Philippine Center for Postharvest Development and Mechanization
TECHNICAL BULLETIN
Vol. 11 No. 1 | 2021
ISSN 2243-8483

DEVELOPMENT AND FIELD TESTING OF GREENHOUSE SOLAR DRYER FOR FOOD SAFE CASSAVA PRODUCTS

Romualdo C. Martinez, Robelyn E. Daquila, Maria Elizabeth V. Ramos, Vanessa C. Largado, Jacky John K. Felix and Katrina S. Lumapas

ISSN: 2243-8483

Cover photos by: Agricultural Mechanization Division (AMD) - PHilMech

DEVELOPMENT AND FIELD TESTING OF GREENHOUSE SOLAR DRYER FOR FOOD SAFE CASSAVA PRODUCTS

Romualdo C. Martinez, Robelyn E. Daquila, Maria Elizabeth V. Ramos, Vanessa C. Largado, Jacky John K. Felix and Katrina S. Lumapas

Department of Agriculture
PHILIPPINE CENTER FOR POSTHARVEST DEVELOPMENT AND MECHANIZATION
CLSU Compound, Science City of Muñoz, Nueva Ecija, 2021

TABLE OF CONTENTS

ABSTRACT

The study was conducted to develop and field test a greenhouse solar dryer for food safe cassava products. The dryer is a greenhouse-like structure, 9.4m long and 7.0m wide. Glazed with twin-walled polycarbonate sheets. Inside the greenhouse are drying tables and multi-tray drying cabinet. Drying surface area is $10m^2$ per drying table and $15m^2$ per cabinet. Total drying capacity is 325kg using two tables and three cabinets at a loading rate of $5kg/m^2$.

The greenhouse solar dryer is installed on a concrete pavement that also functions as heat collector. Solar powered axial fans drawn in ambient air, circulates hot air inside the greenhouse and drawn out moist air. Fans also circulated hot air inside the cabinets. Biomass furnace provides heat during rainy periods and evenings. It was fueled by either rice husk, shredded biomass, or solid biomass.

The fans and the furnace are electrically powered by solar cell panels with storage batteries. The dryer enables small-scale enterprises including farmer cooperatives and associations to engage in processing of cassava food products to increases their production capacity and consistently produce high quality, naturally dried and food-safe products even during rainy periods.

Dryer performance evaluation showed that drying duration was reduced on the average by about 40%. Microbial analysis of dried samples showed that mold and yeast count of dried cassava food products passed FDA standards. Financial analysis showed that investment on the dryer would be recovered after 1.5 years, with internal rate of return of 66.6 %.

INTRODUCTION

Small to medium scale processors including farmer cooperatives and associations engaged in processing high-value crops and food products have problems drying their products properly especially during rainy periods when sun drying is not possible. Drying is often delayed resulting to spoilage, poor quality, low price, and market rejection. Processors have problems consistently producing high quality, naturally dried and food-safe products. Production capacity is hampered by limited dryer capacity and long drying duration. Drying is a heat energy extensive process and the use of fossil fuel to produce heat will make it expensive.

For this reason, sun drying remains the most cost-effective method of drying high-value crops and processed food products. Sun drying, if done properly, remains the most cost-effective method of drying. It maintains good product quality. However, direct sun drying exposes the product to various sources of contamination resulting to food safety concerns.

There are available solar drying technologies that provide some protection to dried products from contamination, including the Multi-Commodity Solar Tunnel Dryer (MCSTD) developed by PHilMech. However, these dryers are not designed to be suitable during rainy periods.

In 2014, PHilMech started working on the development of a greenhouse solar dryer with biomass furnace (Martinez, 2016) as alternative to MCSTD. It was first tested for drying fermented cacao beans. The dryer allowed drying of cacao beans even during rainy periods.

Unlike the MCSTD retrofitted with biomass furnace, it provided convenience when mixing fermented cacao beans when raining. Results of the drying trials showed that average drying time was around 40 % faster compared to the 'all-weather dryer' commonly used by the cacao processors.

The temperature inside the dryer was around 10 to 20°C as compared to the ambient temperature. Quality analysis of the samples showed that the greenhouse dryer produced well dried and browner cacao beans.

Bean recovery was also around 8 % higher. The next prototype of greenhouse solar dryer with biomass furnace was designed for drying coffee (Martinez, 2018). Capacity was around 180kg. Results of drying tests showed that the drying time of Robusta, Liberica and Excelsa varieties in cherries and parchment forms was on the average 60% faster as compared to direct sun drying.

The developed dryer prototypes showed great potential, but further improvement of the technology is needed, including its integration to the high-value crop and food product processing system of agribusiness enterprises to enhance their drying capability and capacity, reduce postharvest losses, produce food safe products and increase income.

The commodity focus of the study is cassava. It is one of the major agricultural crops in the Philippines. In 2015, total production was about 2.711 million tons, ranked sixth after sugarcane, rice, coconut, corn, and pineapple.

In view of the increasing economic importance of cassava, the Department of Agriculture is vigorously addressing the issues and concerns that hinder the growth of the industry. These issues and concerns include among others the limited mechanization and postharvest equipment. Results of baseline assessment conducted by Martinez (2015) on the technical and socio-economic status of mechanization and postharvest processing of cassava in the Philippines identified drying as one of the major concerns that needed to be addressed.

Sun drying remains as the most common method of drying cassava. During sunny weather, granulated cassava, and chips usually dry in two to three days. When drying is delayed due to rainy weather, granulated cassava and chips experience mold growth and unfavorable biochemical reactions that result to physical and quality losses.

Greenhouse-like dryers that use polyethylene films for cover have been used by farmer cooperatives for drying cassava for animal feeds. On a fine weather, the use of greenhouse dryers results to faster drying when compared to direct sun drying. The dryers also protect the cassava from sudden rains.

However, the dryers cannot be used for drying hygienic and food safe cassava products. These are not made of food grade materials and cannot protect the cassava from insects, birds, and animals, and from dusts and other contaminants. Moreover, like direct sun drying, these cannot dry the cassava during prolonged rainy periods resulting to cassava of poor quality, moldy and with possible mycotoxin contamination that is not suitable for human consumption.

OBJECTIVES

The general objective of the project was to develop, and field test a greenhouse solar dryer for hygienic, food safe cassava products suitable for small to medium scale farmers, cooperatives, and processors.

The specific objectives were:

1. Design, fabricate and install greenhouse dryer prototypes using food grade materials, with protection from insects, birds, animals, dusts, and other contaminants, and with biomass-furnace system for heating during prolonged rainy periods.

2. Establish the performance of the dryer prototypes in terms of technical parameters, quality of dried products and costs.

METHODOLOGY

Conceptual Framework

The project adopted the Problem-Input-Process-Output conceptual framework as shown in Figure 1. The main problem addressed was the lack of solar dryer for food safe cassava products that could be used even during prolonged rainy periods. The inputs of the project were the design of existing solar dryers and the drying requirements for food safe cassava products of small and medium scale farmers' cooperatives and processors.

These served as basis for the design of dryer prototypes. The processes implemented were the design, fabrication, installation, and field testing of the greenhouse solar dryer prototypes. The output of the project is a greenhouse solar dryer for drying food safe cassava products. The dryer minimizes entry of insects, birds, animals, dust and other contaminants, uses solar energy to lower drying costs; and uses biomass for heating during prolonged rainy periods.

Project Sites and Cooperators

The dryers were installed and tested in Naguilian, Isabela and Dapitan, Zamboanga del Norte. The Cassava Hills Grower Association. was the farmers association was primarily producing feed grade cassava chips. In 2015, they were granted processing equipment for food grade cassava grate (flour). They were also trained to process cassava grates into value-added food products.

However, their production of grates and food products was occasional and not regular due to lack of dryer and defined market. The local government remained willing to support the group in terms of marketing the food grade cassava products. They would need a food grade dryer and they were more than willing to collaborate with the project.

The second cooperator, the Cassava Growers and Processors Association (CAGAPA) in Dapitan, Zamboanga del Norte consisted of farmers, housewives and unemployed adults with a common goal of uplifting the economic condition of their respective families. With the assistance of the Dapitan LGU, the association started processing of cassava chips food snack that is similar with the well-known chips brand 'Pringles'.

Problem	**Input**	**Process**	**Output**
Lack of solar dryer for food safe cassava products for small and medium scale farmers cooperatives and processors that can be used even during prolonged drying periods.	1. Design of existing soalr dryers 2. Drying requirements for food safe cassava products of small to medium scale farmers	1. Design, fabrication and installation of greenhouse solar dryer prototype 2. Field testing of the performance of solar dryer prototypes 3. Laboratory analysis of quality of dried cassava products	Greenhouse solar dryer for food safe cassava products that can minimize entry of insects, birds, animals, dust and other contaminants that uses solar energy to reduce drying costs and biomass furnace for heating during prolonged rainy periods.

Figure 1. Conceptual Framework of the Project

In 2015, the association was provided with tools, equipment, and raw materials, as well as the processing building, for the expansion of their processing and marketing activities. CAGAPA as Food Manufacturer was issued with License to Operate by the Food and Drug Administration (FDA) and its cassava chips production is HALAL Certified by the Muslim Mindanao Halal Certification Board.

In spite of the assistance from the LGU and other government agencies, the association greatly needed of cassava dryer because of the rainy and cloudy weather that they experienced almost all year round. They only used directly exposed wooden drying tables where they placed the cassava chips to be dried.

Description of the Greenhouse Solar Dryer

The design of the dryer was based on the greenhouse type solar dryer with biomass furnace developed for cacao beans by Martinez (2016) and for coffee (Martinez, 2018). The dryer was similar with the dryer developed by Serm (2014) that was very popular in Thailand for drying high quality and food safe dried products.

These dryers concept used a combined radiation and convection modes of heat transfer. From the perspective of heat transfer, this method was very efficient and could result to faster drying. However, one inherent limitation of this dryer was the need for relatively large area to expose the products to direct solar radiation. This would not pose problem when area for installation was not limited. However, some end user might require a more compact dryer, even if the dryer was relatively less efficient.

In view of the foregoing, a second dryer concept was also designed, fabricated, and tested. It was tray-type convection dryer placed inside the greenhouse. The multi-tray drying cabinet offered significantly larger capacity per unit floor area. However, drying would take longer because the mode of heat transfer to the drying product would be mainly by convection, not a combination of radiation and convection heating.

The developed greenhouse solar dryer is shown in Figure 2. The greenhouse had a dimension of 9.4 m long, 7.0 m wide, and 3.2 m high. The greenhouse dryer had three major components: (1) drying section where cassava chips are loaded, (2) fans and solar cell panels to effect air inside the dryer and (3) biomass furnace system to supplement heat during night time and rainy periods.

The drying section consisted of two elevated drying tables (8.4 m long, 1.2 wide and 1 m high). Each table would have drying area of 10 m^2 and capacity of 50 kg at load density of 5 kg/m^2. The beds were made of 1 mm food grade stainless screen. Drying bed frames were constructed out of 12 mm diameter schedule 40 GI pipes and 6 mm thick by 50 mm width stainless steel sheets.

The furnace system was designed to indirectly heat the air along the length of the dryer. The system was composed of combustion chamber, rice husk feeding system, ducts, and chimneys. Rice husk, saw dust, or firewood could be utilized as fuel.

The combustion chamber was constructed out of insulating firebricks enclosed with mild steel plates. Holes of 6 mm in diameter are drilled through the side wall bricks for entry of primary air supplied by 120 mm diameter solar-powered axial fan.

The rice husk feeding system had a hopper which could accommodate one sack of rice husk weighing about 10kg. The hopper had a feeding auger with a design feeding rate of 10kg/h which not only continuously fed the rice husk to the combustion chamber but also continuously forced the burning husk to move forward inside the chamber and eventually discharged out the burnt husk off the end of the chamber and fell to an ash bin container.

If other biomass such as wood and coconut husk was used, the material was fed manually and directly to the combustion chamber, and then tended manually to maintain good combustion. The ash of the biomass was removed manually from time to time by scraping off the ash. The hot flue gas from the furnace would flow inside four rectangular ducts installed along the length of the dryer, beneath the drying bed.

After passing along the length of the ducts, the flue gas would exit through the chimneys on the opposite end of the dryer. The ducts and chimneys were made of stainless-steel sheets.

The solar cell panel system generated the electricity requirement of the sets of fans for the air circulation inside the greenhouse and for the operation of the biomass furnace. Ambient air was drawn in through an opening on the furnace end of the dryer. There were six axial fans installed at the opposite end of the dryer to facilitate movement of air and exhaust the moist air.

The total airflow rate was about 1,800 m^3/h. The exhaust fans were powered by four solar cell panels rated at 200 W, three units of 120 Ah deep cycle batteries and battery charge controller. The system was designed to enable the dryer fans to run for two to three days of non-charging of batteries during might and continuous rainy periods.

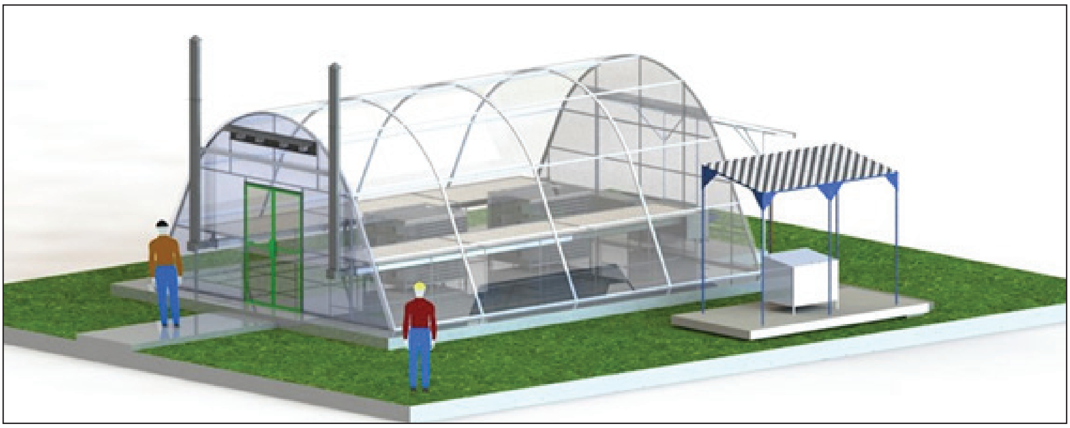

Figure 2. Greenhouse solar dryer with biomass furnace

The multi-tray drying cabinet (Figure 3) was designed to be placed inside the greenhouse. The cabinet have a tray rack that could accommodate 15 stainless trays with $1m^2$ drying area per tray. Each cabinet would have a total drying surface area of $15m^2$ and capacity of 75 kg at load density of $5kg/m^2$.

The dryer frame was made of stainless materials covered with 6 mm clear, twin-walled polycarbonate sheets. The dryer had four solar-powered axial fans installed at the back of the plenum chamber.

The cabinet have louvers to effect even distribution of air flow. The total airflow rate was 1,200 m^3/h, with average superficial air velocity of 0.33 m/s which was fast enough to ensure uniform drying.

Fabrication and Installation

The dryer prototypes were fabricated and initially installed at PHilMech. The pre-testing and debugging were done to address design, fabrication and installation issues, structural and mechanical integrity, and functionality of the prototypes. During the pre-testing, temperature build up and distribution inside the dryer as well as distribution of air flow were checked.

The dryer was operated at various conditions: (1) during the day and during the night, (2) with and without furnace turned on, and (3) during sunny, fair/ cloudy, and rainy conditions. Based on the results of the pre-testing, the dryer was modified and refined to attain good temperature and air distribution when operating at various weather conditions.

After the no load testing, the dryer prototypes were tested with cassava load to verify if the improvements made during the no load tests were maintained during the test with cassava load.

The components of the first greenhouse solar dryer were delivered to Dapitan City, Zamboanga del Norte. Some remaining parts were fabricated at the site. The dryer parts were then installed and anchored to a concrete pavement (Figure 4.1).

The installation of the dryer took 21 days to complete. The second dryer prototype was delivered to Naguilian, Isabela (Figure 4.2). Before the installation, the construction of the concrete pavement was facilitated by the project cooperator.

Again, some of the dryer components were fabricated on site. The construction and installation were completed in two months.

The fabrication of the multi-tray drying cabinets were done after the installation of the greenhouse dryers. The first unit was fabricated in PHilMech including installation of the blowers before the delivery to the project site in Isabela.

The frames of the second unit were prepared at PHilMech and then shipped to the project site in Dapitan. The fabrication of the other parts, including the trays and installation of the components were completed at the site.

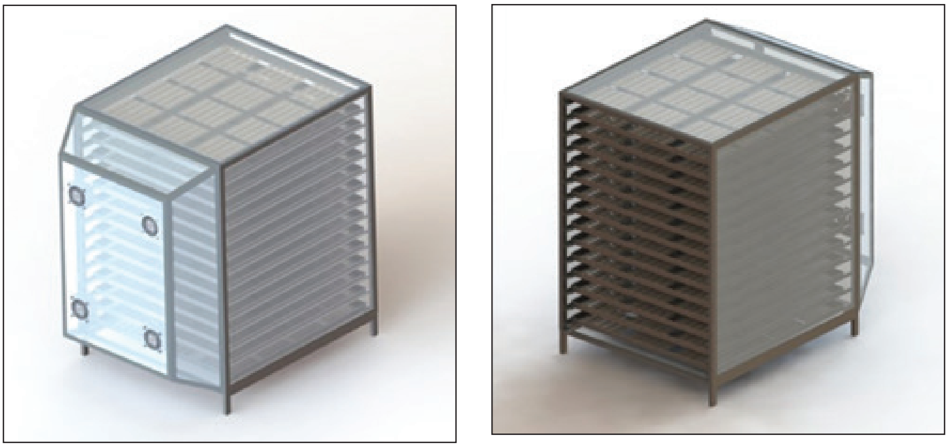

Figure 3. Multi-tray drying cabinets

Field Testing of Solar Greenhouse Dryer

Preparation of Samples

Freshly harvested cassava tubers (Lakan and Rayong 72 var.) were acquired from local farmers. The tubers were packed in sacks and transported to the cooperator processing plant. Two types of cassava products were used in the dryer performance tests: (1) cassava grates and (2) processed cassava chips.

The drying of cassava grates was done in Naguilian, Isabela. The preparation of cassava grate samples was carried out by the project cooperator with the following steps: Selection > cleaning > peeling > washing > grating > dewatering by expelling. The expelled cassava grate would be ready for drying.

The drying of processed cassava chips, on the other hand, was conducted in Dapitan, Zamboanga del Norte. The initial preparation of cassava chips followed similar procedure for preparing cassava grates. The grates were then seasoned with salt and other flavorings, molded in plastic sheet to form rounded chips, and then steamed. The steamed chips would then be ready for drying.

Drying Performance

Drying trials were conducted to test the performance of the dryer. During each trial, the drying tables, the multi-tray drying cabinets and the direct sun drying control were simultaneously loaded with cassava grates / chips prepared by the project cooperators. The dryer fans were operated continuously even during the evening.

During daytime, the cassava samples were stirred every two hours to ensure uniform drying. Parameters monitored during the test were temperatures, air flow rates, moisture content and biomass fuel consumption.

Tests were conducted during sunny weather and rainy periods. The furnace was only operated during daytime rainy periods and at night from 5:00 PM to 8:00 PM to provide supplemental heating. After 8:00 PM, the furnace was no longer operated to allow tempering of the drying cassava products.

The end of the drying trial was decided by the staff of the cooperator who had years of experience in drying of cassava products.

The moisture content of the drying products was estimated by monitoring the weight loss of products loaded in 15cm by 15cm stainless screen trays.

Figure 4.1. Greenhouse solar dryer installed and tested in Dapitan, Zamboanga del Norte

Figure 4.2. Greenhouse solar dryer installed and tested in Naguilian, Isabela

At the end of drying, samples were collected and brought to laboratory for moisture content determination by oven drying. Ambient and drying air temperatures were measured using thermocouple sensors connected to temperature data loggers. Thermocouples placed inside the dryers were placed 50 mm above the drying cassava and shielded from direct sunlight.

Another set of thermocouple sensor was placed outside the dryer to measure ambient temperatures. Hot wire anemometer was used to determine air flow rates. Biomass fuel consumption was determined by weighing the fuel fed to the furnace.

For the cassava grates, samples were dried simultaneously in three locations, (1) drying tables, (2) drying cabinet and (3) direct open sun drying control. Grated cassava samples were laid on the trays with load density of 5kg/m^2. Personnel of the project cooperator assisted in the monitoring of the drying process.

On the other hand, drying of processed cassava chips involved three different drying stages. As shown in Figure 4, the first stage was air drying done by hanging the steamed chips molded on plastic sheet during the evening. The second stage was by sun drying, laying the cassava chips molded on plastic sheet on drying tables and cabinet trays. After the second stage drying, third stage drying was performed by sun drying. The semi-dried chips was carefully removed from the molded sheet and the chips layed on silk cloth on top of the drying tables and cabinet trays.

Quality analysis of samples

The dried cassava samples were analyzed in terms of quality parameters like moisture content, microbial load, and color. The moisture content of fresh and dried cassava chips and grates was determined using the standard oven method at 105°C for 24h. color scale of dried cassava grates and chips was measured using the Konica Minolta Colorimeter.

In the analysis, the L-value was the parameter considered because the cooperator preferred light colored product.

In terms of microbial contamination, the dried samples were sent to DOST-FNRI and analyzed based on Philippine FDA Circular No. 2013-010 “Revised Guidelines for the Assessment of Microbiological Quality of Processed Foods” dated 27 February 2013 and FDA Circular No. 2014-014 “Minimum number of sample units required for each test analysis” dated 16 May 2014 for sun dried fish, fruits and vegetables.

Based on the two circulars, samples from each dryer per trial were analyzed for molds, osmophilic yeasts and *Escherichia Coli*.

Financial Analysis

To determine the financial viability of the dryer, an investment with long gestation period, a financial analysis was conducted. In this analysis, the conditions to viably operate the dryer from the point of view of the investor was determined.

The data gathered from the drying trials of processed cassava chips were subjected to financial indicators such as net present value (NPV), break even volume of dried product (BEP), benefit cost ratio (BCR), payback period (PBP) and internal rate of return (IRR).

RESULTS AND DISCUSSION

Drying Performance

The result of drying trials of the performance tests for cassava grates is summarized in Table 1. In the drying table, the grates with average initial moisture content of 47% was dried to average final moisture content of 10% in 22 hours of continuous operation even at night. Drying on the multi-tray drying cabinet, on the other hand, took an average of 29 hours.

Again, the reduced drying time in the drying cabinet was acceptable to the cooperator, considering the significant increase in drying capacity with its small floor area. Direct sun drying (control) had the longest drying which took 39 hours on the average.

Table 1. Drying performance for cassava grates in Naguilian, Isabela.

PARAMETER	LOCATION		
	Drying Table	Drying Cabinet	Control
Initial moisture content, %	47^{a}	48^{a}	46^{a}
Final moisture content, %	10^{a}	11^{a}	11^{a}
Daytime temperature, °C	51^{a}	44^{b}	34^{c}
Evening temperature with furnace turned on (5:00 PM to 8:00 PM), °C	40^{a}	37^{b}	28^{c}
Daytime temperature with furnace turned on during rainy periods, °C	43^{a}	38^{b}	30^{c}
Biomass fuel consumption, kg/h	6		
Drying time, hours	22^{a}	29^{b}	39^{c}

*Values of the same superscript are not significantly different

The typical temperature profile during drying is shown in Figure 5. The drying operation started in the afternoon, after processing the cassava into grates in the morning.

The profile shows the increase in temperature inside the greenhouse as compared to ambient. With the furnace operating during evening from 5:00PM to 8:00PM, the average temperature on the drying table was 40°C. This was around 3°C higher than the average temperature in the drying cabinet and 12°C higher than ambient.

After the furnace was turned off, the temperature inside the greenhouse remained on the average 3°C higher than ambient during the rest of the evening. During the daytime, the temperature inside the greenhouse was significantly higher than ambient.

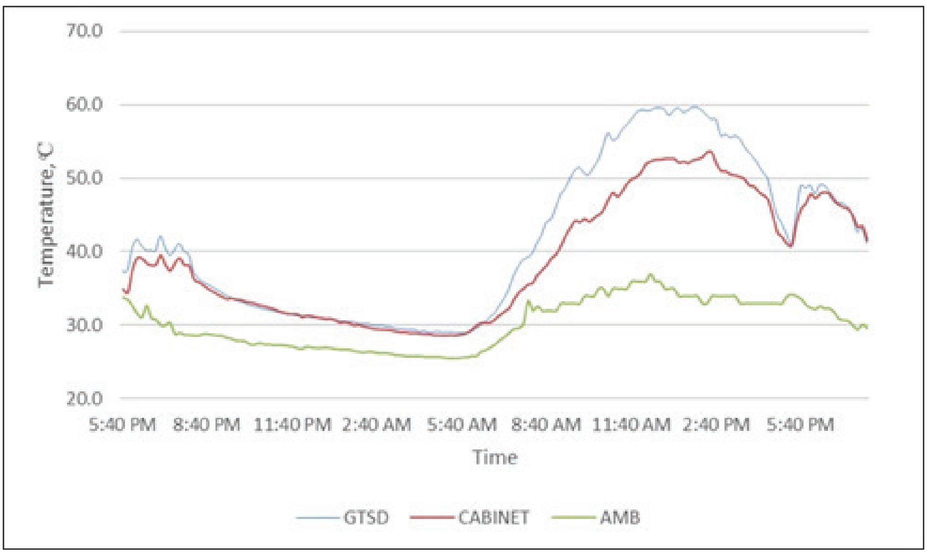

Figure 5. Temperature profile during drying of cassava grates on the drying tables (GTSD), drying cabinet (CABINET) and direct sun drying control (AMB).

On the average, the daytime temperature on the drying table was 51°C. This was around 7°C higher than the average temperature in the drying cabinet. Lowest average daytime temperature of 34°C was measured on direct sun drying control.

During rainy periods when the furnace was turned on, the temperature on the drying table was 43°C. This was around 5°C higher than the average temperature in the drying cabinet. Lowest average daytime temperature of 30°C was measured on direct sun drying control.

For processed cassava chips, the results of the performance tests are summarized in Table 2. For the first stage done during the evening, the drying time was 14.2 hours from average initial moisture content of 64 % to final moisture content of 39 %.

For the second stage on the other hand, chips with average initial moisture content of 39 % was dried on the drying table to average final moisture content of 20 % in 2.1 hours of operation. Drying on the multi-tray drying cabinet in comparison took an average of 2.6 hours.

The reduced drying time in the drying cabinet was acceptable to the cooperator, considering the significant increase in drying capacity with its small floor area. Direct sun drying (control) had the longest drying which took 3.4 hours on the average.

For the third stage, chips with average initial moisture content of 20 % was dried on the drying table to average final moisture content of 9 % in 2.4 hours of operation. Drying on the multi-tray drying cabinet in comparison took an average of 3.2 hours.

Again, the reduced drying time in the drying cabinet was acceptable to the cooperator, considering the significant increase in drying capacity with its small floor area. Direct sun drying (control) had the longest drying which took 8.2 hours on the average.

Table 2. Drying performance for processed cassava chips in Dapitan, Zamboanga del Norte

PARAMETER/LOCATION	DRYING STAGE		
	1st stage	2nd stage	3rd stage
Initial moisture content, %			
Drying table	64[a]	39[a]	20[a]
Drying cabinet	64[a]	39[a]	20[a]
Control	57[b]	47[b]	26[b]
Final moisture content, %			
Drying table	39[a]	20[a]	8[a]
Drying cabinet	39[a]	20[a]	9[a]
Control	47[b]	26[b]	8[a]
Daytime temperature, °C			
Drying table	30[a]	44[a]	47[a]
Drying cabinet	30[a]	44[a]	44[b]
Control	27[b]	33[b]	34[c]
Drying time, h			
Drying table	14.2[a]	2.1[a]	2.4[a]
Drying cabinet	14.2[a]	2.6[b]	3.2[b]
Control	14.2[a]	3.4[c]	8.2[c]

*Values of the same superscript are not significantly different

The typical temperature profile during drying of processed cassava chips is similar with drying of cassava grates shown in Figure 5. The drying operation started in the afternoon, after processing the cassava into chips in the morning.

The profile showed increase in temperature inside the greenhouse as compared to ambient when the furnace was turned on. After the furnace was turned off, the temperature inside the greenhouse remained higher than ambient during the rest of the evening.

During the daytime, the temperature inside the greenhouse was significantly higher than ambient. During daytime operation, the average temperature on the drying table was 47°C.

This was around 3°C higher than the average temperature in the drying cabinet. Lowest average daytime temperature of 34°C was measured on the control.

During the drying trials, firewood was used as biomass fuel for the furnace. The average fuel consumption was 6kg/h.

Quality Analysis

Results of microbial analysis of dried cassava grates and processed chips sent to DOST-FNRI are summarized in Table 3. Results showed that cassava chips dried on the drying table, drying cabinet, and control all passed the standard of FDA for mold and yeast count.

The cooperator in compliance to its FDA license strictly enforced its Good Manufacturing Practice. On the other hand, the cassava grates dried in Isabela did not pass the FDA standard.

This could be attributed to the lack of Good Manufacturing Practices in Isabela. Results showed that the use of the multi-tray drying cabinet for drying cassava grates and processed chips did not result to significant reduction of quality in terms of microbial analysis as compared to the use of drying table.

Table 3. Microbial analysis of dried cassava products

PRODUCT	LOCATION	E.COLI COUNT (MPN/G)	MOLD AND YEAST COUNT (CFU/G)
Processed Chips	Table	< 3	< 3
	Cabinet	< 3	< 3
	Control	< 3	< 3
Grates	Table	< 3	160,000
	Cabinet	< 10	1,200,000
	Control	< 3	870,000

The results of the color analysis of dried cassava samples are summarized in Table 3. The L-value indicated the lightness in color of the products which ranges from 0 (darkest black) to 100 (brightest white).

Comparing the results, cassava chips and grates dried on the drying table have relatively higher L-values, followed by the direct sun drying control.

Relatively lower L-values were obtained from samples dried on the drying cabinet.

However, the differences were slight and not statistically significant. Thus, the use of the multi-tray drying cabinet for drying cassava grates and processed chips did not result to significant reduction of quality in terms of color as compared to the use of drying table.

Table 4. Color analysis of dried cassava products.

PRODUCT	LOCATION	L VALUE
Processed Chips	Table	59.3[a]
	Cabinet	58.4[a]
	Control	58.9[a]
Grates	Table	91.0[a]
	Cabinet	90.0[a]
	Control	90.4[a]

* a - Not significantly different

Financial Analysis

The cost of the greenhouse dryer used in the study amounted to around Php 930,000. The cost included materials and labor to fabricate and install the dryer, and the cost was for two drying tables and one multi-tray drying cabinet.

Based on the results, the proposed final dryer system would include two drying tables and three drying cabinets inside the greenhouse placed along the center walkway of the greenhouse. It had a design capacity of 325 kg of cassava grates and processed cassava at load density of 5 kg/m2.

The system would be composed of modular components for ease of transport, assembly, installation, and maintenance. The commercial price of proposed greenhouse dryer was estimated at Php 1,460,000.

The feasibility of utilizing the proposed greenhouse solar dryer for processed cassava chips production was determined through a 10-year projection operation.

It was assumed that the initial investment would be Php 1,460,000.00 for the acquisition of the dryer and Php 850,000.00 for the working capital, loaned for 12% and 10 % interest rates, respectively.

Results of the financial analysis showed that the investment in the dryer for cassava chips generated positive streams of discounted net cash flows. The project generated Net Present Value of 7,500,000, Internal Rate of Return of 66.6 % and Benefit Cost Ratio of 4.2 (Table 5).

Results showed that the project would be able to recover the initial investment after 1.5 years with the average break-even volume sales of 48,300 kg.

Table 5. Financial Analysis.

INDICATORS	VALUE
Net Present Value, NPV	7,450,000
Benefit Cost Ratio, BCR	4.2
Internal Rate of Return, IRR, %	66.6
Pay Back Period, PBP, years	1.5
Break Even Volume, kg	48,300

Project Cooperator's Feedback

The project cooperators were pleased with the performance of the greenhouse solar dryer with drying tables and drying cabinet. The dryer protected the product from rain, bird, animals, dust, and other sources of contamination. The cooperator in Dapitan was able to operate continuously even with continuous rain.

They were very satisfied with the dryer that they applied for a loan from DOST SETUP for the installation of additional two dryers. The said installation was covered by a MOA between PHilMech and CAGAPA with PHilMech providing technical assistance in the installation of the dryers to be fabricated by CAGAPA. The fabrication is currently on-going.

Likewise, the cooperator in Isabela was pleased that they could finish drying in one day using the dryer. They also noted that the product was whiter compared with their previous production.

CONCLUSION AND RECOMMENDATION

Based on the results of the study, it can be concluded that a greenhouse solar dryer with biomass furnace and multi-tray drying cabinet was successfully developed and field tested.

The dryer would enable small-scale agribusiness enterprises including farmer cooperatives and associations engaged in processing of high-value crops and food products to increase their production capacity (bigger dryer capacity and shorter drying duration) and to consistently produce high quality, naturally dried and food-safe products even during rainy periods.

The dryer is powered by solar cell panels and could be installed in areas without access to grid electricity. Dryer performance evaluation showed that drying duration is reduced by around 40 %.

It protects the product from rain, bird, animals, dust, and other sources of contamination. Experimental results showed good potential to produce high quality food-safe products.

Pilot testing of the greenhouse solar dryer is recommended to assess socio-economic considerations for its eventual commercialization.

REFERENCES

MARTINEZ, R.C. 2015. Enhancing Agricultural Mechanization Technologies for Crop Production and Postharvest Processing of Cassava in the Philippines. Country Report presented during the AFACI (Asian Food and Agriculture Cooperation Initiative) Program Workshop on Food Crops held on September 14-19, 2015 in Colombo, Sri Lanka.

MARTINEZ, R.C., DAQUILA, R.E., RAMOS, M.E.V. 2018. Development of Greenhouse Type Solar Dryer for Coffee. Project Terminal Report. Philippine Center for Postharvest Development and Mechanization, CLSU Compound, Muñoz, Nueva Ecija.

MARTINEZ, R.C.,DAQUILA, R.E.,RAMOS,M.E.V.,LARGADO, V.C., PABILLONIA, R.O.,BARAYUGA, J.C. and BARBERO, A.L. 2016. Field Testing of Improved Drying Technology for Fermented Cacao Beans. Project Terminal Report. Philippine Center for Postharvest Development and Mechanization, CLSU Compound, Muñoz, Nueva Ecija.

SERM, J. 2014. A greenhouse type solar dryer for small-scale dried food industries: Development and dissemination. International Journal of Energy and Environment, 3(3): 383-398.

ACKNOWLEDGMENT

The financial support of the Bureau of Agricultural Research is gratefully acknowledged.

NOTES

NOTES

NOTES

NOTES

NOTES

About PHilMech

The Philippine Center for Postharvest Development and Mechanization, known then as the National Postharvest Institute for Research and Extension (NAPHIRE), was created on May 24,1978 through Presidential Decree 1380 to spearhead the development of the country's postharvest industry.

As a subsidiary of the National Grains Authority in 1980, the agency's powers and functions were expanded in line with the conversion of NGA to the National Food Authority.

In 1986, PHilMech moved to its new home at the Central Luzon State University compound in Muñoz, Nueva Ecija.

The agency was transformed from a government corporation into a regular agency through Executive Order 494 in 1992. It was renamed the Bureau of Postharvest Research and Extension (BPRE).

For years now, PHilMech is engaged in both postharvest research, development and extension activities. It has so far developed, extended and commercialized its research and development outputs to various stakeholders in the industry.

With Republic Act 8435 or Agriculture and Fishery Modernization Act (AFMA) of 1997, PHilMech takes the lead in providing more postharvest interventions to empower the agriculture, fishery and livestock sectors.

Pursuant to Executive Order 366 or the government's rationalization program in November 2009, BPRE became the Philippine Center for Postharvest Development and Mechanization (PHilMech) with twin mandates of postharvest development and mechanization.

For more information, please contact:

Executive Director
Philippine Center for Postharvest
Development and Mechanization
CLSU Compound, Science City
of Muñoz, Nueva Ecija
Tel. No.: 0917-813-0852
Fax No.: (044) 456-0110
Website: www.philmech.gov.ph

PHilMech Liaison Office
3rd Floor, ATI Building
Elliptical Road, Diliman, Quezon City
Tel. Nos.: (02) 927-4019; 4029
Fax No.: (02) 926-8159