prevent accidents or equipment damage. It also obtain consent from participants involved in usability testing.

4. Results and Discussion

4.1 Design and Fabrication of the Multi-fuel Dryer

The developed multi-fuel dryer was presented in the figure below. Its technological advantages, economical advantages, and actual view were presented.

Figure 2. The Developed Multi-fuel Dryer

Technological Advantages:

- Customize in design w/ various scale: Large **(80 kg.cap)** -7'Hx 6'Lx3'W., Medium **(15-40kg. cap -** 5'Hx1.8'Lx1.8'W Small ` - 1.5'Hx1'Lx1'W)
- Collapsible parts for ease management.
- Fuels are solid and gaseous like large/chips of wood, charcoal, recyclable papers or any combustible materials which is not harm to environment and LPG.
- Uses both conduction and convection heat transfer principles, thus, dried products/goods are safe from contaminants.
- Equipped with controls for quality product such as gauge, throttle system, LPG control knobs, industrial fan/blower switch and damper.

LARGE SCALE

VARIANTS

Economical Advantages:

- 2 in 1 device (Dryer and Oven). It can utilize the other chamber as oven device while the other chamber is @ drying mode using one source of fuel.
- Offers variants fitting to industry, entrepreneurs and household needs.
- Multi-in-function as dryer for farmers and fishermen's goods/products.
- Uses both LPG and any combustible materials or any of the two fuels, it depends on operator's choice or availability.
- User's ROI-6 months @ once-a-day operation.
- Welder's/Manufacturer's income – at least 10% of the total cost of fabrication.

4.2 Evaluation of the Multi-fuel Dryer

The developed large-scale multi-fuel dryer was evaluated by **30 respondents** to determine its structural composition and overall acceptability. The assessment focused on the device's design, dimensions, and materials to establish whether it meets the functional and operational requirements of an efficient drying system. The evaluation results indicate that the developed technology possesses desirable structural characteristics, demonstrating its suitability for agricultural, fishery, and food-processing applications.

Table 1. Evaluation of the structural composition of the large-scale multi-fuel dryer with 30 evaluators.

Structural Composition	Observation Frequency				Weighted Mean	Descriptive Interpretation
	4	3	2	1		
Design	20	10	0	0	3.66	VS
Dimension	13	17	0	0	3.43	S
Materials	18	12	0	0	3.60	VS
Overall Weighted Mean					3.56	VS

Legend: Range of Means	Descriptive Interpretation
3.51-4.00	Very Satisfactory (VS)
2.51-3.50	Satisfactory (S)
1.51-2.50	Moderately Satisfactory (MS)
1.00-1.50	Unsatisfactory (U)

Table 1 presents the evaluation results on the structural composition of the large-scale multi-fuel dryer. The device obtained an overall weighted mean of 3.56, interpreted as Very Satisfactory, indicating that the evaluators found the dryer to be structurally sound, durable, and appropriate for its intended purpose.

Among the evaluated indicators, design received the highest level of acceptance with a weighted mean of 3.66 (Very Satisfactory). This suggests that the overall configuration, layout, and construction of the dryer are functional, aesthetically acceptable, and suitable for efficient drying operations. The materials used in the fabrication of the dryer also received a Very Satisfactory rating with a weighted mean of 3.60. The evaluators recognized that the selected materials are durable, readily available, cost-effective, and capable of withstanding the operating conditions required during the drying process.

Meanwhile, the dimensions of the dryer obtained a weighted mean of 3.43, interpreted as Satisfactory. This indicates that although the size of the device is generally appropriate for its intended application, minor refinements in its dimensions may further improve portability, workspace efficiency, and user convenience.

Overall, the findings demonstrate that the developed multi-fuel dryer possesses a well-designed and reliable structural composition. The high evaluation ratings affirm that the device meets acceptable engineering and functional standards, making it suitable for practical utilization in drying agricultural products, fishery products, fruits, vegetables, and other commodities. The results further validate the effectiveness of the design and fabrication process employed in developing the technology.

Table 2. Evaluation on the acceptability and convenience in operating the large-scale multi-fuel dryer by technology teachers and food technology students.

Indicators	WM	DI
The device is movable and position to other places through it wheels that can push and pull by 1 or 2 persons.	3.49	A/C
Other parts are collapsible for ease transport.	3.89	SA/VC
Different fuels can easily load or unloaded due to its sliding fuel chamber and basin.	3.81	SA/VC
It accommodates different types of combustible materials suited for cooking such as wood (Large, medium, small) sawdust, charcoal, papers and others.	3.39	A/C
Igniting the combustible materials as fuels are made easy via vents provided in the fuel basin.	3.41	A/C
Equipped with LPG system and controls to be used as other alternative of fuel.	3.69	SA/VC
Harnessed with acceptable electrical wiring and switches	4.00	SA/VC
Mechanical dampers are provided to control heat and smoke during	4.00	SA/VC

operations.		
Electrical switches are provided to control the industrial blower and vacuum fan.	4.00	SA/VC
Doors are made up of tempered glass that products to be process are monitored easily.	4.00	SA/VC
The processing chamber is wide enough to accommodate different types of commodities to be processed.	4.00	SA/VC
Overall Mean	3.79	SA/VC

Legend: Range of Means — Descriptive Interpretation
3.51-4.00 — Strongly Agree/ Very Convenient (VSA/VC)
2.51-3.50 — Agree/Convenient (A/C)
1.51-2.50 — Disagree/Not Convenient (D/NC)
1.00-1.50 — Strongly Disagree/Very Inconvenient (SD/VI)

Table 2 presents the evaluation of the developed large-scale multi-fuel dryer in terms of its acceptability and convenience of operation as assessed by the respondents. The evaluation focused on the device's portability, operational features, fuel flexibility, safety mechanisms, control systems, and overall ease of use. The results reveal an overall weighted mean of 3.79, interpreted as Strongly Agree/Very Convenient, indicating that the respondents considered the developed technology to be highly acceptable, user-friendly, and convenient to operate.

Among the evaluated indicators, five operational features obtained the highest possible weighted mean of 4.00, namely: the acceptability of the electrical wiring and switches, the effectiveness of the mechanical dampers in regulating heat and smoke, the electrical controls for the industrial blower and vacuum fan, the tempered glass doors for easy monitoring of the drying process, and the spacious processing chamber capable of accommodating various commodities. These findings indicate that the safety features, control mechanisms, and operational design of the dryer effectively support efficient and reliable drying operations.

The respondents also strongly agreed that the collapsible components facilitate transportation (WM = 3.89), the sliding fuel chamber allows convenient loading and unloading of different fuel types (WM = 3.81), and the integrated LPG system provides an effective alternative fuel source (WM = 3.69). These results demonstrate the versatility and practicality of the developed dryer, enabling users to operate the system using locally available fuels while ensuring ease of maintenance and transport.

Meanwhile, the indicators on the device's mobility through its wheel assembly (WM = 3.49), its capability to accommodate different combustible materials (WM = 3.39), and the ease of igniting fuels through the provided air vents (WM = 3.41) were rated Agree/Convenient. Although these indicators received slightly lower ratings than the others, they still reflect positive user acceptance and suggest that minor improvements in mobility and fuel-handling mechanisms may further enhance the device's operational convenience.

Overall, the evaluation confirms that the developed multi-fuel dryer possesses a high level of operational acceptability and user convenience. Its portable design, multiple fuel options, integrated safety features, and user-friendly control systems make it suitable for household, agricultural, fishery, and small-scale industrial applications. The high ratings

further validate the effectiveness of the design and fabrication of the developed technology and support its potential for practical utilization and commercialization.

Table 3. Cost analysis of energy consumption of the large-scale multi-fuel dryer during processing different commodities using LPG, Wood, Charcoal and Electricity.

Fuels	Temperature Setting as per Commodities	Number of Hours in Trial Operation	Number of Fuel used (Kg)	Fuel Cost per operation (Php)	Cost of Electricity per Operation (1 Exhaust Fan and 2 Blower fan) (Php)
LPG	50kg of Anchovy - low setting @ 45 Deg. Celsius	12 hours @ 5x tray rotations with half damper control open	4 kg	290.90	10.71
	20 pcs of wet clothes hang inside the chamber @ low setting with 50 Deg. Celcius	3 hours with fully damper control open	.5kg	36.36	2.68
Wood	20kg of Rice paddy @ 40 Deg. Celsius	4 hours @ 3x tray rotations with fully open damper	30kg	180	3.57
Charcoal	1 tray of Sliced Dragon Fruits and 1 Tray of Vegetable Fruits @ 40 Deg. Celsius	15 hours for Dragon fruit and 6 hours for vegetables @ Trays positioned at lowest part and no rotation with fully damper control open	15kg	225	13.39

Table 3 presents the energy consumption and operating cost of the large-scale multi-fuel dryer when processing various commodities using different fuel sources, namely LPG, wood, charcoal, and electricity. The results indicate that the developed dryer can efficiently operate with multiple fuel options depending on the commodity being processed and the availability of fuel.

Using LPG, drying 50 kg of anchovy at a temperature of 45°C required 12 hours of continuous operation with five tray rotations and consumed 4 kg of LPG, resulting in a fuel cost of ₱290.90 and an electricity cost of ₱10.71 for operating one exhaust fan and two blower fans. In comparison, drying 20 pieces of wet clothes at 50°C required only 3 hours, consuming 0.5 kg of LPG, with a fuel cost of ₱36.36 and an electricity cost of ₱2.68.

When wood was used as the primary fuel, drying 20 kg of rice paddy at 40°C required 4 hours of operation with three tray rotations. The process consumed 30 kg of wood, corresponding to a fuel cost of ₱180.00 and an electricity cost of ₱3.57. Meanwhile, using charcoal as the fuel source, drying one tray of sliced dragon fruit required 15 hours, while one tray of mixed vegetables required 6 hours at the same operating temperature of 40°C. The process consumed 15 kg of charcoal, with a fuel cost of ₱225.00 and an electricity cost of ₱13.39.

Overall, the findings demonstrate that the multi-fuel dryer can effectively utilize different fuel sources while maintaining reasonable operating costs. The flexibility of using LPG, wood, or charcoal enables users to select the most economical and readily available fuel based on local conditions and commodity requirements. Furthermore, the electrical energy consumed by the exhaust and blower fans remained relatively low across all trial operations, indicating that the developed dryer is energy-efficient and economically viable for both household and commercial drying applications.

Table 4. Drying time difference of the large-scale multi-fuel dryer with sun drying.

Commodity Sample Used	Sun Drying No. of Hour/s	Multi-fuel Drying No. of Hour/s	Hour/s Difference
Fish (50kg of Anchovy)	36 (3 days) staggered operation	12 -Continuous operation	24
Fruits (1 tray of sliced Dragon Fruit)	41 (3.5 days) staggered operation	15- Continuous operation	26
Vegetables (1 tray of mix vegetables)	18 (2 days) staggered drying	6	12
Rice Paddy	9 (1 day) continuous drying	4	5
Clothes (20 pcs)	7 (1 day) continuous drying	3	4

Table 4 presents the comparison between the drying time of the developed large-scale multi-fuel dryer and the conventional sun-drying method for various commodities. The results clearly demonstrate that the multi-fuel dryer substantially reduced the drying time for all commodities tested while providing continuous operation independent of weather conditions.

For 50 kg of anchovy, conventional sun drying required approximately 36 hours (three days of staggered drying), whereas the multi-fuel dryer completed the process in only 12 hours of continuous operation, resulting in a 24-hour reduction in drying time. Similarly, one tray of sliced dragon fruit required about 41 hours (3.5 days) under sun drying but only 15 hours using the developed dryer, reducing the drying duration by 26 hours.

Likewise, one tray of mixed vegetables required 18 hours (two days) through conventional sun drying but only 6 hours with the multi-fuel dryer, representing a 12-hour time savings. Drying rice paddy was completed in 4 hours, compared to 9 hours using sun drying, while 20 pieces of wet clothes required only 3 hours in the developed dryer compared to 7 hours under natural sunlight.

The findings indicate that the developed multi-fuel dryer significantly improves drying efficiency by reducing processing time across different commodities. Unlike conventional sun drying, which is highly dependent on favorable weather conditions and often requires staggered drying over several days, the multi-fuel dryer provides a controlled and continuous drying process. This capability not only increases productivity but also minimizes the risk of contamination, spoilage, and quality deterioration associated with prolonged exposure to the outdoor environment. These results demonstrate the potential of the developed technology as an efficient and reliable alternative to traditional sun-drying methods for agricultural, fishery, and household applications.

4.3 Cost Analysis

Table 5 presents the estimated fabrication cost, selling price, and projected income per unit for the different capacity variants of the developed multi-fuel dryer. The analysis demonstrates that the technology can be customized to meet the varying requirements of household users, small-scale entrepreneurs, farmers, fisher-folk, and commercial processors while remaining economically viable.

Table 5. Cost analysis of the variants of the device.

Variants	Dimensions (Length x Width x Height) Inches	Cost of Fabrication (Construction, Materials, Bills and Labor) Php	Selling Price	Income per unit
Small Scale				
1kg	12”x12”x17” (1’Lx1’Wx1.5’H)	2,200.00	2,500.00	300.00
2 kg Capacity	14”x10”x28” (1.2’Lx.10’Wx2.4’H)	3,600.00	4,000.00	400.00
3 kg Capacity	14”x10”x30” (1.2’Lx.10’Wx2.6’H)	4,300.00	5,000.00	700.00
5 kg Capacity	18”x15”x36”	8,500.00	10,000.00	1,500.00

	(1.6'Lx1.3'Wx3'H)			
10 kg Capacity	18"x15"x48" (1.6'Lx1.3'Wx4'H)	25,000.00	30,000.00	5,000.00
Medium Scale				
15kg Capacity	20"x20"x60" (1.8'Lx1.8'Wx5'H)			
20 kg Capacity	18"x24"x60" (1.6'Lx2'Wx5'H)	45,000.00	65,000.00	20,000.00
40 kg Capacity	30"x30"x65" (2.6'Lx2.6'Wx5.5'H)	83,000.00	120,000.00	37,000.00
Large Scale				
80 kg Capacity	36"x72"x84" (6'Lx3'Wx7'H)	170,060.00	250,000.00	79,940.00

For the small-scale variants, fabrication costs range from ₱2,200.00 for the 1 kg capacity model to ₱25,000.00 for the 10 kg capacity model. The corresponding selling prices range from ₱2,500.00 to ₱30,000.00, providing an estimated profit of ₱300.00 to ₱5,000.00 per unit. These compact models are suitable for household use and small food-processing enterprises because of their affordability and portability.

The medium-scale variants are designed for small and medium enterprises engaged in agricultural and fishery processing. The 20 kg capacity model has an estimated fabrication cost of ₱45,000.00 and a selling price of ₱65,000.00, yielding an estimated profit of ₱20,000.00 per unit. Likewise, the 40 kg capacity model has a fabrication cost of ₱83,000.00 and a selling price of ₱120,000.00, resulting in a projected profit of ₱37,000.00.

For commercial and institutional applications, the large-scale 80 kg capacity model requires an estimated fabrication cost of ₱170,060.00 and has a projected selling price of ₱250,000.00, generating an estimated profit of ₱79,940.00 per unit. Although the initial investment is higher, its larger processing capacity, operational efficiency, and multi-fuel capability make it suitable for high-volume drying operations.

Overall, the cost analysis indicates that the developed multi-fuel dryer is economically feasible across different capacity levels. Its customizable design enables prospective users to select a model that matches their operational requirements and financial capacity. Furthermore, the projected profit margins demonstrate the technology's commercialization potential, making it a promising innovation for manufacturers, fabricators, and entrepreneurs while providing an efficient post-harvest processing solution for the agricultural and fishery sectors.

5. Conclusion

The study successfully achieved its objective of designing, fabricating, and evaluating a Multi-fuel Dryer capable of utilizing both solid combustible materials (wood, charcoal,

recyclable paper, and similar biomass fuels) and LPG as alternative energy sources. The developed technology demonstrated versatility by functioning as both a dryer and an oven, making it suitable for agricultural, fishery, household, and small-scale industrial applications.

The evaluation results confirmed that the structural composition of the device was Very Satisfactory (Overall Weighted Mean = 3.56), indicating that the design, dimensions, and materials used are appropriate, durable, and capable of meeting the intended operational requirements. Likewise, the respondents rated the device as Strongly Agree/Very Convenient (Overall Mean = 3.79), affirming its ease of operation, portability, safety features, and user-friendly controls.

Performance testing further demonstrated that the multi-fuel dryer significantly reduced drying time compared with conventional sun drying. The device provided continuous drying regardless of weather conditions, resulting in substantial time savings in processing fish, fruits, vegetables, rice paddy, and clothes. Moreover, the energy cost analysis showed that the dryer can efficiently operate using different fuel sources depending on their availability, offering users flexibility while maintaining reasonable operating costs.

The cost analysis also established the economic feasibility of the technology. The availability of different capacity variants allows the device to cater to households, entrepreneurs, farmers, fisher-folk, and commercial users. The projected return on investment and potential manufacturing income further indicate that the developed multi-fuel dryer is commercially viable.

Overall, the findings demonstrate that the developed Multi-fuel Dryer is a technically sound, economically feasible, efficient, and user-acceptable technology that offers a practical alternative to conventional drying methods while promoting productivity, energy flexibility, and sustainable post-harvest processing.

6. Recommendations

Based on the findings of the study, the following recommendations are offered:

1. The developed Multi-fuel Dryer should be adopted by farmers, fisherfolk, food processors, entrepreneurs, and households as an alternative drying technology to improve drying efficiency, reduce processing time, and minimize dependence on favorable weather conditions.
2. Government agencies, local government units, agricultural extension offices, and livelihood organizations may consider supporting the production, demonstration, and dissemination of the technology to enhance post-harvest processing and value-added food production in rural communities.
3. Manufacturers and fabricators are encouraged to commercialize the different capacity variants of the Multi-fuel Dryer to meet the varying needs of household, institutional, and industrial users while maintaining quality and safety standards.
4. Future researchers may conduct further performance evaluations involving additional agricultural commodities, different climatic conditions, and long-term durability testing to further validate the efficiency and reliability of the technology.

5. Further studies may incorporate automation features such as programmable temperature control, digital monitoring systems, humidity sensors, and Internet of Things (IoT)-based remote monitoring to improve operational efficiency, energy management, and product quality.
6. An economic impact assessment and market acceptability study may also be conducted to determine the long-term financial benefits, commercialization potential, and sustainability of the Multi-fuel Dryer in various sectors.

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