Development of Commercial Belt Dryer for Granulated Cassava

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ABSTRACT - ***This research has successfully designed, fabricated, and field tested a technically feasible mechanical dryer for granulated cassava. Test results revealed that the developed drying technology has an input capacity of 1,158kgh^{-1}, output capacity of 509kgh^{-1}, and cassava product recovery of 44.2% with an average moisture reduction rate of 40.2%h^{-1}. Cost-benefit analysis showed that the technology is financially feasible given an internal rate of return of 17.12%. Total drying cost per kilogram output is estimated at US$0.027 (US$=Php45). By accounting all the costs involved in drying, the farmers can realize net benefits of US$136.40 per hectare for using the technology given a higher product recovery of 44-48% as compared to the traditional sun drying method of only 34-38%. As such, this technology provides a viable alternative solution to the drying problem of farmers to sustain the growth of commercial production of cassava in the Philippines.***

Keywords: Cassava, *Manihotesculenta L,* Belt Dryer, Postharvest, Agricultural Machinery

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1. INTRODUCTION

Cassava, a tropical root crop rich in carbohydrates, is cultivated by small farmers in the marginal lands of Asia, Latin America, and Sub-Saharan Africa. Its cultivation and on-farm processing are sources of rural employment opportunities[1]. Besides its direct use as food, cassava is also utilized as feed for livestock and poultry and as raw material for manufactured starch, tapioca, and snack foods. Cassava can adapt to diverse climatic conditions, survive long dry spells, and be harvested on a flexible time schedule, all of which qualifies as a food security crop [2]. The development of cassava industry in developing countries like the Philippines could contribute to food security problem and improve the welfare of the poorest sector of the population. In fact, the Department of Agriculture has selected cassava as one of the important commodities to achieve food sufficiency in the country.

The high demand on cassava for animal feeds in recent years has transformed cassava production in the Philippines from just a mere backyard gardening[3]into a commercial farming endeavour.The current volume of production is not enough to meet the high demand for cassava. Based on the Supply/Utilization Accounts of the Department of Agriculture, 60.3% of the total volume of production of 2.22 million metric tons in 2012 is mostly used for feeds while the remaining balance is used as food (20.9%), converted to starch (15.2%) and used in the production of alcohol (3.6%) [4].

However, the domestic market has set strict quality requirements for dried and peeled granulated cassava, i.e., moisture, ash and fiber contentsshall be 13%, 3% and 3%, respectively.For unpeeled dried granulated cassava, it should have a moisture content of 14%, 5% fiber and 5% ash. Any deliveries with moisture content of 14.5% and higher are rejected.

It is a common knowledge that cassava roots senesce and deteriorate rapidly after being detached from the plant. The roots of cassava are highly perishable compared to those of other major temperate or tropical root crops [5]. This may be associated with the physiological characteristics of cassava given the fact that, unlike other root crop's storage organs, cassava roots exhibit no endogenous dormancy, no propagation function, and possess no bud primordia from which re-growth can occur [6,7]. Due to physiological and pathological deterioration, cassava roots cannot be kept in a satisfactory condition in more than three days. As such, fresh cassava must be processed within two to three days from harvest by completely passing through chipping or granulating and drying operations to minimize quality deterioration [8]. It is fully recognized that drying is widely practiced to improve the shelf life of the cassava tuber and could also induced detoxification process [9,10].

The purpose of this research was to develop a viable commercial belt-type dryer for granulated cassava to address the lack of appropriate cassava drying facilities in the Philippines.A belt dryer was chosen as the type of dryer to be used for cassava because of its several technical advantages [11]. During the turnover of drying material from a higher belt to a lower belt, the drying material is loosened and mixed at the same time. The air flow is adapted for each drying belt according to the amount of water that is evaporating, i.e., the air flow is increased from bottom belt to top belt. In the same manner, the air temperature can be increased, because the cooling effect of evaporation prevents overheating in the upper belts. Therefore, belt dryers can be operated at higher temperatures than batch dryers, which mean the drying capacity is increased without excessive temperature stress of the drying product. Furthermore, belt speed is reduced from top to bottom to utilize the drying better by raising the bulk height of the drying material. By mechanical filling, turning and emptying, the labor requirement is lowered in comparison with flat-bed dryers. However, continuous operation requires constant control, and therefore, a shift-operation set up is required.

2. METHODOLOGY

2.1 Design of Commercial Belt Dryer

The technical parameters used in the design of commercial belt dryer were based on the results of the laboratory setup in the preliminary research entitled "Development of Drying Systems for Granulated Cassava as Animal Feed Ingredient".Alaboratory set-up (Figure 1) was constructed to establish the physical properties and drying rates related to the design and operation of acassava belt dryer. The researchthen proceeded in the design and fabrication of a prototype unit of cassava belt dryer with input capacity of 100 kgh^{-1}. Parameters monitored during the test trials were temperatures, air flow rates, power and fuel consumption, capacity and heating efficiencies, as well as suitability and stability of mechanical parts. A bigger design of cassava belt dryer was fabricated with input capacity of 400 kgh^{-1}. The second prototype features a four belt conveyor with dimension of 9.6 m in length and 1.2 m in width.

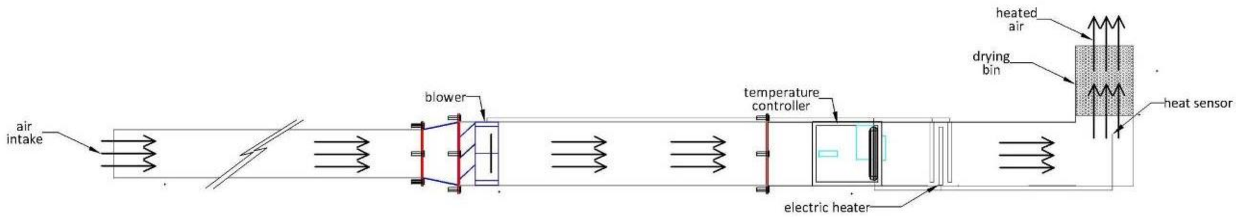

Figure 1. Schematic diagram of the laboratory cassava belt dryer

Once the technical drying parameters were fully established, the design of commercial cassava belt dryer was pursued. The detailed engineering drawings of the different parts and components of the dryer were prepared using AutoCAD as shown in Figure 2.

2.2 Fabrication and Setting-up of Dryer in the Project Site

The AutoCAD drawings have served as basis in the fabrication and assembling of the different components of the dryer.The prototype of the cassava belt dryer was fabricated by Agricomponent Machinery and Construction Corporation or "Agricom", the partner manufacturer in this particular project. Agricom is a local manufacturer of agricultural machineries including grain dryers and biomass furnaces. The project collaboration with Agricom was sanctioned by a Memorandum of Agreement covering the intellectual property issues and other concerns that mutually protect the role, responsibilities and benefits of both parties. The Agricomhas also provided the needed Biomass Furnace of the dryer.

The commercial cassava belt dryer was installed in Villa Luna Multi-Purpose Cooperative (VMPC), Villa Luna, Cauayan City, Isabela, Philippines. VMPC was recognized as the biggest cassava assembler in Cagayan Valley Region with around 1,000 hectares devoted to cassava production. The cooperative was selected based on the screening process conducted by PHilMech among all active cassava assemblers in the Region. Project collaboration was entered with VMPC after successful negotiation of their counterparts, i.e., drying shed and transformer as well as their commitment to be involved during the actual operation of the dryer. Based on the actual drying space and shed that were allprovided by VMPC, the layout of the cassava dryer and its biomass furnace werefinalized.

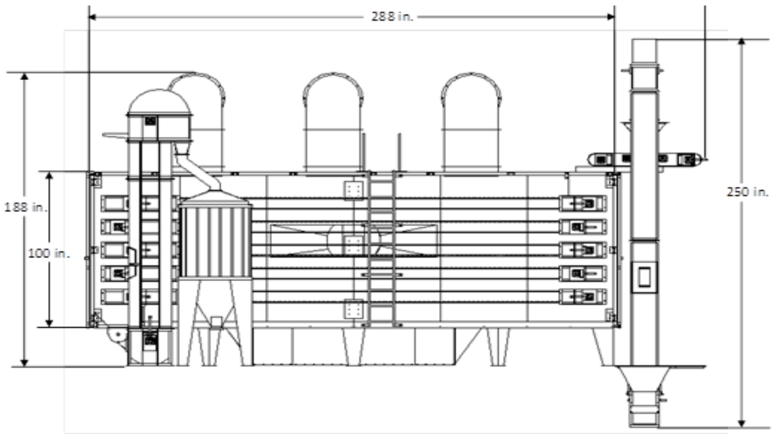

Figure 2. AutoCAD drawing of the commercial cassava belt dryer

2.3FieldTrials

The field testing on the cassava belt dyer was conducted during the period May 3, 2013 to December 13, 2013. During the six-month period, a total of 17 test trials were conducted using a total sample of 63,500 kg of fresh cassava provided by VMPC and its members. Several test trials were conducted to establish the technical performance of the dryer and verify the durability of materials used.

The technical performance of the cassava dryer was regularly monitoredduring field trials. Parameters evaluated and collected include the temperature inside the drying chamberwhich was measured in each belt layer, the moisture content of cassava as it entered the loading conveyor, the moisture content of granulated cassava at the tail-end of each belt, the final moisture content of the dried cassava as it discharged from the fifth belt, the residence time of cassava inside the drying chamber, the airflow inside the dryer, the input and output capacity of the dryer, the sprockets' drive speed, and the fuel and electricity consumption of the dryer.

The temperature and airflow inside the dryer wereestablished using a four-channel data logging thermometer and vane anemometer and/or hot wire anemometer, respectively. The total electric current that flows inside the dryer was established using clamp ammeter and the speed of the belt or sprocket was determined using analogue tachometer. The fuel consumption was determined based on the total weight of corn cob or ricehull used in each trial.

2.4 DataAnalysis

Data gathered during test trials were thoroughly analysed to establish the optimum operational parameters that will enhance the efficiency of the dryer. Likewise, continuous monitoring on the performance of the dryer during operation were undertaken to establish the durability of materials used in the proto-type unit. The cost of drying per kilogram output was established based on the actual technical performance and requirements of this technology.

The farmers' cassava production data were also summarized to establish the economic benefits of using the technology by the farmers. More specifically, the cost of drying using traditional method was estimated to compare the net economic benefits of using the cassava belt drying technology.

The economic viability of the dryer was determined using the Financial Internal Rate of Return (FIRR). The FIRR is an indicator to measure the financial return on investment of anincome generation project and is used to make the investment decision. The FIRR is obtained by equating the present value of investment costs (as cashout-flows) and the present value of net incomes (as cash in-flows). This can beshown by the following equality:

$$I_0 + \frac{I_1}{(1+r)^1} + \frac{I_2}{(1+r)^2} + \cdots . + \frac{I_m}{(1+r)^m} = \frac{B_1}{(1+r)^1} + \frac{B_2}{(1+r)^2} + \cdots . + \frac{B_m}{(1+r)^m}$$

$$\sum_{n=0}^{m} \frac{I_n}{(1+r)^n} = \sum_{n=1}^{m} \frac{B_n}{(1+r)^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (1)$$

where; I_0 is the initial investment costs in the year 0 (the first year duringwhich the project is constructed) and $I_1 \sim I_m$ are the additionalinvestment costs for maintenance and operating costs during the entireproject life period from year 1 (the second year) to year m.$B_1 \sim B_m$ are the annual net incomes for the entire operation period(the entire project life period) from year 1 (the second year) to year m.

By solving the above equality, the value of r or commonly known as the Financial Internal Rate of Return(FIRR) was obtained.

3. RESULTS AND DISCUSSION

3.1 Basic Design of the Commercial Cassava Belt Dryer

The technical specifications of the developed commercial cassava belt dryer featuresa full load input capacity of 1,000 kg granulated cassava at bed depth of 5 cm and drying residence time of 1.6 hour, equivalent to product unloading rate of 450 kgh^{-1}. As illustrated in Figure 3, the dryer has five belt conveyors; each conveyor has a total length of 5.13 meters and total width of 2.21 meters. A large axial fan draws-in heated airand eventually pushed to the plenum. On top of the dryer along its length are three axial fans that suck hot air upward from the plenum. Drying starts at the bottom most part of the drying chamber where the air passes through the conveyor belts carrying loads of cassava. As the flow of air continues, drying progresses as the air moves upward. Air serves two basic functions in drying granulated cassava: firstly, air supplies the necessary heat for moisture evaporation, and secondly, air serves as carrier of evaporated moisture.

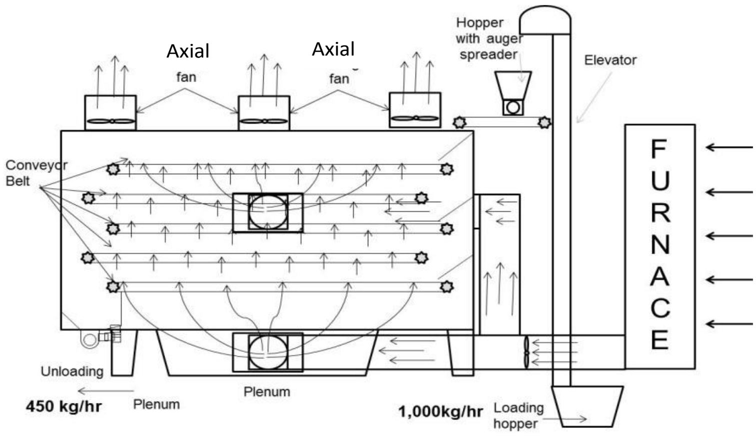

Figure 3. Schematic diagram of the commercial cassava belt dryer

As designed, fresh granulated cassava is continuously loaded to the dryer at the rate of 1,000 kgh^{-1}. Fresh granulated cassava is loaded, conveyed and spread to the first belt through the elevator and hopper with auger-spreader mechanism, respectively. The cassava samples are then conveyed from the first belt to the fifth belt before reaching the unloading auger. The first, third and fifth belts are all moving in similar forward direction while the second and fourth belts are moving at backward direction. The initial moisture content of cassava was determined so that the drying time was also established so that once the dried granulated cassava is discharged from the drying chamber,its moisture content should be 13% or less.

3.2 Technical Performance of the Commercial Cassava Belt Dryer

Table 1 shows the result of initial test trials conducted in May 2013. Using a total of 2,822.9 kg of fresh cassava samples with initial moisture content of 54.1% and at average loading rate of 1,313 kgh^{-1},the cassava samples was successfully dried to 15.4% at drying efficiency of 85.3%. The product recovery was recorded at 45%. During the test trial, rice hull was used as the source of fuel for the biomass furnace of the cassava belt dryer. Fuel consumption was recorded at 234.3 kg of rice hull per hour.

The performance of the developed commercial cassava belt dryer was validated by the Agricultural Machinery Testing Center (AMTEC) of the University of the Philippines at Los Banos also in May 2013. AMTEC is a recognized and independent body that conduct testing of agricultural machineries in the Philippines. Using a total weight of 3,797 kg of samples with initial moisture content of 51%, the AMTEC test results revealed that the developed cassava belt dryer hadsuccessfully dried granulated cassava with initial moisture content of 51% down to moisture content of 10.8% with moisture reduction rate of 498.2 kgh^{-1}. The drying efficiency of the dryer was recorded at 96.9% and product recovery was recorded at 44.2%. Using corn cob as the source of fuel of the biomass furnace of the dryer, fuel consumption was recorded at 125.9 kg of dried corn cob per hour with heating system efficiency of 71.5%.

Table 1–Results of test trials on the cassava belt dryerconducted byPHilMech and AMTEC

PARAMETERS	PHilMech	AMTEC
Initial Weight, kg	2,822.9	3,797.0
Final Weight, kg	1,270.9	1,679.6
Initial Moisture Content, %	54.1	51.0
Final Moisture Content, %	15.4	10.8
Product Loading Rate, kg/h	1,313.0	893.4
Ambient Air Temperature		
Dry Bulb, °C	33.5	33.6
Wet Bulb, °C	27.5	25.5
Average Drying Air Temperature, °C	71.8	97.9
Air Flow Rate, m/h	49,910.0	45,554.4
Type of Fuel	rice hull	corn cobs
Fuel Consumption, kg/h	234.3	125.9
Product Recovery, %	45.0	44.2
Heating System Efficiency, %	75.9	71.5
Drying Efficiency, %	85.3	96.9
Drying System Efficiency, %	64.7	69.3

3.3 Relationship of Moisture Content with Respect to Drying Time

As shown in Table 1,the target final moisture content of 14% of cassava product as it was discharged from the drying chamber was not achieved: it was either over dried or under dried. As such, this research has found a way to estimate the drying time from which the cassava product should stay inside the drying chamber to achieve the safe level moisture content of 14% or below during drying.

It is noteworthy to mention that the conveyor belt in each layer of the dryer have the same length of 5.13 meters and moving at a constant speed of 0.00427 ms^{-1}. Therefore, the total residence time of cassava samples in each belt is around 20 minutes.

With this objective, cassava samples from the tail end of each belt were collected to determine the rate of moisture reduction with respect to time. As shown in Figure 4, the average rate of moisture content reduction increases over a period of time, or from the first belt down to the second, third, fourth and fifth belts. More specifically, small increment of moisture reduction was observed from the first belt down to the second belt before a significant rate of moisture reduction from the third belt down to the fifth or last belt. Overall, the result revealed that there was an exponential rate of moisture content reduction from the first belt down to the fifth belt.

Through mathematical calculation, the relationship of drying time with respect to moisture content was estimated as follows:

$$y = -0.0041x^2 + 0.061x + 0.779 + MC_i \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

where*y*is thefinal moisture content in %, *x*is thedrying time or residence timein minutes,and $MC_i$is theinitial moisture content of the fresh granulated cassava before it is subjected to drying.

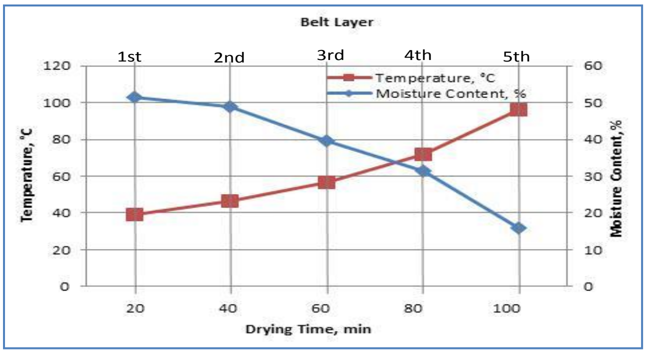

Figure 4: Drying temperature and moisture content with respect to drying time in each belt

Using this equation, the residence time or the drying time was estimatedto achieve the desired final moisture content of at least 14% as the cassava product discharged from the drying chamber. Note that in the derived equation, there are two known variables: the initial moisture content (MC_i)and the desired final moisture content of 14% (y). Therefore, once the residence time wasestimated using equation 2, the desired speed of the conveyor belt can be set from the speed controller of the belt dryer.

3.4DryingCost

Based on the technical performance of the dryer during the whole duration of the test trials, the average power and fuel consumption using ricehull wererecorded at 12kWh^{-1} and 160kgh^{-1}, respectively. In the estimation of labor cost, a total of two operators have been used. Based on these accounts and given atotal projected operating time of 1,440hryr^{-1}providing a total annual projected capacity of 662,400kg, the drying cost per kg output is estimated at Php1.23kg^{-1} as shown in Table 2. The total capacity of the dryer was 8,000kg per day.

Table 2. Estimated drying cost per kg output of dried cassava

Particulars	Amount
I. Fixed Cost Per Year	301,000
Depreciation Cost	193,500
Repairs and Maintenance	107,500
II. Variable Cost Per Year	510,480
Electricity Cost	190,080
Fuel Cost	230,400
Labor Cost	
- Laborer	36,000
- Operator	54,000
III. Total Cost per Year	811,480
Total Cost per Kg	1.23 (US$ 0.027)

*Assumptions used in the estimation:
Input Cap.: 1,000 kg Output Cap.: 460 kg
Operating time : 1,440 hyr^{-1}Operating days: 180 dyr^{-1}
Total Capacity: 662,400 kgyr^{-1}Investment Cost (IC) :P2,150,000
Power Reqt:12.00 KW/h Lifespan of the dryer:10 years
No of operators: 2 Wage rates: P300/d and P200/d
Cost of ricehull: P15bag^{-1}Weight of ricehull/bag: 15 kg
Fuel/ricehull consumption: 160 kg/hSalvage value: 10% of IC
Repair and maintenance: 5% of IC US$=Php45.00

3.5 Economic Viability of the Dryer

To determine the economic viability of the commercial cassava belt dryer, the estimated cost of drying wascompared with sundrying. Based on actual field interview, a total of four laborersare needed to dry 100 bags of 60 kilogramsof fresh granulated cassava while the total drying period to reduce the moisture content from 60% down to 14% is about four to five days. As such, the total cost involved in sun drying is estimated at Php1.02 per kg output. On the other hand, the cost of drying using the cassava belt dryeris estimated at Php1.23 per kgor a difference of Php0.20 per kgin favor of solar drying as shown in Table 3. However, field interview revealed that the estimated average recovery of cassava product using sundrying was only 34-40% which is far below the average recovery of 44-48% using the commercial cassava belt dryer. Therefore, the farmers could realize a total net benefitsof Php0.60 per kg of dried granulated cassava or a total of Php6,138 per hectare for using the cassava belt drying technology. Total benefits of the farmers for using the full annual capacity of the dryer is estimated at Php395,781.

In order to confirm the financial soundness of the technology at investment cost of Php2.15 million and at total annual capacity of 662,400 kg of fresh granulated cassava, the estimation of Internal Rate of Return (IRR) using equation 1 is pursued.

Table 3: Benefits of using the cassava belt dryer as compared to solar drying, In Peso

Particulars	Solar Drying	Mechanical Drying	Net Benefits
Cost of Product Recovery per Kg	3.80	4.60	0.80
Less: Drying Cost Per Kg			
Labor Cost	1.02	0.14	0.89
Fixed & Variable Cost . (Except Labor Cost)	0.00	1.09	-1.09
Total	1.02	1.23	-0.20
Total Net Benefits Per Kg	2.78	3.37	0.60
Total Benefits per Year [1/]			395,781

1/ At full capacity of 662,400 kg per year US$=Php45.00

Table 4 reveals that the estimated financial rate of return of the technology is 17.12% which is higher than the current interest rate in commercial bank of eight percent for loans with collateral. The results indicate that the end-user could viably invest in the technology even by borrowing the needed capital atcommercial bank at interest rate of 8% given aFIRR of 17.12%.

What are the different basic technical parameters that may influence the economic viability of the dryer? To verify this issue, the estimation of FIRR under different scenarios is followed.

As shown in Table 4, the impact of any price increase on the cost of fuel and electricity by 25% will result to only a slight decrease in the rate of return to 15.81% and 14.89%,respectively. The results of the estimation strongly suggest that the viability of the developed cassava dryer is not so much affected by the fluctuation of price of fuel and electricity. However, the estimated FIRR when the investment cost of the dryer will increase by 25%, from Php2.15 million to Php2.69 millionis 4.15%. Under this condition, the technology is no longer viable since the estimated IRR of 4.15% is lower than the prevailing interest rate in the bank of 8.0%. Therefore, in the eventual commercialization of the project, the accredited local manufacturer of this technology shall be sensitive for any price escalation; otherwise,this will imperil the successful and sustainable commercialization of the technology.

The economic viability of agricultural machinery often hinges on the rate of operation, as is the case for milling machine. In here, a reduction of the total annual capacity of the dryer to 496,800 kg per year or by 25% will significantly affect the viability of the dryer given an estimated IRR of only 0.68%. The break-even volume to at least recover the total operating cost including the interest on investment at interest rate of 8% per annum is 568,267 kg per year. Therefore, the minimum volume to be dried should not be less than 568,267 kg per year to realize positive benefits in investing in the technology. Note however that the break-even volume is equivalent to the total volume of production of 56 hectares of farm land given an average cassava yield of 10.23 tons per hectare as estimated by the Bureau of Agricultural Statistics in 2012.

Table 4. Financial internal rate of return (FIRR) of the commercial cassava dryer under different economic conditions, in percent (%)

Parameters	FIRR
Internal Rate of Return	17.12
Internal Rate of Return Under Different Scenarios	
Scenario 1 - Fuel cost will increase by 25%	15.81
Scenario 2 - Electricity cost will increase by 25%	14.89
Scenario 3 - Investment cost will increase by 25%	4.15
Scenario 4 - Decrease in annual capacity by 25%	0.68

3.6 Factors Affecting the Performance of the Dryer

Based on the test trials conducted, it was observed that the following operational and management drying protocols should be observed to achieve higher drying efficiency:

(1) *Size uniformity of granulated cassava.* Large variation on sizes of granulated cassava affects the performance of the dryer. A too small granule tends to dry faster than large granules. The ideal size of granulated cassava ranges from 10 to 15 mm;

(2) *Freshness of cassava granules.* Longstanding granulated cassava of more than three days could easily form into clump and become large particle. As evident, the size of granules has significantlyaffects the rate of drying. It is recommended that the cassava granules shall be dried immediately right after passing through the granulator to avoid quality deterioration;

(3) *Regularity of loading.* The even distribution of fresh cassava granules in the drying conveyor belt is highly critical in achieving uniformity of drying. Drying air tends to go directly towards any unfilled area of the conveyor instead of passing through all areas with fresh cassava. As such, the operator should ensure the continuous loading of fresh cassava in the feed hopper to avoid creating a gap in the conveyor drying chamber; and,

(4) *Air temperature setting.* The air temperature shall be set first to 90°C until the loaded product reached the end of the third belt to prevent gelatinization. Afterwards, air temperature could be set at 120°C to increase the capacity of the dryer.

4.CONCLUSION AND RECOMMENDATION

Based on the results of this project, the developedcommercial model of the cassava belt dryer is found to be technically feasible. Such finding is consistent with the results of actual testing conducted by the Agricultural Machinery Testing and Evaluation Center (AMTEC) of the University of the Philippines at Los Banos.

The results of economic analysis revealed that the newly developed technology is highly feasible given an estimated financial internal rate of return of 17.53%. The total drying cost per kilogram of dried granulated cassava is estimated at Php1.23.

As expected, the economic viability of the dryer is highly dependent on the total volume of fresh granulated cassava that can be dried each year. The estimated break-even volume to defray all expenses is estimated at 568,267 kg/yr. The break-even volume is equivalent to the total production of 56 hectares of cassava farm land. With the total capacity of the dryer of 8,000 kg per day, the dryer should be operated in 71 days or 36 days in case of two shifts per day to at least recover the total operating cost.

The utilization of cassava belt dyer canproduce higher recovery of dried granulated cassava toat least 46% as compared to the traditional sun drying method of only 38%. By accounting all the costs involved in drying, the farmers can realize a total net benefits of Php0.60 per kgof dried granulated cassava or a total of Php6,138 per hectare for utilizing the technology. Total benefits of the farmers for using the full annual capacity of the dryer is estimated at Php395,781.

Certain operating protocols shall be observed to efficiently operate the dryer, as follows: (i) Utilization of efficient granulator to ensure uniformity of size of fresh cassava granules before this will be fed inside the dryer; (ii) Regularity of loading of granulated cassava in the belt conveyor; (iii) Proper setting of air temperature inside the drying chamber; and, (iv) Immediate drying of fresh cassava right after granulation.

The wider adoption of the cassava belt dryer by the farmers and cassava assemblers provides opportunities in increasing the available supply of cassava in the country given the capability of the dryer to produce higher recovery of dried cassava product. Most importantly, the technology can induce the production of cassava year round in anymarginal or idle areas of the country without worrying significant quality deterioration and huge economic losses during unfavourable weather condition.

In order to sustain the technical and economic soundness of the newly developed technology, the following recommendations are inevitable: (i) Continues monitoring of the technical performance of the dryer including the durability of materials used in the fabrication; (ii) Post-evaluation on the impact of the dryer to the farmers; (iii) Development of “Operator’s Manual” to guide the end-user on the proper operation and maintenance of the dryer; and, (iv) Conduct of training and extension activities to ensure the effective commercialization of the technology.

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