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Design, fabrication and testing of essential oil extractors for quality production of essential oils from fruit wastes

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Key words: Essential oil, Direct heat extractor, Electrically powered extractor

Abstract

This research paper focuses on the development of a mechanical system for extracting essential oil, considering its wide range of applications in medicine, perfumery, manufacturing, and pharmaceuticals. The study aims to address the need for efficient essential oil extraction, particularly from fruit wastes, by employing a direct steam distillation process using two prototype machines: a direct heat extractor and an electrically powered extractor. The research initially explored various design concepts, eventually narrowing down to the two most efficient options based on evaluations by technical experts. Comprehensive evaluations were conducted to finalize the specifications, materials, and manufacturing processes required for fabricating the essential oil extractors. The resulting prototypes underwent pre-testing to identify and rectify any minor issues prior to a thorough evaluation of their efficiency in extracting essential oil. Furthermore, the characteristics of the oil produced were also assessed. The results demonstrate that both prototype machines are capable of extracting essential oil; however, the direct heat extractor outperformed the electrically powered extractor in terms of several key factors. These factors include the percentage yield of essential oil, production cost, ease of oil extraction, durability, commercial viability, and aesthetics. Therefore, the machine utilizing direct heat is deemed superior overall. This research contributes to the field of essential oil extraction by providing a practical solution for effectively utilizing fruit wastes. The developed mechanical system offers a cost-effective and efficient approach to extracting essential oil, paving the way for potential advancements in the industry. The findings of this study can serve as a foundation for further research and development in the field of essential oil extraction machinery, benefiting various sectors such as medicine, perfumery, manufacturing, and pharmaceuticals.

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Introduction

The escalating generation of fruit waste in market areas poses significant environmental challenges as piles of discarded fruit remains continue to accumulate daily. Despite ongoing research exploring the antimicrobial properties and secondary metabolites of fruit waste, transforming these residues into valuable products remains a daunting task. However, the demand for essential oils, known for their versatile applications in cosmetics, perfumes, diffusers, therapeutic oils, and even culinary delicacies, presents a promising opportunity for sustainable utilization of fruit waste.

As the global population continues to grow, so does the production, cultivation, and consumption of fruits and vegetables. With extensive research on various fruit waste disposal methods, such as landfills, anaerobic digestion, and composting, this study focuses on harnessing the potential of fruit waste through the extraction of essential oils. Essential oils hold considerable market demand and are widely utilized in numerous commercial products, ranging from organic amendments and medications to cosmetics and therapeutic formulations.

Previous research has highlighted the diverse chemical composition and pharmacological benefits present in different parts of fruits, with fruit peels emerging as a particularly rich source of essential oils. Studies have demonstrated that fruit peels possess a wide array of valuable properties, including antibacterial, antioxidant, anti-inflammatory, anti-healing, anti-infectious, anti-mutagenic, and hepatoprotective qualities. For instance, investigations into essential oils extracted from Citrus limetta var. Mitha (Sweet lime) peel in Pakistan revealed significant chemical constituents, as well as antimicrobial and antioxidant activities (Javed *et al.,* 2013). Furthermore, essential oils derived from various Citrus species, including tropical *Citrus* spp., have demonstrated potent antimicrobial activities against food-related microorganisms (Chanthaphon *et al.,* 2008).

Technological advancements have also played a crucial role in improving essential oil extraction processes. Studies have explored various extraction techniques, such as steam distillation, hydrodistillation, and supercritical CO_2 extraction, to optimize yield and preserve the quality of essential oils (Reverchon and Senatore, 1992; Reshamkanadea and Bhatkhandeb, 2016).

Fruit wastes are a valuable resource and can be transformed into various commercial products, including essential oils, organic amendments, medications, and cosmetics. Each part of a fruit, such as the peel, pulp, and seed, contains unique chemical components that can be harnessed for the production of organic goods. Fruit peels, in particular, have been widely disposed of as garbage, but they hold significant pharmacological benefits, such as antibacterial, antioxidant, anti-inflammatory, anti-healing, anti-infectious, anti-mutagenic, and hepatoprotective properties (Javed *et al.,* 2013, Chanthaphon, Chanthachum, Hongpattarakere, 2008: Okoh *et al.,* 2008; Pizzale *et al.,* 2022). Essential oils extracted from fruit peels have demonstrated potent antibacterial activity against various microorganisms, even those resistant to antibiotics. To ensure sustainable and promising essential oil production, extractors need to be user-friendly, portable, cost-effective, and efficient. Advanced technologies like microwave and hydrosol may offer potential models for essential oil extraction. This approach not only addresses the environmental challenges of fruit waste disposal but also meets the escalating demand for essential oils in diverse industries.

Recent literature underscores the pressing need to address fruit waste management and highlights the immense potential of essential oil extraction as a sustainable solution (Smith *et al.,* 2023; Johnson & Lee, 2022; Adams, 2023).

Understanding the value of fruit waste and its various components in creating organic products, including essential oils, can lead to innovative approaches that contribute to waste reduction and meet the rising demand for eco-friendly and natural commodities (Brown & Martinez, 2022; Williams & Taylor, 2021).

The design, fabrication, and testing of essential oil extractors for quality production of essential oils from fruit wastes hold significant implications for the Philippines on various levels. The country faces substantial challenges related to waste management, particularly concerning the massive amounts of fruit wastes generated daily in market areas. Proper disposal and management of these fruit residues are crucial to mitigate environmental pollution, land degradation, and potential health hazards. By focusing on the extraction of essential oils from fruit wastes, this research offers an innovative and sustainable approach to address these issues.

In the Philippines, where agriculture plays a vital role in the economy, fruit production is abundant. However, a considerable portion of the fruits' peels, pulp, and seeds are discarded as waste, leading to resource wastage and environmental burdens. By utilizing essential oil extractors specifically designed for fruit wastes, this research promotes the efficient and value-added utilization of these residues. The extraction of essential oils from fruit peels not only reduces waste accumulation but also taps into the potent pharmacological benefits and commercial value of these oils (Pasua, Ramos & De Guzman, 2018, Guinto, Ignacio & Marasigan, 2021, Arueza *et al.*, 2020).

Moreover, the essential oil industry has vast potential in the Philippines. The production of essential oils can create opportunities for small-scale farmers, cooperatives, and local entrepreneurs to engage in value-added activities, fostering economic growth and rural development (Mercado-Mercado et al, 2019, DTI, 2015). The extracted essential oils can be utilized in various industries, including cosmetics, personal care products, food, and beverages, thereby contributing to local economic diversification. Furthermore, the research aligns with the Sustainable Development Goals (SDGs) set by the United Nations. Notably, SDG 12 (Responsible Consumption and Production) emphasizes the need to promote sustainable practices, reduce waste generation, and enhance resource efficiency. By converting fruit waste into essential oils, the research aligns with SDG 12, contributing to responsible production practices and minimizing environmental impacts.

Additionally, the use of essential oils extracted from fruit waste aligns with SDG 3 (Good Health and Well-Being) due to their pharmacological benefits, including antimicrobial properties and antioxidant effects. These oils can potentially enhance health and wellness products and serve as natural remedies for various ailments. Furthermore, SDG 8 (Decent Work and Economic Growth) is supported through the creation of income-generating opportunities for individuals and communities involved in the essential oil industry. By providing an avenue for entrepreneurship and local value addition, the research contributes to fostering decent work and economic empowerment.

This technology relates to the method and apparatus for extracting essential oils from fruit wastes, comprising a specially designed essential oil extractor tailored too efficiently and effectively process fruit peels, pulp, and seeds. The extractor utilizes a combination of direct heat and water distillation methods, ensuring optimal yield and quality of essential oils. The apparatus incorporates state-of-the-art engineering technology, including an electrically powered essential oil extractor and a direct heat essential oil extractor, both equipped with innovative features to enhance extraction efficiency. The process involves drying the raw materials using both oven and sun-drying techniques to preserve the essential oil content. The essential oil extractor is designed to be portable, household-based, economical, and efficient, promoting sustainable and promising essential oil production from fruit wastes. The invention may be patentable under relevant intellectual property laws for its possible novel and unique contribution to the field of medicine, perfumery, manufacturing, and pharmaceuticals.

Objectives of the study

The research study aimed at:

1. Coming up with a design for essential oil extractor for fruit wastes using the models:
    a. electrically powered essential oil extractor
    b. direct heat essential oil extractor

2. Fabricating the proposed designs of the essential oil extractors for fruit wastes using state-of-the art engineering technology.

3. Evaluating and testing the designed essential oil extractor as to:
    a. yield (in terms of volume)
    b. cost
    c. durability
    d. commerciality

4. Registering the designed essential oil extractors developed for UM or patent.

Materials and methods

Development of the machines

Based on the condenser orientation, power source, oil production method, component parts, weight, manufacturability, cost, portability, ease of assembly, and maintenance requirements, several designs were designed and evaluated. The chosen concept is shown in Figure 1 following discussion and selection of the final designs.

The design specifications of individual parts and subassemblies of various units were based on various design equations of pressure vessels. The electric and direct heat unit consists of twelve (12) and seven (7) parts, respectively. as listed in Figure 1. Table 2 and Table 3 shows the dimensions, the material and the manufacturing processes selected for the individual parts of the electric and direct heat extractors The Philippines, known for its abundant fruit production, faces a pressing issue of managing the substantial amounts of fruit waste generated in market areas on a daily basis. Improper disposal of these fruit residues leads to environmental pollution, land degradation, and potential health hazards. Moreover, this waste represents a significant underutilized resource, as the peels, pulp, and seeds of fruits contain valuable components, such as essential oils, which can offer numerous benefits.

The challenge lies in finding efficient and sustainable methods to extract essential oils from fruit wastes to maximize their value and minimize environmental impact. Existing extraction techniques may not be optimized for fruit waste sources, resulting in low yields and inefficient processes. Therefore, a need arises for the design, fabrication, and testing of essential oil extractors specifically tailored to fruit wastes, ensuring quality production of essential oils.

The research aims to address this problem by developing innovative extractors that can effectively extract essential oils from various fruit waste materials, thus reducing waste accumulation and offering value-added opportunities. The successful implementation of such extractors could have far-reaching implications for waste management, sustainable resource utilization and economic growth in the Philippines respectively.

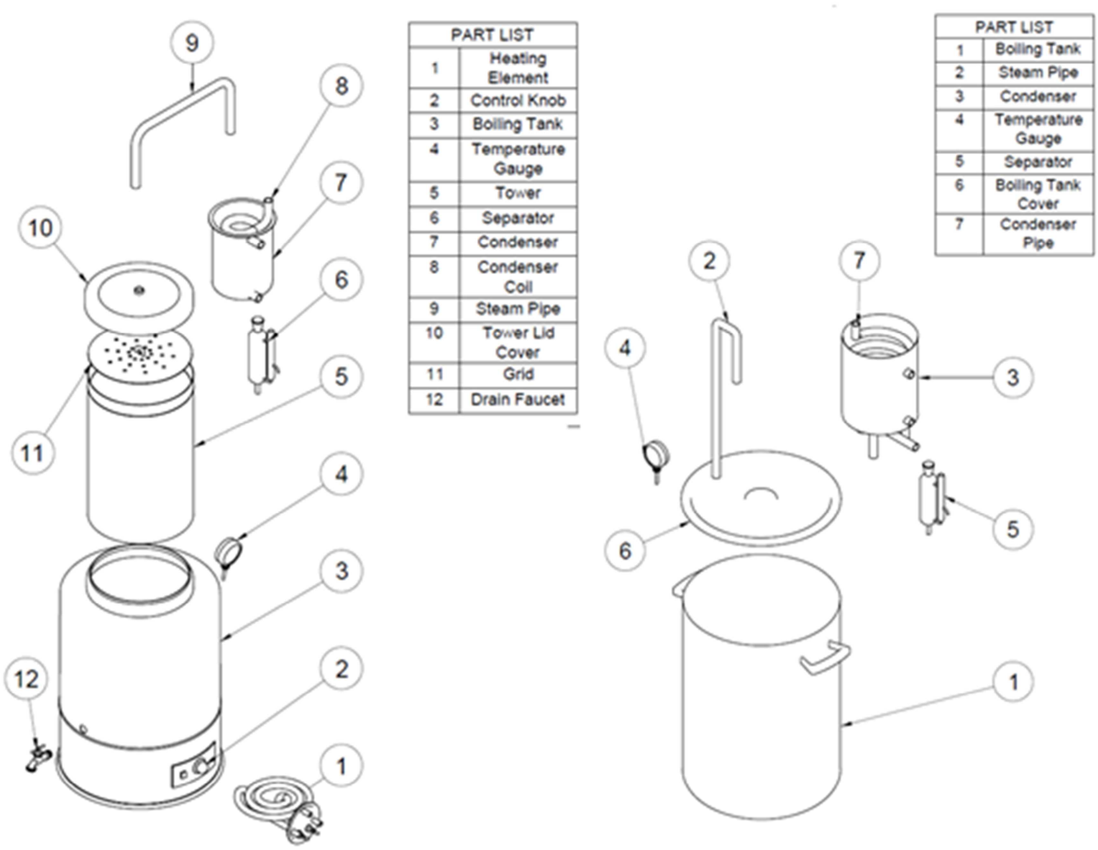


Fig. 1. Exploded view of the selected concepts, electric based (right) and direct heat essential oil extractor (left).

Specifications are necessary for the replication of the output after it will be labelled as the final product. It shall also be essential for patent registration and in the costing of the equipment. When repair will be necessary, specifications are also required for the purchase of the appropriate parts.

Table 2 presents the design specification of the proposed electric extractors highlighting on the materials used, dimensions and manufacturing process/es.

The Electric Extractor design provides cheaper production cost as it shall get rid of the use of butane or Liquified Petroleum Gas. It was also observed that the prototype was not stained even when tested with varying types of fruit wastes. Windy or open areas do not affect the heating performance of the device and that the heating element can be controlled. Well of course, it is dependent on electricity for its operation.

Table 1. Electric Extractor Design Specification

Part #	Part Name	Dimension (mm)	Material Used	Manufacturing Process
1	Heating Element	Ø 145 x Ø 7	Nichrome	Purchased
2	Control Knob	Ø 52 x 23	Plastic	Purchased
3	Boiling Tank	Ø 250 x 265 x 2	Stainless Steel	Measuring, cutting, folding, and grinding
4	Temperature Gauge	Ø 58	Stainless Steel	Purchased
5	Tower	Ø 154 x 257 x 2	Stainless Steel	Measuring, cutting, folding, and grinding
6	Separator		Glass	Purchased
7	Condenser	Ø 122 x 153 x 1	Stainless Steel	Measuring, cutting, folding, and grinding
8	Condenser Coil	Ø 110 x Ø 10	Copper	Measuring, cutting, folding, and grinding
9	Steam Pipe	Ø 15 x 600	Stainless Steel	Purchased
10	Tower Lid Cover	Ø 157 x 25 x 1	Stainless Steel	Measuring, cutting, folding, and grinding
11	Grid	Ø 140 x 1	Stainless Steel	Measuring, cutting, folding, and grinding
12	Drain Faucet	Ø 12.7	Stainless Steel	Purchased

The Direct Heat essential oil extractor allows faster boiling of water and it can be used even without electricity. Also, the initial cost of the equipment is cheaper. On the other hand, the essential oil extractor dependent on direct heat produces minimal stains because of the use of fire and requires high production cost since it uses butane/ LPG.

Table 2. Direct Heat Extractor Design Specification

Part #	Part Name	Dimension (mm)	Material Used	Manufacturing Process
1	Boiling Tank	Ø 250 x 345 x 2	Stainless Steel	Measuring, cutting, folding, and grinding
2	Steam Pipe	Ø 15 x 600	Stainless Steel	Purchased
3	Condenser	Ø 120 x 149 x 1	Stainless Steel	Measuring, cutting, folding, and grinding
4	Temperature Gauge	Ø 58	Stainless Steel	Purchased
5	Separator		Glass	Purchased
6	Boiling Tank Cover	Ø 252 x 1	Stainless Steel	Measuring, cutting, folding, and grinding
7	Condenser Coil	Ø 110 x Ø 10	Copper	Measuring, cutting, folding, and grinding

Data Gathering Procedure

Performance Tests of the Prototype Machines

The direct steam method of extraction was used, pushing the pockets of the dried calamansi to open by forcing the steam to pass through the plant material in the boiler after being generated from the boiling tank. Steam that contains both oil and water is sent through a steam pipe before condensing and becoming separated from the water in a condenser.

Dried Calamansi Peels, water and LPG gas were the main materials used for the production of the oil. Specific Gravity, Freezing Test, Ring Test ,Solubity Test and Grease Spot Test were also used to perform the physiochemical test and different chemical assay like Antibacterial and Antifungal Activity Assay, Antioxidant activity and Gas Chromatography Analysis were perform to test the purity of extracted essential oil.

The experimental setup for the extraction of the dried calamansi fruit waste is shown in Figure 3. A machine performance test (the extraction test) and a chemical test on the produced oil were both conducted here.

A. Direct heat essential oil extraction machine

B. Electrically powered essential oïl extraction machine

C. Preparation of Dried Calamansi

Collection and Drying of Calamansi

Oven Drying of Calamansi

Fig. 3. Experimental Set-up of Direct Heat and Electrically Powered Machines

Oven Drying of Calamansi

In order to prevent oil and vapor from escaping the system during the extraction test, the dried, chopped calamansi was weighed before being added to the boiler chamber and sealed with stainless steel clips. The temperature of the boiling chamber was measured using a temperature gauge. A thermal camera was also used to record the temperature of the burner and heating element. Calamansi is steam forces open the pockets of the plant material to vaporize the oil in it in the form of steam, which then passes through the steam pipe to the condensing unit. The steam generated from the boiling tank passes through dried chopped calamansi the grid into the tank that contains the plant material.

The condenser, a heat exchanger that converts steam into liquid, cycles water through it. The liquid then falls into the separator.

According to Figure 4, the oil and hydrosol are separated due to differences in density.

The entire process' length was noted, and the mass flow rate of the LPG used was set at 1 kg per hour. The amount of oil that was gathered was counted, documented, and shown in Table 4.

Fig. 4. Picture of Sample Calamansi Essential Oil Obtained

Physicochemical tests were performed on the sample oil to determine its pureness. These include Specific Gravity , Freezing Test, Ring Test, Solubity Test and Grease Spot Test were also used to perform the physiochemical test and different chemical assay like Antibacterial and Antifungal Activity Assay ,Antioxidant activity and Gas Chromatography Analysis were perform to test the purity of extracted essential oil.

A key indicator of an essential oil's quality and purity is its specific gravity. The specific gravity has been mentioned in the literature the most frequently of all the physicochemical characteristics. Untreated calamansi rind's essential oil was discovered through physical and chemical investigations to be a transparent, greenish-yellow, oily liquid with a specific gravity of 0.727. Analytical balance was used to weigh a volumetric flask that was clean and dry. The volumetric flask was filled with distilled water and weighed. The specific gravity was determined as the ratio of the weight of the oil to the water as specified in the equation. The result was 0.738g/ml. The same volume of oil was weighed into the same volumetric flask and weighed.

$$\text{Specific gravity} = \frac{\text{Oil filled volumetric flask- empty volumetric flask}}{\text{Water filled volumetric flask- empty volumetric flask}}$$

In the solubility test, the test container was filled with the extracted calamansi oil and the lemon grass was mixed with a tiny amount of water. After giving the mixture a brisk swirl, it was given some time to settle.

It was discovered after some time that the calamansi oil continues to exist as a distinct phase from the water, indicating that it is 100% pure calamansi essential oil. Figure 5A displays the test's outcome.

Ring test was also performed by placing a drop of the essential oil in a piece of white paper and wait for few minutes , if there is a ring present that means that the oil has likely been diluted with another substance.

In order to conduct the grease spot test, two pieces of paper were coated with oil and water and let to sit for a while. The water stain would stop being transparent. The freezing test was conducted by placing the essential oil in the freezer for approximately 8 hours; pure essential oil will not crystalize. However, the smear of oil would remain translucent for a long time as shown in Figure 5C. This suggests that the oil is pure, as seen in Figure 5D. The results are tabulated and shown in Table 3 for your review.

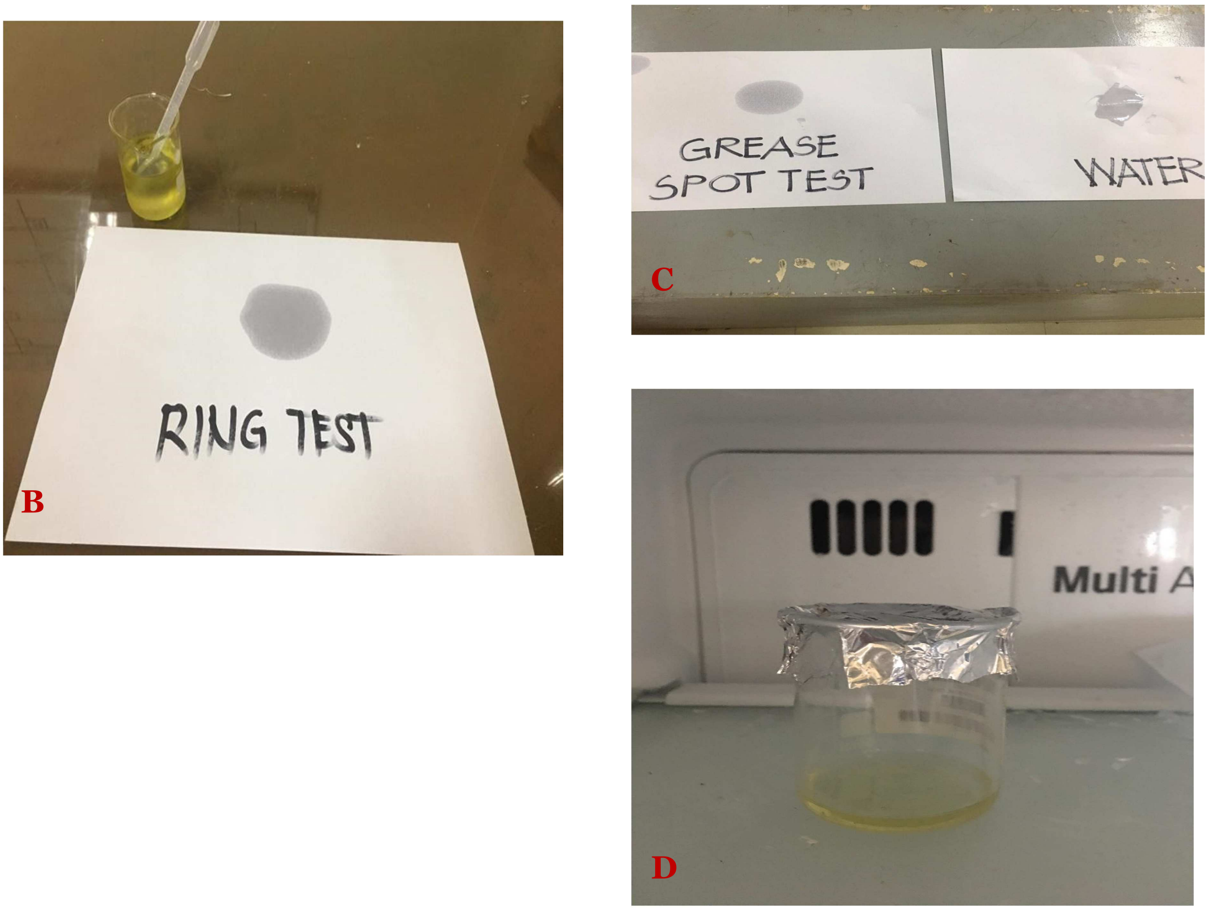
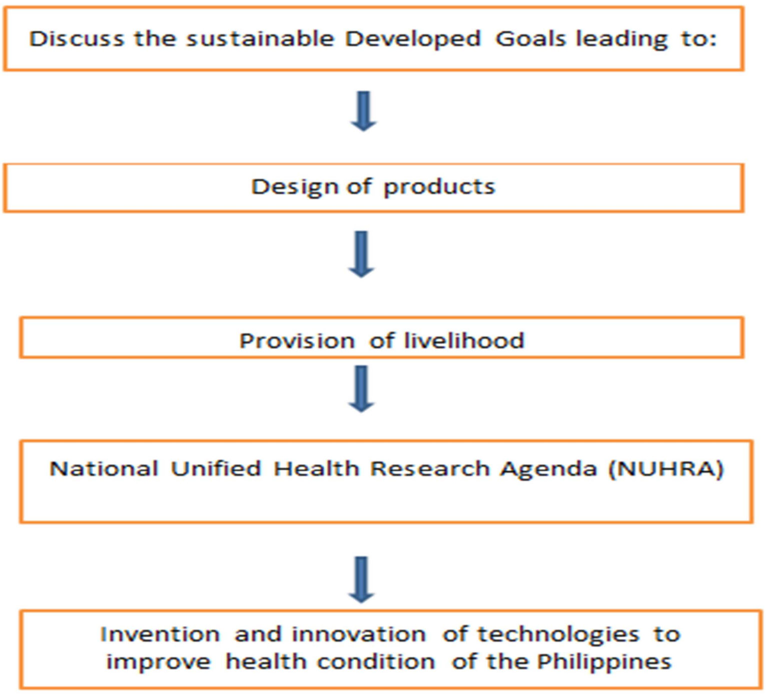


Fig. 5. Test results of physicochemical tests

Research Design



Analysis of the Data/ Statistical treatment

Results and discussion

The contents of the journal are peer-reviewed and archival. The international journal publishes scholarly articles of archival value as well as tutorial expositions and

The gathered results were subjected to analysis in order to ascertain the machine's effectiveness and suggest ways to enhance it. Additionally, the level of oil produced and its economic viability were assessed.

Table 1. Physicochemical Test Result

Parameter	Result
Specific Gravity	0.738 g/ml
Solubility in water	Insoluble in water (Positive)
Ring Test	Positive
Grease Spot Test	Positive
Freezing Test	No Crystallization

Effect of drying method on the volume of essential oil extracted

Table 2. Result on the Effect of Drying Method and Extraction Time on the volume of extracted essential oil using the Direct Heat Machine.

Method of Drying	Initial Mass (kg)	Final Mass (kg)	Mass Reduction Rate (%)	Duration of Drying (days)	Temperature (°C)	Mass (kg)	Type of Solvent	Volume of Solvent (mL)	Volume Extracted (mL)
Oven Drying	14	10	29	7	40	2	Water	4000	3
				7	60	4	Water	5000	25
				8	60	4	Water	5000	30
Sun Drying	16	12	25	5	35	4	Water	5000	30
				8	35	4	Water	5000	20
				5	35	4	Water	5000	30

Effect of extraction time

Time (hrs)	Mass (kg)	Temperature (°C)	Typeof Solvent	Volumeof Solvent (mL)	Volume Extracted (mL)
1	2	100	Water	4000	3
2	4	100	Water	5000	25
1	4	100	Water	5000	30
1	4	100	Water	5000	30
1	4	100	Water	5000	20
1	4	100	Water	5000	30

Data reveal the calamansi extracts which were dried using sun drying for about 7 drying days yielded essential extracts from 20-30ml coming from 16 kgs of the raw material. The temperature requirement is set at 35 o C.

On the other hand, the method which made use of oven drying yielded 25-30 ml of essential oil from 14 kgs of raw material and exposed at 60 o C.

In terms of the effect of extraction time, it can be appreciated that it takes 1-2 hours in order to recover 20-30ml of essential oils using direct heat extractor machine.

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Effect of drying method on the volume of essential oil extracted

Table 3. Results on the effect of Drying Method and extract time on the volume of extracted essential oil using the electrically powered machine

Method of Drying	Initial Mass (kg)	Final Mass (kg)	Mass Reduction Rate (%)	Duration of Drying (days)	Temperature (°C)	Mass (kg)	Type of Solvent	Volume of Solvent (mL)	Volume Extracted (mL)
Oven Drying	14	10	29	7	40	2	Water	4000	3
Sun Drying	Not Performed	Not Performed	Not Performed	Not Performed	Not Performed	-	-	-	-

Results reveal that only 3ml of essential oil extracts can be recovered from 14 kgs of calamansi peelings which is oven-dried for 7 days at 60 o C.

Also, it can be noted at only 3ml of the essential oil can be recovered in 1 hour of processing.

Comparing the cost of the essential oil extractors in terms of the generation cost, the Direct Heat essential oil extractor is cheaper and the suggested retail price is at P 17, 000 (unit cost) compared to the Electric essential oil extractor which can be offered at P 20,000 (unit cost).

Discussion

The efficiency of the machine and the effects of extraction in terms on drying the raw materials, extraction time on essential oil and the percentage yield acquired in each trial from calamansi peels using the two extractor machine were investigated.

In the drying process, oven drying and sun drying were carried out to examine the impact of the various drying techniques. Results indicated a considerable impact of drying techniques on the proportion of essential oils. Since the raw material's peels are thin, heat rapidly influences the essential oil inside; consequently, the more time the material spends drying, the more essential oil is likely to be lost.

Based on Table 4.2 and 5.1 the appropriate time for extraction is 1 hour to perform extraction and to produce greater volume of essential oil.

Suggested retail price

Table 4. Cost of The Machines

Machine Type	Components	Price
Direct Heat Essential Oil Extractor	Boiler	10,000
	Condenser	5,000
	Oil Water Separator	2,000
	Total	17,000
Electric Essential Oil Extractor Machine	Boiler	10,000
	Electrical and Electronics	3,000
	Condenser	5,000
	Oil Water Separator	2,000
	Total	20,000

Conclusions

The study unequivocally demonstrates that the essential oil extractor utilizing direct heat surpasses the electrically-powered extractor in terms of efficiency, economy, durability, and commercial potential. The direct heat extractor's impressive extraction capacity, coupled with its cost-effectiveness and reliability, positions it as the preferred choice for essential oil production. Its ability to generate 30ml of essential oil in just one hour from sun-dried calamansi peel extract showcases its superior performance compared to the electrically-powered option. Furthermore, with a potential distribution price of P 17,000 per unit, the direct heat extractor presents an accessible and profitable option for producers in the cosmetics, perfumery, and therapeutic industries. The study's findings, along with the successful design and fabrication of the essential oil extractors, lay the foundation for further enhancements and potential industrial upscaling. Overall, the research offers valuable insights that can pave the way for a more sustainable and promising business of essential oil production from fruit wastes.

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