Dehydrator Machine for Herbal Tea

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Abstract
The idea behind designing and developing a hybrid solar dehydrator machine is to lower the cost of the drying process of herbal teas by using solar energy as the primary source of drying energy and electric power as a backup source. The hybrid solar dehydrator has a solar heat collector, a drying chamber, and electric heaters that only turn on when the drying temperature provided by the sun is not enough to keep the desired drying temperature. This research also includes devising protocols for collecting, drying, and brewing herbal tea materials to determine the potential phytochemicals they might contain. An evaluation of the performance of the hybrid solar dehydrator machine showed that solar radiation and electric power use energy efficiently, with a drying efficiency of 54.52%. This technique keeps the temperature where it should be and lowers the humidity to 6%. The drying moisture reduction was 94.8% while keeping the phytochemicals: alkaloids, flavonoids, saponins, and tannins, in the guava and guyabano samples.
Keywords: Dehydrator machine; Hybrid solar dryer; Herbal tea; Phytochemical; Moringa; Guyabano; Guava

1. Introduction

Herbal teas and herbal and fruit infusions have an extensive market worldwide. The current demand for medicinal plants, estimated by the World Health Organization (WHO), is worth $14 billion annually and will reach $5 trillion by 2050 (Yashin et al., 2011). The increase in demand for such products could be directly related to the increased health awareness of consumers. In recent years, encouraging data showing cancer-preventive effects and beneficial cardiovascular and metabolic health effects of tea consumption have been published (Nirmal, 2013; Philippine et al., 2010).

In Europe and ASEAN countries, guidelines are already in place for ensuring the quality of herbal teas or infusions (Tea and Herbal Infusion Europe, 2014). In the Philippines, the government supported identifying and recommending ten medicinal plants as beneficial for health (Tupas & Gido, 2020). However, their use did not become popular because of questions about their claimed effectiveness and a lack of scientific evidence, as local industries needed more expertise to perform these undertakings. A partnership between local industries and research academies is thus an integral move for local industry produce to make it in the international market.

Preserving the highest possible nutrients and phytochemicals in herbal tea production is crucial to preserve the potential health benefits of the products. One factor to consider is the drying method. Drying tea leaves removes moisture, arrests fermentation, reduces volume, increases shelf life, and gives quality to the brew. The most common low-cost method of drying food products is sun-drying, where food product materials are placed under sunlight in an open space, having the drawback of microbial contamination. This technique, however, is not possible at night or during the rain. Limitations, such as prolonged drying times and unstable temperature control, are inevitable. Also, the product is of lower quality because of contamination, loss of vitamins and nutrients, and unacceptable colour changes due to direct ultraviolet exposure (Aremu et al., 2013). Another form of drying is convective drying, which circulates heated air throughout trays inside a chamber where the products are situated [12]. This mechanism involves the convection current passing over the product and not through it. This system provides control and optimised drying conditions, with the heat source commonly being steam coils or batteries. However, one of its limitations is its utilisation of fuel or electricity, which increases production costs.

A comparison between direct sun drying and solar drying revealed that the latter generates higher temperatures, lower relative humidity (RH), lower product moisture content, and reduced spoilage (Aremu et al., 2013). Using solar minimises the cost of the drying process. According to Burguillos et al., 2015, a dark cotton cloth below the transparent glass covering absorbs solar radiation and radiates it at a long wavelength to the drying materials.

Ferreira et al., 2007 built a hybrid solar-electrical dryer. The dryer comprises a solar chamber and an auxiliary heating system to complement solar heating at the bottom of the drying chamber. A chimney installed on the top allows drying air to exit. The eight trays fit inside the dryer, and they installed a thermostat to control the airflow. Aremu et al. built a similar dryer in Ibadan, Oyo State, Nigeria.

The above techniques expose the operators outside the production area, especially in drying preparation. According to Teshome et al. 2013, limited studies determine the teas' biochemical composition as affected by drying temperature and drying duration. Thus, this emphasises the need to develop a dehydrator machine that is an improvement from the existing designs and is convenient to the user, as well as establishes protocols for the drying process of products, particularly herbal teas.

The antioxidant properties of tea are primarily responsible for its positive health effects (Khan & Mukhtar, 2014). Brewing temperature and hot water infusion duration vary from area to region, affecting antioxidant capabilities and overall phenolic levels. Gallic acid, caffeine, catechins, and flavonols—the main ingredients in green tea—all alter depending on the brewing process (Jin et al., 2019). According to Jin et al., catechins, among other chemicals, can be damaged by brewing beyond 90 degrees and degrade at greater temperatures and longer brewing durations (Jin et al., 2019). However, research on the impact of infusion duration on these antioxidants and phenolic characteristics is nonexistent (Nikniaz et al., 2016). This result emphasises the necessity of developing guidelines for brewing herbal tea products.

There have already been studies on the efficacy of herbal products in several nations (Noor et al., 2013; Okafor & Ogbobe, 2015; Omogbai & Ikenebomeh, 2013; Singh et al., 2014; Ting et al., 2013). However, despite positive findings and great market potential, local tea producers hesitate to be bold in mass-producing herbal tea products. Local tea producers need more knowledge of its processing and need more equipment and technical skills to perform laboratory experiments and analysis. On this premise, the project enforces these local enterprises with processes backed by science and producing technologies to improve its position as a global player.

To enhance the technology for herbal tea processing, researchers continued to conduct research to improve drying processes further. Studies are conducted to enhance the current design to maximise solar energy over electric power as backup energy. The study focuses on developing drying technology using a hybrid solar dehydrator machine to address the production problem of a start-up industry in post-harvest processing operations. Information brought about by the study helps upgrade processing techniques and ensure high-quality products for consumers. Applying the results from this project boosts the competitiveness of processed products in the market, achieves inclusive economic growth in the countryside, benefits small farmers and locals, and ultimately increases the herbal tea industry in the Philippines.

2. Objectives of the Study

This project aims to design and develop a Hybrid Solar Dehydrator Machine for Herbal Tea (DMHT) that use solar and electric power backup and generate protocols for science- and technology-based tea production. This project specifically targets the following:

a) Create a programmable dehydrator machine for drying herbal tea;
b) Evaluate the dehydration performance;
c) Devise protocols for herbal tea material collection, drying, and brewing;
d) Screening and quantitative analysis of phytochemical properties of herbal tea materials subjected to different parameters; and
e) Determine the shelf life of the processed herbal tea materials.

3. Conceptual Paradigm

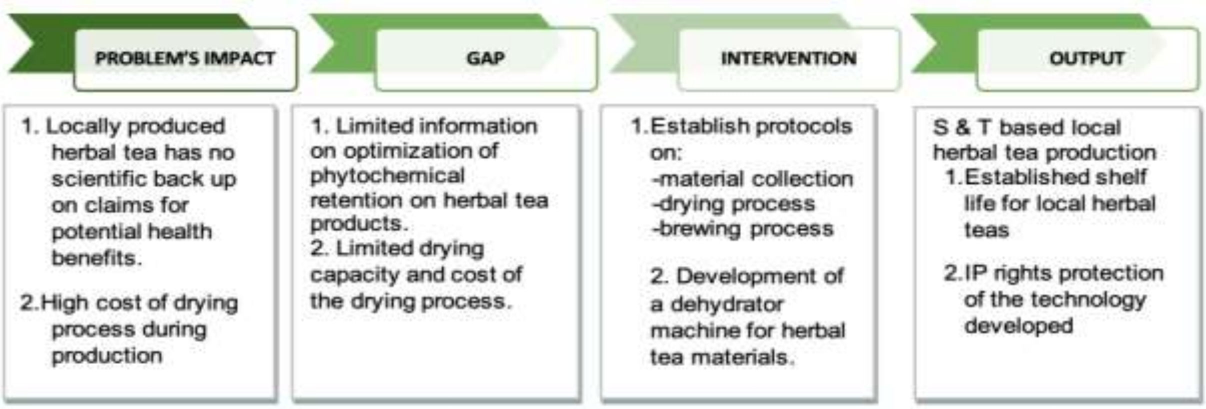

Figure 1. The conceptual paradigm of the project.

Figure 1 shows how the project could increase local herbal tea production by (1) substantiating claims of potential health benefits and (2) reducing drying and processing costs.

To maximise the health advantages of these tea products, protocols for material collection, drying, preparation, and processing, as well as the brewing method, are devised based on research findings. With the development of the dehydrating machine, the processing of herbal teas got more convenient, and the drying process is more efficient than traditionally practised by locals.

4. Materials and Methods

4.1. Established Ideal Settings to Improve the Machine's Design

The initial sampling and drying of herbal tea materials as traditionally practised by locals to process their herbal tea products. The researchers collected fresh and dried samples for laboratory analysis to determine herbal teas' phytochemical content and antioxidant activity. The assessment and baseline data used to construct the dehydrator machine served as the basis for the requirements for ideal conditions for the manufacture of herbal tea. Figure 2 shows the process flow of the phytochemical analysis.

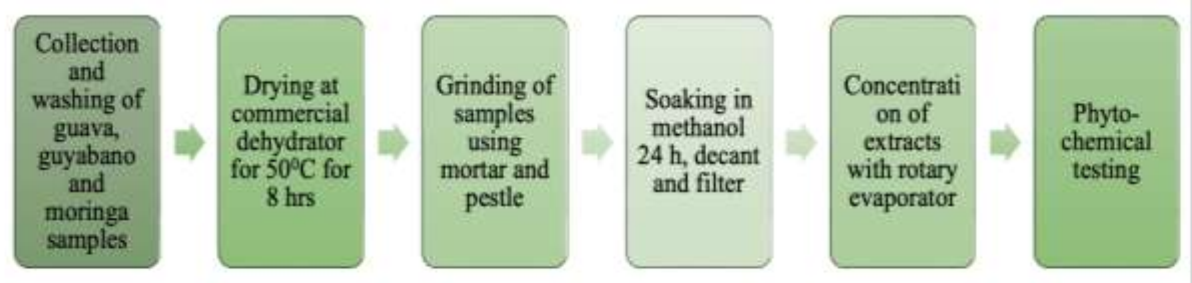

Figure 2. Process flow for phytochemical analysis of plant materials

4.2. Fabrication of the Prototype Unit

Design considerations of the dehydrator machine include the volume of materials to be dried, the temperature range, drying duration, and location for installation. The general design was modified until the prototype unit's performance met the users' expectations. The materials used in fabrication are food-grade/high-grade stainless steel (SUS 304) for the body and frames and tempered glass for the doors. It is impermeable to surface contamination and made to have a smooth surface for easy cleaning.

The dehydrator machine contains three major components: the solar heat collector, the drying chamber, and the control and monitoring unit to maintain and determine the moisture, airflow, and temperature of the drying chamber.

Heat Catcher Module

The heat catcher, also known as the heat collector, is made of aluminium framing material to reduce weight, is double-walled, and fibre insulated. This design keeps the heat absorbed from solar irradiation to retain inside. The tempered glasses are mounted on top of the module to trap heat. Air intake is through a force convection method driven by a solar-powered driving fan with a screen filter. The exhaust outlet attached to an insulated air duct is responsible for heating air and forcibly transferred to the heating chamber using a blower installed in the heat catcher module.

Drying Chamber

The drying chamber installed inside the production area is made of stainless steel sheets with a tempered glass door for easy viewing of dried tea materials. The drying chamber is a double-walled cabinet with a one-inch thick fibre material for heat isolation. The solar dryer can cause hot drying air at 10–25 °C in the drying chamber above the ambient temperature when solar radiation is present. The dehydrator has a combined feature of electric heaters and a solar collector that stabilises the temperature in the chamber—the thermal isolation prevents the re-absorption of moisture from external ambient. The air-circulating blowers provide heated airflow from electric heaters and the heat catcher. This method ensures that we maintain the temperature inside the drying chamber.

Control and Monitoring Unit

The HSDMHT has a programmable temperature controller, humidity sensors, and an Internet of Things (IoT) support system for remote temperature and humidity monitoring while the material is drying.

4.3. Devising Protocols for Herbal Tea Material Collection, Processing and Drying, and Brewing

The fresh plant materials from the local tea producer were utilised to determine the effect of post-harvest drying and processing on the bioactive components. The methods described by Guevarra et al., 2005 were modelled in this study. This method intends to devise protocols for collecting herbal tea material, processing and drying, and brewing. The process flow is as follows:

Figure 3. Process flow for herbal tea processing of guava, guyabano, and moringa leaves

Drying experiments were performed at varying conditions to identify which bioactive compounds were most affected. The data generated were used to evaluate the efficiency of the constructed dehydrator machine. The water temperature and brewing time were considered for the brewing process. At the same time, drying protocols were set to produce the best herbal tea product.

5. Results and Discussion

5.1. Test Inspection of the Programmable Dehydrator Machine

The installed heat catcher and drying chamber are assembled, respectively. The solar heat catcher, painted black for optimum heat absorption, effectively captured solar heat. Solar radiation is used to heat the dehydrator, creating a functional, inexpensive, and simple-to-use drying device that is effective in drying herbal tea products. It has 12 metal trays with front and back apertures for enhanced warm air circulation and more effective drying. With a goal capacity output of 5 kg/day (ten times the output of the local producer of 0.5 kg/day), the dehydrator was successfully developed to suit the demand of the drying process of herbal tea products. The operating performance of the machine through each of its main components was individually assessed. The solar heat catcher was tested for its temperature and humidity and compared with ambient temperature and humidity.

Figures 4 and 5 illustrate the significant difference as the solar heat catcher significantly lowers relative humidity and increases the temperature. The temperatures measured from the solar heat catcher ranged from 55 °C to 71 °C, showing a good rise in the solar heat catcher temperature compared to the ambient temperature. The ambient temperatures outside ranged from 39 °C to 45 °C. As a result, the contrast between the two systems shows how the heat catcher lowers the air humidity required for drying. Additionally, it was established in the data that the temperature rise creates impacts inversely proportional to the relative humidity of the dry air, as expected.

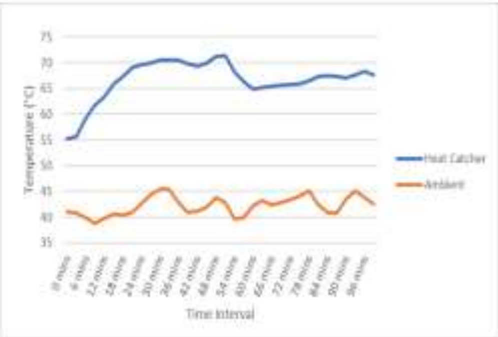

Figure 4. Comparison of solar heat catcher and ambient temperatures over time

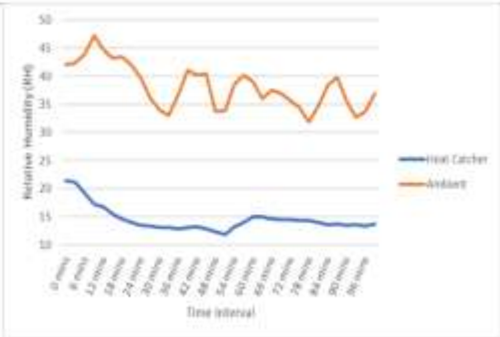

Figure 5. Comparison of solar heat catcher and ambient relative humidity over time

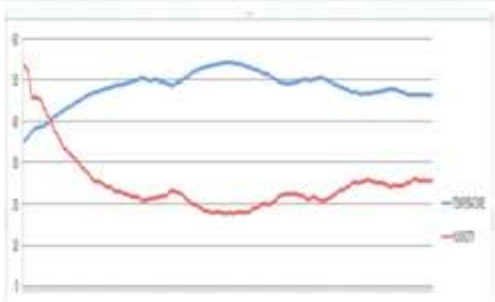

Figure 6. Temperature and humidity values inside the drying chamber without electric heater back up over time.

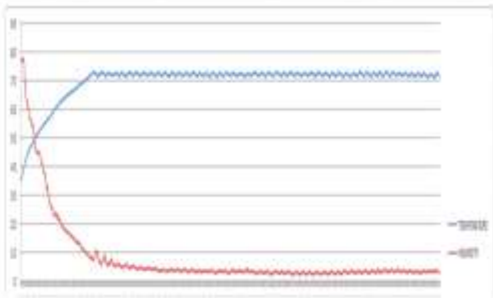

Figure 7. Relationship of temperature and humidity when an electric heater backs up the machine over time.

The drying chamber and its control and monitoring unit were also at a temperature setting of 70 °C. Results indicate that using solar energy and electricity allows for efficient energy use while keeping the ideal temperature. Because electric backup is provided whenever solar radiation is insufficient, temperature and humidity levels are more stable than those powered by solar radiation alone, as shown in Figures 6 and 7.

5.2. Establishment of optimal parameters for better design of the machine

Moisture Content (MC) and Drying Temperature

Three different setups were used to compare the moisture content. As shown in Table 1, the research team's findings generally show higher MC, except for moringa dried at 68 °C.

This result is reasonable because a lower drying temperature would cause the drying process to proceed more slowly, resulting in a lower evaporation rate. Despite having higher MC values, the numbers are acceptable because herbal tea components must meet a threshold of 12 per cent (World Health Organization, 2018). The change in drying temperature was dependent on the change in relative humidity. The airflow employed in the dehydrator machine was approximated for the hot air to move equally over all trays inside the drying chamber. The settings for the abovementioned parameters that encouraged the retention of appropriate phytochemical characteristics and high drying efficiency were considered optimal for better machine design.

Table 1. The moisture content of tea samples at different drying temperatures

Sample	Average Percent Moisture (%)	Preparation		
		Standard Preparation (68 °C)	Research Team preparation (68 °C)	Research Team preparation (50 °C)
Guava		4.98	5.85	9.18
Guyabano		4.46	9.56	9.88
Moringa		9.26	7.14	9.18

Phytochemical Screening of Fresh and Dried Samples

Phytochemicals, including protection against diseases, antioxidant activities, anti-carcinogenic properties, and antibiotics, have benefited human health. Field screening of fresh and dried samples was conducted to test for the presence of several phytochemicals and determine the effect of drying on these. The results are shown in Tables 2 and 3.

Table 2. Phytochemicals present in fresh leaves samples

Phytochemical	Herbal Tea Material			Observation
	Guava	Guyabano	Moringa	
Alkaloids	+++	+++	+++	Formation of the heavy orange precipitate
Flavonoids	+++	+++	++	Samples turn from green to yellow.
Saponins	++	++	+	The Level of plant extract is more than half compared to water
Tannins	+	+	+	Blue-black colouration

+++ highly present; ++ moderately present; + slightly present

Table 3. Phytochemicals are present after drying at 50 °C for 8 hours.

Phytochemical	Herbal Tea Material			Observation
	Guava	Guyabano	Moringa	
Alkaloids	+	+	+	Slightly turbid
Flavonoids	+	+	-	(+) Changes in color of the solution; (-) No change in color of the solution
Saponins	+	+	-	(+) The Level of plant extract is more than half compared to water; (-) Level of plant extract is less than half compared to water level
Tannins	+	+	+	Blue-black colouration

+ present; - absent

5.3. Drying capacity

The basis for determining the drying capacity of the HSDMHT is from the Philippine National Standard of agricultural machinery – Fruit Dryer – Methods of Test. It is stated that the drying capacity is the maximum capacity that the fruit dryer can remove the moisture content per unit of time and is expressed in kg/h. The drying capacity is calculated using the formula below:

$$D_c = \frac{initial\ weight\ of\ material}{actual\ drying\ time} = \frac{8.67\ kg}{24\ h} \quad (1)$$

$$D_c = 0.36\ kg/h \quad (2)$$

5.4. Drying Efficiency

Drying efficiency is the ratio of the total heat used to vaporise moisture in the material to the amount of heat added to the drying air, expressed in per cent (Nirmal, 2013). PNS (Philippine et al., 2010) stated that a formula was used to compute drying efficiency.

Drying efficiency is equal to 54.52% at 45 °C drying temperature. This value is near that reported by Aremu et al., which was 66.7%, in their study of the performance of a hybrid solar dryer used to dry fresh yam slices at 51 °C. The lower efficiency can be attributed to the difference in the drying temperature. According to Atuonwu, 2013, lower dryer efficiencies can be expected when mild drying conditions (lower drying temperatures) reduce the effects of thermal degradation. Also, the high amount of heat energy supplied to the dryer can be explained by various additional energy penalties, which may include thermal inefficiencies in the dryer. These factors are attributed to the exhaust heat content in convective dryers, heat losses from the dryer body, thermal inefficiencies in the utility (heat supply) system, such as steam leaks, and additional energy demands for air fans (Kemp, 2012).

5.5. Moisture Content and Moisture Reduction Rate

Initial MC was 73.01% (wet basis), and final MC was 12.35% after 24 hours. This moisture was achieved by drying at 37.9 °C to 45 °C. Therefore, the moisture reduction rate was 94.8% every 24 hours. Required MC after drying is set at <12% (WHO, 2018). Actual values recorded are slightly more significant than the set standard. However, during the testing of MC, the target capacity output of 5 kg was exceeded, and the actual loading weight of leaves was 8.67 kg. Therefore, the initial load weight should be limited to 5kg to achieve the target MC, as was observed in the preliminary testing, where an average MC of 9.41% was achieved.

5.6. Temperature Range and Humidity

Drying air temperature is the mean temperature of the air used for drying the fruit, measured at several points as close as practicable to its entry to the drying bed (Philippine et al., 2010). The temperature range recorded for drying air was 40.4 °C – 46.7 °C and the recorded range for relative humidity was 40.8 °C –69.5 °C. As seen in Figure 10, temperature and relative humidity are inversely proportional.

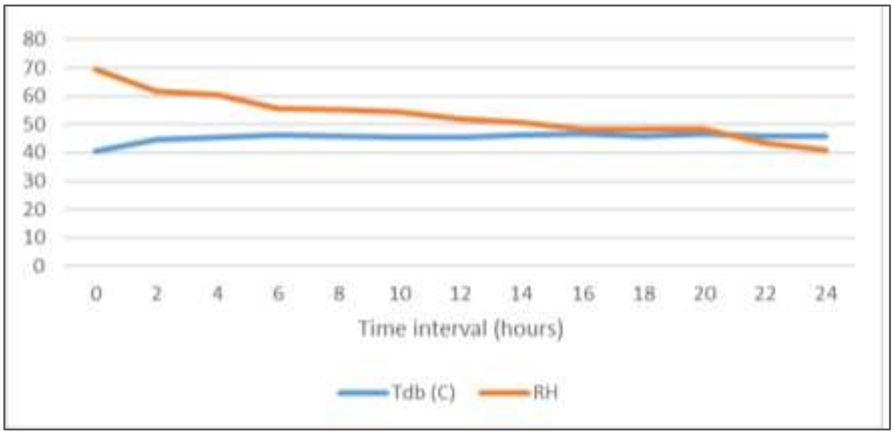

Figure 8. Relationship of drying air RH and temperature at different time intervals.

5.7. Quantitative Analysis of Total Phenol Content and Antioxidant Activity of Guava Leaves at Different Drying Conditions

Estimating the total phenol content (TPC) in the leaf samples was determined using the Folin-Ciocalteu method with gallic acid (GA) as standard. For the antioxidant capacity, phosphomolybdate assay (PMA) was used, and DPPH assay was used for antioxidant activity. As shown in Table 5, it could be concluded that guava leaves for herbal tea infusions should be dried at 45 °C to attain desired moisture and retain most of the tea materials' phenol content and high antioxidant activity.

Table 5. Total phenol content and total antioxidant activity of guava methanolic extracts at different drying temperature conditions

Sample	Total Phenol Content (mg GAE/L)	Total Antioxidant Activity (mg AAE/L)	DPPH assay (% inhibition)
A (Fresh leaves)	319	76.3	65
B (EF 68°C)	225	54.7	64.8
C (EF 50°C)	228	44.3	65.8
D (ISAT 68°C)	319	71.8	66.1
E (ISAT 45°C)	532	128	67

5.8. Effects of Water Temperature and Steeping Time On TPC, Antioxidant Activity, and Quality of Herbal Tea Infusions

In order to preserve the ideal sensory qualities, it was investigated how brewing parameters affected the extraction of bioactive substances and the enhancement of the antioxidant activity of herbal tea infusions. The three herbal tea materials were evaluated for their TPC, antioxidant content, and activity at four different brewing temperatures (10 °C, 30 °C, 60 °C, and 100 °C) and three different steeping times (5, 10, and 30 minutes.)

It was determined that for guava tea infusion, TPC is unaffected by the brewing time and temperature between 60 °C for 10 minutes and 100 °C for 30 minutes. The highest antioxidant activity is obtained at 100°C brewed for 30 minutes. For the guyabano infusion, TPC is not affected by the brewing time and temperature between 30 °C brewed for 30 minutes and 100 °C for 30 minutes. The highest antioxidant value was obtained at 100°C brewed for 10 minutes. For Moringa infusion, brewing at 100 °C for 30 minutes gave higher TPC than other brewing temperature conditions. The highest antioxidant content was observed at 30 °C brewing temperature for 30 minutes.

5.9. Stability and Shelf-Life Analysis

The stability of the herbal tea materials was determined based on the amount of TPC and their total antioxidant activity from 0 months (initial) to 9 months. All herbal teas were exposed at 40°C ± 2°C and 75% relative humidity ± 5% RH during this duration of 9 months. The TPC, antioxidant activity, and antioxidant capacity in each accelerated stability sample of each herbal tea material decreased concerning the control–0 month.

The estimated shelf life of the herbal tea materials is presented in Table 6. However, a real-time study at lower temperature and humidity conditions should be conducted to determine the actual shelf-life of the products since significant degradation of the identified biomarkers was observed only after three months of testing.

Table 6. Estimated Shelf-Life of Guava, Guyabano, and Moringa Herbal Teas Exposed at 40 °C ± 2 °C and 75% Relative Humidity ± 5% RH

Biomarker	Estimated Shelf-Life (Month)		
	Guava Tea	**Guyabano Tea**	**Moringa Tea**
Total Phenolic Content	10.0	9.29	7.30
Total Antioxidant Activity	8.00	9.24	10.15

5.10. Microbiological Analyses

Table 7 summarises the microbiological quality of the herbal tea materials studied and the limits for different categories of microbiological quality of herbal medicinal products (Association of South East Asian Nations, 2015). The standard used is for health supplement products containing material of plant origin, with or without excipients, intended to prepare infusions and decoctions using boiling water (for example, herbal teas, with or without added flavourings).

The microbial quality of the herbal tea materials studied is within limits set by the ASEAN (Association of South East Asian Nations, 2014), except for *S. aureus*. Moringa herbal tea is more susceptible to yeast and mould than guava and guyabano. An essential step in lowering the microbial count was brewing and even more brewing time because pathogenic microbes can survive at 90 °C for a short while (Kosalec et al., 2009).

Table 7. Microbiological quality of the herbal tea materials studied and the limits for different categories of microbiological quality of herbal medicinal products

Parameter	Guava Tea			Guyabano Tea			Moringa Tea			ASEAN Limit
	Time (month)			Time (month)			Time (month)			
	0	3	6	0	3	6	0	3	6	
Aerobic Plate Count (CFU/g)	$7.6x10^4$	$6.4x10^4$	$2.6x10^4$	$3.4x10^4$	$1.4x10^4$	$2.9x10^4$	$1.1x10^6$	$1.3x10^6$	$6.2x10^5$	$5.0x10^7$
E. coli Count (CFU/g)	<3.0	<3.0	<1.8	<3.0	<3.0	<1.8	<3.0	21	<1.8	10^3

Parameter	Guava Tea			Guyabano Tea			Moringa Tea			ASEAN Limit
	Time (month)			Time (month)			Time (month)			
	0	3	6	0	3	6	0	3	6	
S. aureus Count (CFU/g)	<10 EPC	<10 EPC	<10 EPC	<10 EPC	<10 EPC	<10 EPC	<10 EPC	<200 EPC	<10 EPC	Absent
Yeast and Molds Count (CFU/g)	640	<10 EPC	$3.1x10^4$	730	<100 EPC	100	170	<100 EPC	$6.0x10^5$	$6.0x10^5$

6. Conclusions

The DMHT products comprise a solar heat collector, solar panel, ducting system, drying chamber, and a programmable controller. The device's design is to dry herbal tea leaves regardless of weather conditions. The solar collector is exposed to solar radiation outdoors and is responsible for collecting heat radiated from the sun. The surface ensures maximum absorption of solar radiation regardless of the time of day due to the angle and broader area using the corrugated configuration coated with black material for maximum heat absorption. The collected heat is suctioned to the drying chamber using a blower installed at the upper midmost portion attached to the matting of the solar heat collector and the entry point of the central air duct. The solar heat collector is disposed of with an air inlet with a filter adjacent to the blower to ensure clean air enters the machine. The air intake for the drying chamber is regulated by a gating mechanism controlled by a thermal sensor, which controls the blower in the entry portion of the central air duct.

Further, hot air circulating inside the drying chamber is distributed and passes the layers (upwards and downwards) of other trays allowing maximum usage of hot air in the chamber. The temperature and humidity are controlled and monitored by a programmable controller by setting the desired temperature and humidity inside the drying chamber. Suppose solar heat is insufficient to provide the required heating temperature in the room. A heating device connected to the grid and installed inside the pressure chamber complements it to maintain the desired temperature. The drying process of herbal tea products using this method follows the established drying protocol to ensure the retention of selected phytochemicals of particular herbal tea products.

The DMHT performance shows that the developed design is efficient in reducing moisture content (94.8% reduction) and maintaining the desired temperature (54.52% drying efficiency) and is effective in producing finished products with retained phytochemicals beneficial for consumer health. The shelf life of finished products, with total phenolic content and total antioxidant activity as biomarkers, was determined to be seven months minimum.

Established protocols to maximise health benefits were established, namely: (1) mature and healthy leaves should be collected and immediately transported and processed in the production area; (2) leaves should be dried at 45°C until the moisture content is ≤ 10 %; and (3) guava, guyabano, and moringa tea should be infused in 100 °C water for 30 minutes.

7. Acknowledgement

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