Asian Journal of Postharvest and Mechanization

AJPM

Asian Journal of Postharvest and Mechanization
Vol. 5, No. 1. 2022

Goal and Scope

The aim is to produce and publish an international refereed journal published on-line and on-print for the science and academic community worldwide. Through this journal, an accessible venue for sharing research information is provided.

The scope of the journal is specifically on postharvest and mechanization research, development and extension (RD&E). It is divided into the following content categories: Engineering, Biology and Chemistry, and the Social Sciences.

About the Publication

The journal is published semi-anually by the Philippine Center for Post-harvest Development and Mechanization (PHilMech) in partnership with the Sustainable Agriculture, Food and Energy (SAFE) Network. It has a print circulation of 1,000 copies per issue sent to local and international partner institutions and organizations.

Published by the:
Philippine Center for Postharvest Development and Mechanization (PHilMech)
CLSU Cmpd., Science City of Muñoz, Nueva Ecija, Philippines
Tel. Nos. 0917-813-0852
Fax No: (044) 4560-110

ISSN: 2546-1346

ASIAN JOURNAL OF POSTHARVEST AND MECHANIZATION

Department of Agriculture
Philippine Center for Postharvest Development and Mechanization
CLSU Compound, Science City of Muñoz, Nueva Ecija, 2022

CONTENTS

POSTHARVEST HANDLING AND POSTHARVEST LOSS OF TOMATO (*SOLANUM LYCOPERSICUM)* THE CASE OF NUEVA ECIJA, PHILIPPINES

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ABSTRACT

This paper analysed the postharvest handling system and the corresponding postharvest losses of tomato in the province of Nueva Ecija, the top producer of tomato in Central Luzon, Philippines. The study employed value chain analysis framework to map out the tomato market channels, identify the value chain actors, determine the series of postharvest handling operations and measure the qualitative and quantitative losses from farm to the retail market. Quantitative loss was measured by direct measurement of physical losses while qualitative loss was measured using visual quality rating (VQR) based on established quality profile (QP). Two market channels were observed in the measurement of postharvest losses: Nueva Ecija to Divisoria and Nueva Ecija to Bulacan market channels. Survey, focus group discussion (FGD), key informants interview (KII) and literature search were used by the study to obtain the required primary and secondary data.

The study revealed that the major postharvest handling operations of tomato were as follows: Farmer level- harvesting and hauling, sorting and packing, transport and marketing; at the trader/wholesaler level- transport, storage, marketing; at the retailer level- transport, sorting, marketing. Postharvest loss in Nueva Ecija to Divisoria was measured at 9.97% and 18% for quantitative and qualitative loss , respectively in five days while Nueva Ecija to Bulacan market channel had 37.71% and 41%, respectively in seven days. The value chain segment of the retailer and the famer, in both market channels, had the highest contribution to overall postharvest loss. Therefore, targeted interventions should be focused on these value chain segments to significantly curb postharvest loss.

Keywords: Tomato, Value chain analysis, Postharvest handling system, Postharvest losses

Submitted for review on August 3, 2021. Accepted for publication on August 13, 2022

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INTRODUCTION

Tomato (*Solanum licopersicum*) is considered as the fourth most important vegetable crop in terms of value and volume of production (PSA). The Philippines has an average annual production of 213,305 MT valued at Php 2,773M (PSA 2018). In terms of world production it only contributes 0.12% (FAOSTAT, 2019). The country's average annual per capita consumption was recorded at 1.63 kilogram consumed in various forms such as pastes, sauces, purées, jams, candies, juices and ketchup but majority of the production are consumed in fresh form as salad (PSA.gov.ph).

In Central Luzon, Nueva Ecija, Philippines is the top producer, and ranks fifth nationwide (PSA, 2018). Dubbed as "cash crop" because of its short gestation and marketability, it plays a vital role in the countryside's economy providing high returns for lowland vegetable farmers while contributing to labor generation across the value chain activities both on-farm and off-farm.

Tomato, like any other vegetable crops, is also confronted with a number of challenges. A highly perishable vegetable, it is subject to high postharvest losses which can be attributed to any combinations of the following limitations such as poor handling practices, lack of postharvest facilities such as packing house and cold storage, poor infrastructure, poorly orchestrated supply chain, market layers, volatile market price, among others.

Apaga and Nuevo (2010) reported that postharvest loss of tomato ranges from 18 to 38 percent which can be attributed to physiological weight loss and rotting. From the producers and other value chain actors point of views, these losses can significantly reduce the potential income received by each actors along the value chain. On a peso per kilogram (Php/kg) basis it negatively affects the crop sector's competitive advantage with other countries producing the same crop.

In relation to attaining the country's food security, these estimated losses can be highly significant especially for developing countries where access to resource is often limited. The effort to attain the country's food security to feed its growing population through increased production will be undermined if the postharvest losses is not mitigated. Duman (2010) underscored that it is imperative that losses across the different levels supply chain should be addressed more so for developing countries to attain food security.

Addressing the postharvest losses, however requires comprehensive information so that corresponding interventions to address the multi-faceted problem can be designed and implemented effectively. Equally essential, the information should capture the actual situations on-site since every production areas at the provincial and municipal levels would have their unique setting and predominant production and postproduction practices.

This paper aimed to: 1) determine the postharvest handling system and practices of tomato in Nueva Ecia, and; 2) Measure the qualitative and quantitative losses across the value chain from farm to the retail market.

METHODOLOGY

The postharvest handling operations and the postharvest losses of tomato were determined by applying the value chain framework. Value chain refers to the series of primary and support activities performed by an enterprise to transform inputs into value added outputs for its external consumers (Porter, 1985). It is a connected series of interdependent organizations, resources and knowledge streams involved in the creation and delivery of value to end customers (AsiaDHRRA, 2008). Value chain analysis, an offshoot of the supply chain analysis, is a tool for presenting and analysing the value that is created in a product or service as it is transformed from raw inputs to a final product for its end users (Subramanian, 2007). It describes the value chain actors' activities within each node and subsystems and can be related to assess the industry's competitive strength..

Tomato value chain actors and their specific roles were established using key informants interview (KII) and focus group discussion (FGD). Tracing method and actual observations of operations were done to map out the major market channels and the series of postharvest handling operations from the farm to the retailer as the coverage of the system under study.

Conceptual Framework

The study was designed to provide two major outputs : 1) the postharvest handling system of tomato, 2) the level of postharvest losses (Figure 2). To construct the value chain structure of tomato the study used primary and secondary data. Secondary data such as yield, production costs, price, geographic flow of commodity were used to construct the costs and income structure of the tomato value chain. The primary data such as farm profile, series of production and postharvest operations, qualitative and quantitative measures of losses were used to establish the postharvest handling system and losses of tomato.

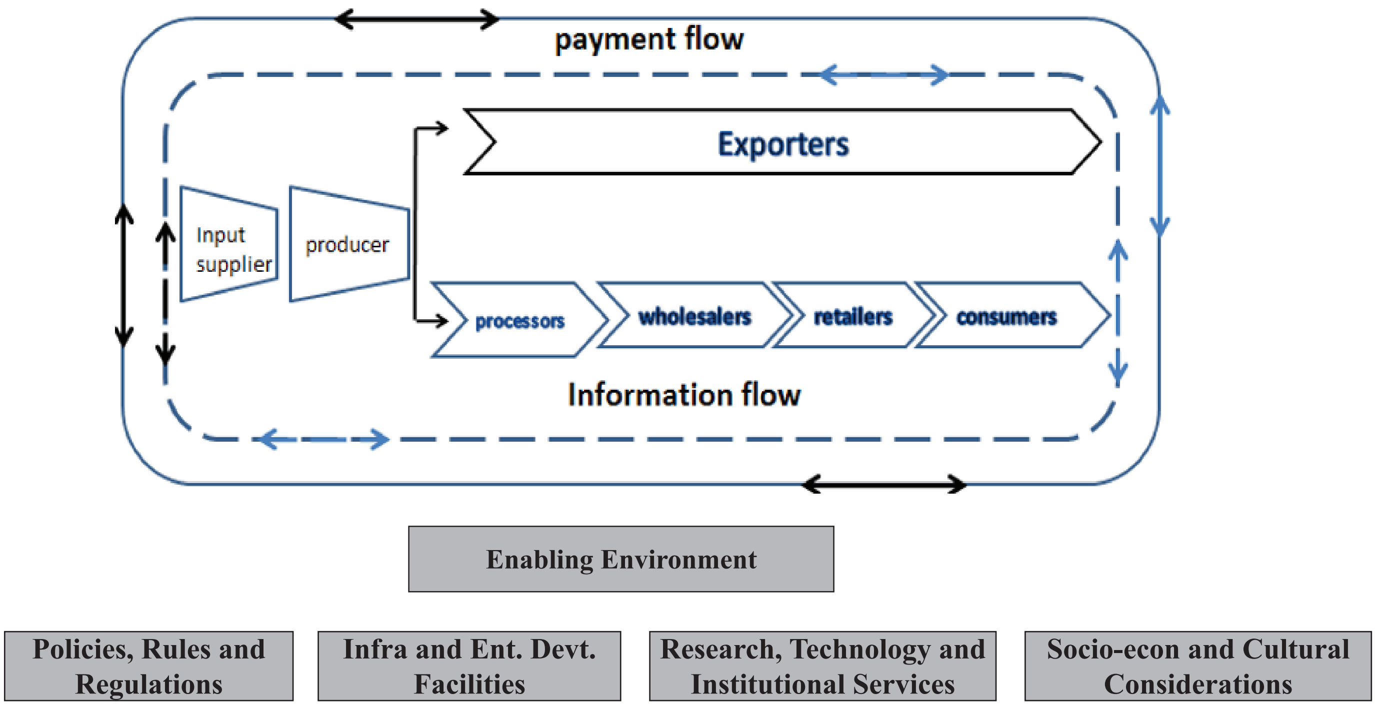


Figure 1. The Value Chain Analysis model (AsiaDHRRA, 2008).

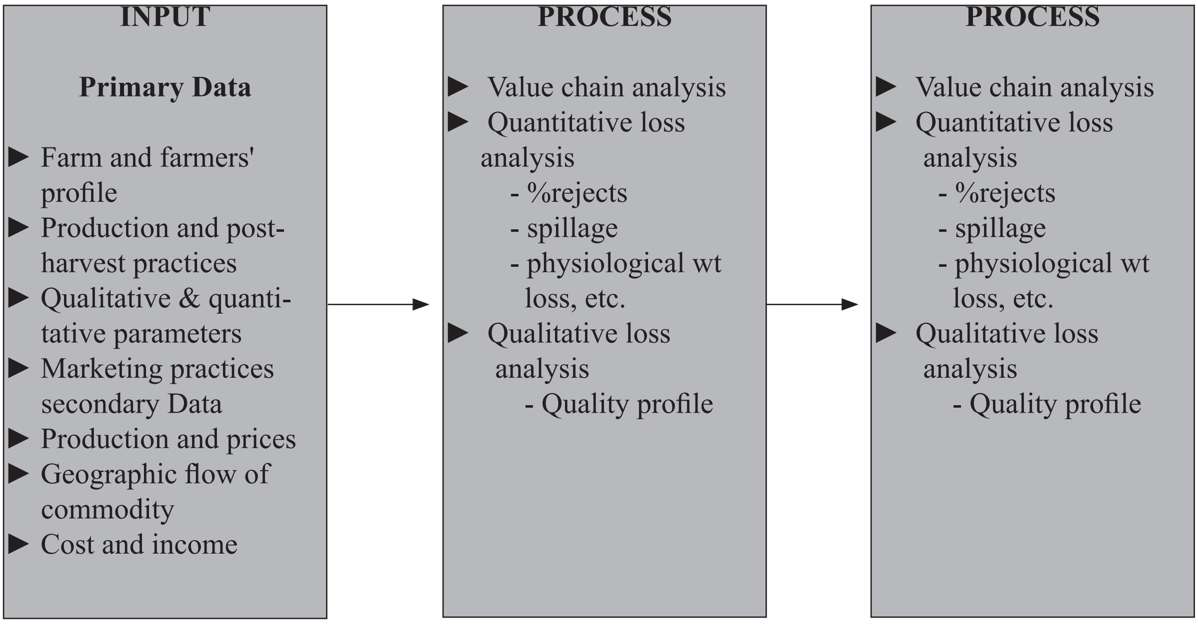


Figure 2. Conceptual framework of the study

Time and Place of the Study

The study was conducted in the province of Nueva Ecija, specifically in Talavera and Aliaga which are the major tomato producing municipalities of the province. The study was conducted in 2015 covering two types of production systems: on-season and off-season.

Type and Sources of Data

Primary and secondary data were used by the study. Primary data were obtained using survey, FGD, KII and actual measurements of qualitative and quantitative parameters of losses. Secondary data were obtained from published literatures, provincial and national databases from the Department of Agriculture, Department of Trade and Industry, Philippine Statistics Authority and attendance to stakeholders meeting.

Postharvest Losses Measured by the Study

The study measured two types of postharvest losses: qualitative loss and quantitative loss. Quantitative loss is defined as the physical loss due to reduction in product's marketable weight, measured in percentage while qualitative loss refers to decline in the physical and visual attributes of the product caused by mechanical injury, pathogen damage and physiological defects measured using a system of visual quality rating. The details on the description and measurement of the different types of losses are presented below.

Quantitative losses

Quantitative losses considered in the study were further classified and disaggregated according to operations and specific points along the production and post-production system. These losses included: pre-harvest loss, harvesting loss, sorting loss, physiological weight loss and the total postharvest system loss. The formulas used in the computation of these losses were as follows:

Pre-harvest losses (%PhL). Refers to losses occurring in the field attributable to cultural management, soil conditions, genetic traits of the crop, pest and diseases and other environmental factors that manifested in the fruits such as sunscald, cracking, catface, insect damage, etc. Pre-harvest loss was computed using equation 1.

$$\%PhL = \frac{wt.PhL}{Total\ wt.of\ harvest} \times 100$$

Harvesting loss (%HL). Refers to good marketable fruits that are unintentionally left in the field during harvesting caused by spillage or harvestable fruits that were unpicked during harvesting . Harvesting loss was computed using equation 2.

$$\%\ HL = \frac{wt.of\ harvesting\ loss}{Total\ wt.of\ harvest} \times 10$$

Sorting loss (%SL). Fruits that are accidentally thrown off as rejects but are marketable during sorting. Sorting loss was computed using equation 3.

$$\%\ SL = \frac{wt.of\ sorting\ loss}{Total\ weight\ of\ sorted\ tomato} \times 100$$

Physiological weight loss (%PWL). Refers to losses that are due to transpiration and spillage. Physiological weight loss was computed using equation 4.

$$\%\ PWL = \frac{weight\ initial - weight\ final}{weight\ initial} \times 100$$

Postharvest System Loss (PSL). The total loss incurred from the series of pre and postharvest handling operations from farm to the retailer market. PSL was computed using equation 5.

$$PSL = \%PhL + \%HL + \%SL + \%PWL$$

Qualitative Losses

Visual quality rating (VQR) refers to the physical qualitative attributes of the commodity and is determined based on quality profile (Table 1). VQR is a unit less measure of the quality rating of the product being analysed. In this study, adopting the methods used by Flores et al, (2018a); Flores et al, (2018b), Calica, et al., (2014a), Calica et al.,(2014b), the VQR rating ranges from 1 to 5 with 5 being the highest QP score. VQR was determined across the series of postharvest handling points . In each sampling point, 10% of the total weight of fruits per container was subjected to visual quality evaluation. This was performed by four trained researchers/evaluators getting their average score as the final rating. VQR was computed using equation 6.

$$VQR = \frac{WR + W2R2 + .. + WnRn}{Wt}$$

where: VQR = average visual quality rating
W = weight of sample, in kg
R = quality rating of sample; 1 to 5
Wt = total weight of all the samples, in kg

Quality profiling

Quality profile (QP) is a method of describing the general quality of the commodity as influenced by the degree of defects or physical damage present, expressed in numerical rating. The QP description was based on the standard that is generally applied in the market in estimating the commodity's quality. The scores were carefully agreed upon by the trained researchers in the conduct of VQR for a more standard scoring/rating of samples. The QP rating used in the study is presented in Table 1.

Table 1. Quality profile (QP) rating used in visual quality rating (VQR) of tomato samples for qualitative analysis.

Rating	Description
5	Excellent condition, fresh, no defects
4	Fair, with moderate or small defects (small lesions, cuts, dents or stains)
3	Minimum level of marketability (5 to 10% physical & physio logical damage)
2	Minimum level of edibility (11 to 20% physical damaged and/ or visible pathogen damage)
1	Non-edible (>20% physical and physiological damage)

RESULTS AND DISCUSSION

Description of Study Area

The province of Nueva Ecija is situated 15.5784° N, 121.1113° E with its capital located 130km North of Manila. It has an annual average temperature of 39^{o}C and average annual rainfall of 659mm and belongs under Type I climate. Because of its geographic and climatic condition, it is suited for the production of tomato. Annual average production is recorded at 11,018MT and accounts for 5.33% of national production (PSA, 2018).

The average area devoted by each farmer for tomato production was recorded at 0.66 ha. Both on-season and off-season is produced in the province, on season on the months of September to December and off season during the months of May to June which are normally grown in the elevated rolling areas of the province because of the advantage of good drainage. A short term crop, it is a major source of income for vegetable growers which is typically grown in combination or rotated with other lowland vegetables such as eggplant, beans, bitter gourd, squash and hot pepper. Majority of the farmers (n=99) plant the Diamante max variety (84%) because of their good shelf life and performance during transport.

Tomato Market Channel

Majority (91%) of the tomatoes produced in Nueva Ecija are traded in Sangitan Public Market located in Cabanatuan City, the trading hub of vegetables in the province. There are four major players involved in the marketing of tomatoes namely: 1) agent or sakadora; 2) wholesaler; 3) wholesaler-retailer; and 4) retailers. Daily market transaction happens between 9:00 AM and 2:00 PM.

From Sangitan market, tomatoes are packed and transported to Divisoria (30%), Balintawak (18%), Bulacan (16%) and other nearby cities and provinces. The tomatoes were then redistributed at layers of whosalers and retailers before the final purchase of the consumer. Figure 3 illustrates the market channel of tomatoes produced in Nueva Ecija.

Tomato Value Chain Actors and their Roles

The value chain actors and their specific roles in the value chain of tomato are presented below.

1. **Input Suppliers.** Supply and sell seeds, fertllizers, pesticides, plastic mulch and other farm inputs. In some cases provide credit for some farmers in their line of products at a certain interest rate.

2. **Farmers**. Manage and finance the farm and directly oversee the crop management and farm operations including land preparation, irrigation, pest management, and postharvest operations such as harvesting, sorting and packing. Some farmers also di-

rectly deliver and market their produce to traders and consolidators.

3. **Agent/Consolidator.** Purchase or negotiate with farmers on behalf of the wholesaler/retailer. Receives incentive for every successful transactions based on the agreed selling price and volume of tomato purchased. Arrange the hauling and transport of tomatoes to the stall/warehouse of the wholesaler.

4. **Wholesaler.** Purchase tomato from farmers at agreed farmgate price. Also buys tomato from walk-in farmer-seller at wholesale price. In their stalls or warehouses the next handling operations such as sorting, packing and transport are accomplished. If agent is employed, provides cash outlay for the purchase and transport of tomato from farm to their stalls/warehouse.

5. **Wholesaler-retailer.** Purchase from wholesaler operating in Nueva Ecija. Sells and distribute tomato in the retail markets. These include wholesalers and retailers from Divisoria, Balintawak, Bulacan and other neighboring provinces and cities.

6. **Retailers.** Purchase tomatoes from wholesaler-retailer . Operate and rent stalls in public markets where tomato along with other vegetables are retailed at prevailing market price.

7. **Consumers**. Purchase tomato from retailers in the local market for consumption.

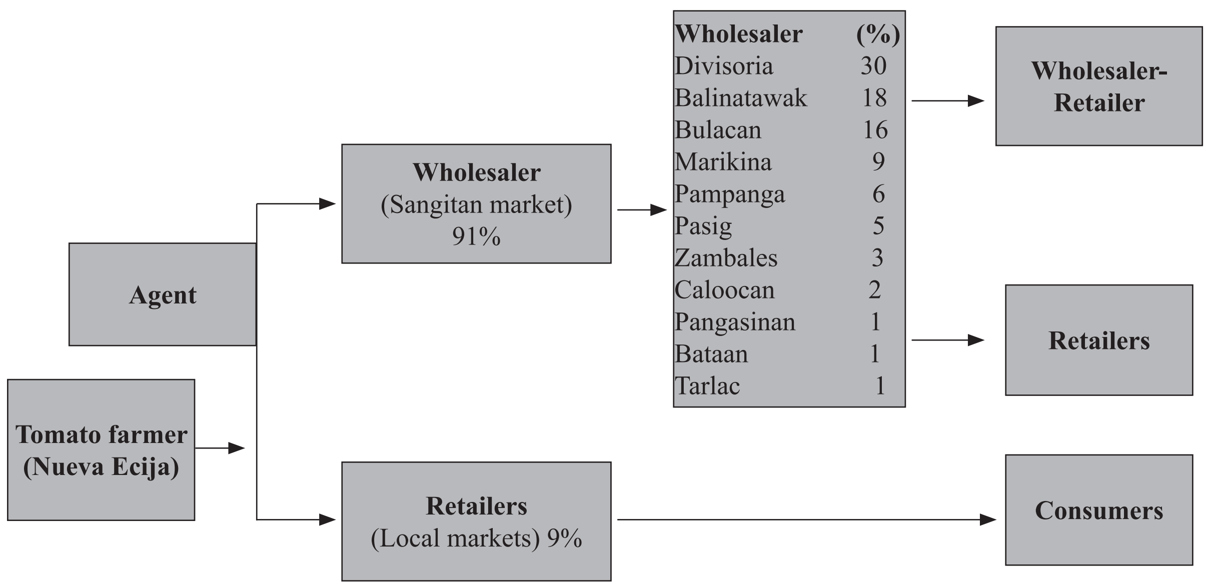


Figure 3. Market channels of tomato

Cost and Income Structure

The cost of production of tomato during regular and off-season is Php 2.20 and Php 14.06 per kilogram, respectively. The cost of producing off-season tomato is higher as compared with on-season because the yield is lower and the amount of other inputs particularly pesticide and fungicide is also higher due to higher incidence of pest and diseases.

Following the major supply system which is the on-season, the total expenses of the farmers in producing tomato is Php 4.81 per kilogram. At selling price of Php 9.00 per kilogram there is a profit of Php 4.19 per kilogram. Next to farmer the wholesaler/retailer had the highest profit at Php 3.32 per kilogram, followed by retailer at Php 1.49/kg and agent/consolidator at Php 0.87/kg. It is also worth noting that the retailer node incurred significant cost in terms of losses from rejects and weight loss.

Table 2. Cost and returns of tomato based on two market channels: Nueva Ecija – Divisoria and Nueva Ecija-Bulacan; Php/kg, 2015.

Items	Nueva Ecija – Manila	Nueva Ecija – Bulacan
1. FARMER		
Production cost	2.19	14.06
Harvesting, hauling fee & sorting Fee	1.79	2.29
Transportation fee	0.92	(a)
Sub-total of expenses	***4.81***	***16.35***
Farmgate/selling price	9.00	18.00
Profit, Php/kg	***4.19***	***1.65***
2. AGENT/CONSOLIDATOR/MIDDLEMEN	**Sangitan Market**	
Buying price	9.00	
Labor expenses	0.04	(b)
Stall fee, Electricity & water bill	0.08	
Communication & other expenses	0.01	
Sub-total of expenses	***9.13***	
Selling price	10.00	
Profit	***0.87***	
3. WHOLESALER/RETAILER	**Divisoria Market, Manila**	**Talavera - Bulacan**
Buying price	10.00	18.00
Agent's share	-	0.50
Loading & transport cost	1.14	1.43
Unloading & hauling to storage	0.11	-
Laborer in stalls	0.30	0.22
Stall fee, Electricity & water bill	0.13	0.20
Sub-total	***11.68***	***20.37***
Selling price	15.00	22.00
Profit	***3.32***	***1.63***
4. RETAILERS	**Manila Markets**	**Malolos, Bulacan**
Buying price	15.00	22
Communication cost	0.06	0.05
Labor expense	0.34	0.34
Transportation cost	0.45	0.45
Stall fee and other expenses	0.34	0.34
wt. loss, % :	***0.13***	***0.59***
wt.of rejects	***0.19***	***0.55***
Sub-total	***16.51***	***24.32***
Selling price	18	26
Profit	***1.49***	***1.68***

(a) tomato is picked- up by traders at the farm
(b) absence of agent/consolidator participation

Postharvest Handling System of Tomato

The series of postharvest handling of tomato from the farm to the retail market included harvesting, hauling, sorting, packing, transport, marketing, resorting and marketing. The details and descriptions of each postharvest handling operations are presented below.

Harvesting and Field Hauling

1. Usually done early in the morning
2. Maturity of fruit is based on color and number of days
3. Tomatoes are hand picked and placed in pails (5kg cap.) then transfered to wooden crates (23kg cap.) or "kaing" (Figure 4)
4. Takes 12 persons/hr to harvest 1000kg
5. From the field, tomatoes in crates or "kaing" are manually carried by individuals to the sorting area

Sorting

1. At the sorting area tomatoes were spread in the sorting table or flooring provided with underlays to minimize bruising (Figure 5)
2. Tomatoes were manually sorted according to size and color
3. Only green mature and pinkish or "breaker" were selected
4. Overripe fruits were considered rejects together with small fruits, mechanically damaged, insect and pest damage
5. Only large and medium sizes were selected
6. A trained sorter can accomplish around 200kg/hr
7. Sorted tomatoes were placed in crates weighing around 23 kg each

Transport and Marketing

1. From the sorting area, tomatoes in crates were loaded in tricycle , jeepney or truck (Figure 6)
2. Tricycle, jeepney and truck has a capacity of 20, 60 and 150 crates, respectively
3. Tomatoes were then delivered to the stall or storage facility of the wholesaler
4. From the stall/storage facility of the wholesaler, the tomatoes were transferred to a jeepney or trucks for delivery in Manila and nearby provinces

Marketing at wholesale

1. Upon arrival in the next level wholesaler, tomatoes were placed in air conditioned rooms to retard ripening and deterioration
2. From the wholesaler storage, the tomatoes were either delivered or picked up by retailers (Figure 7)
3. A wholesaler can dispose around 100 crates in a day

Marketing at retail

1. Upon arrival to the retailer's stall, toma toes were resorted according to ripeness, size and physical quality
2. Tomatoes for sale were placed in crates or spread in the table for consumers' access
3. A retailer can dispose five crates on the average in a day
4. It takes two to three days in the stall to completely market the same batch of tomato
5. Everyday, resorting is done to remove rotten and rejects that can infect the whole stock leading to losses

Figure 4. Tomato harvesting and hauling

Figure 5. Manual sorting

Figure 6. Tomato loaded to tricycle and truck for marketing

Figure 7. Retailers buying tomato from wholesaler.

Figure 8. Tomato in retail market.

Postharvest Losses of Tomato

Two market channels were considered in the measurement of postharvest loss from farm to the retail markets: 1) Nueva Ecija to Divisoria market channel, and 2) Nueva Ecija to Bulacan market channels. These market channels were purposively selected by the study as they were the major corridors of tomato produced in Nueva Ecija constituting 30% and 16% share, respectively. The postharvest losses of the two market channels are presented below.

Quantitative Loss of Tomato

Nueva Ecija to Divisoria Market Channel. Postharvest loss at farmer level was measured at 4.05%. This comprised of losses from pre-harvesting (3.67%), harvesting (0.10%), sorting (0.13) and transport (0.15%). At the wholesaler and wholesaler-retailer levels, the postharvest loss were measured at 0.57% and 0.47%, respectively. At the retailer level the postharvest loss was measured at 4.88% which is the highest among the value chain segment. Majority of losses incurred at the retailers level were due to spoilage and rejects since the tomato, a highly perishable crop, is already on its 5th day from the time it was harvested. The total postharvest loss for this market channel was measured at 9.97% in five days (Table 3) .

Nueva Ecija to Bulacan Market Channel. The postharvest loss at the farmer level was measured at 8.49 % comprising of losses from pre-harvest (6.57%), harvesting (0.09%), sorting (0.01%) and transport (1.82%). At the wholesaler and wholesaler-retailer levels, the postharvest loss were measured at 0.96% and 2.60%, respectively. At the retailer's level the postharvest loss increased dramatically, 7.28% on the fifth day and 18.38% on the seventh day. Similarly, the high loss can be attributed to rejects and spoilage. The total postharvest loss for this market channel was measured at 37.71% (Table 10). The findings of this study is also similar with the findings of Apaga and Nuevo (2010) where they measured 18-38% postharvest loss of tomato.

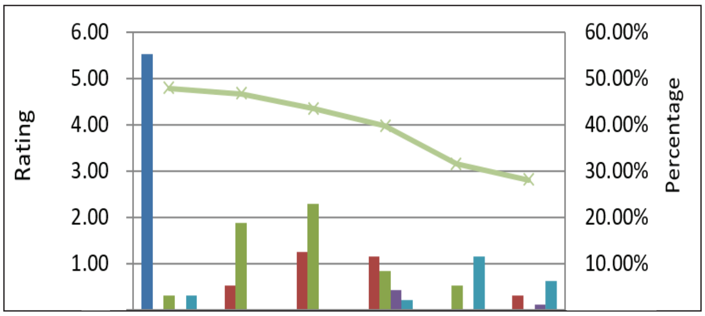
Qualitative Loss of Tomato

Nueva Ecija to Bulacan Market Channel. Figure 5 presents the quality profile of tomato from day 1 to day 7. At day 1, the average VQR was measured at 4.79 and based on quality profile description it is between fair and excellent. On the second and third day it declined to 4.67 and 4.35, respectively, which is still fair to excellent. On the sixth and seventh day VQR was measured at 3.16 to 2.80, respectively with corresponding qualitative description of between fair and minimum level of edibility. From day one to day seven, there was a qualitative reduction of 41%.

Table 3. Summary of quantitative losses: Nueva Ecija – Divisoria channel and Nueva Ecija – Bulacan channel. 2015.

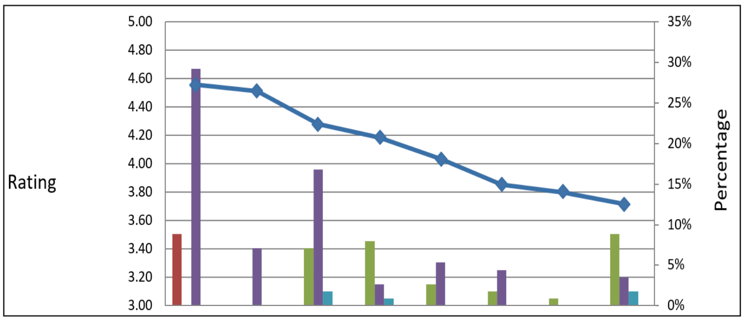
Value chain segment and activities	Nueva Ecia - Divisoria channel[1]		Nueva Ecija – Bulacan channel[2]	
	DAH	% losses	DAH	% losses
1. Farm level	Day 1	**4.05**	Day 1	**8.49**
● Pre-harvest loss		3.67		6.57
● Harvesting		0.10		0.09
● Sorting and packing		0.13		0.01
● Transport		0.15		1.82
2. Wholesaler level	Day 2	**0.57**	Day 2	**0.96**
● Marketing and transportation		0.57		0.96
3. Wholesaler-retailer	Day 3	**0.47**	Day 3	**2.60**
● Sorting marketing and transportation		0.47		2.60
4. Retailers level	Day 4 to 5	**4.88**	Day 4 to 5	**25.66**
● Sorting and marketing		4.88		7.28
● Resorting and marketing			Day 6 to 7	18.38
TOTAL	**5**	**9.97**	**7**	**37.71**

[1] tomato was sold in 5 days
[2] tomato was sold in 7 days
DAH = days after harvest



	November 5	November 5	November 6	November 7	November 10	November 11
Preharvest defects	55.21%	0.00%	0.00%	0.00%	0.00%	0.00%
Mech. Damage-Maj.	0.00%	5.21%	12.50%	11.46%	0.00%	3.13%
Mech. Damage Minor	3.13%	18.75%	22.92%	8.33%	5.21%	0.00%
Physiological defects	0.00%	0.00%	0.00%	4.17%	0.00%	1.04%
Pathological defects	3.13%	0.00%	0.00%	2.08%	11.46%	6.25%
Average VQR	4.79	4.67	4.35	3.99	3.16	2.80

Figure 9. VQR and quality profile of tomato in Nueva Ecija – Bulacan market channel.



	0-DAH	0-DAH	0.5-DAH	1-DAH	2-DAH	3-DAH	4-DAH	5-DAH
Preharvest defects	8.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mechanical damages (major)	0.0%	0.0%	7.1%	8.0%	2.7%	1.8%	0.9%	8.8%
Mechanical damages (minor)	29.2%	7.1%	16.8%	2.7%	5.3%	4.4%	0.0%	3.5%
Pathogen damage (major)	0.0%	0.0%	1.8%	0.9%	0.0%	0.0%	0.0%	1.8%
Physiological defects (minor)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Average VQR	4.56	4.51	4.28	4.19	4.03	3.85	3.80	3.72

Figure 10. VQR and quality profile of tomato in Nueva Ecija – Divisoria market channel.

CONCLUSION AND RECOMMENDATION

The study established the postharvest handling system and postharvest loss of tomato by analyzing two market channels: Nueva Ecija to Divisoria and Nueva Ecija to Bulacan, the major corridors of tomato produced in Nueva Ecija. The postharvest handling of tomato can be disaggregated according to four major segments of the value chain: farmer , assembler , wholesaler and retailer segments. At the farmer segment, the series of postharvest handling operations being performed included harvesting and hauling, sorting, transport and marketing. At the assembler segment the postharvest handling operations included packing and transport. At the wholesaler segment it included storage, transport, and marketing. At the retailers segment the postharvest handling activities included sorting, marketing and resorting.

The total physical postharvest loss of tomato was measured at 9.97% and 37.71% for Nueva Ecija to Divisoria and Nueva Ecija to Bulacan, respectively. Note that Nueva Ecija to Divisoria channel had lower loss since the tomato is marketed within five days as compared with Nueva Ecija to Bulacan channel that took seven days. This can be attributed to the fast turn over and disposal of product in Divisoria. Correspondingly, quality grade declined by 18% (initial VQR of 4.56 to 3.72) and 41% (initial VQR of 4.79 to 2.8) for Nueva Ecija to Divisoria and Nueva Ecija to Bulacan, respectively.

Based on the results of the qualitative and quantitative loss analyses, the farmer's and retailer's segments of the value chain incurred the highest level of losses. Particularly these losses included pre-harvest loss and non-marketable rejects due to accelerated deterioration of tomato at the retail market. While the study did not cover the evaluation of potential interventions, the study provided some take-off point for policy, planning and project development work by particularly identifying the specific actors and activities in the value chain that urgently needed intervention. This can be valuable information in the design of targeted interventions to effectively address the postharvest losses of tomato.

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PILOT-SCALE PROCESSING SYSTEM FOR PRODUCTION OF PHARMACEUTICAL GRADE PECTIN FROM MANGO PEELS

Ma. Cristina B. Gragasin[1], Aileen R. Ligisan[2] and Ofero A. Capariño[3]

ABSTRACT

A pilot-scale processing system for the production of pharmaceutical grade pectin from mango peels was established and assessed to verify its technical requirements and performance. The processing plant was put-up in one of the mango processing plants in Mandaue City through participatory action research. It was comprised of the following components: drying mango peels in a cabinet-type mechanical dryer for four to five hours at 70^{o}C, solubilization of mango peels twice with acidified water (pH=2.5) using steam-jacketed kettle at 100^{o}C for 90 and 60 minutes, respectively, pressing/filtration of pectic liquor using mechanical screw press, precipitation of pectic liquor with ethanol (1:2) in stainless tank, washing of pectic coagulum four times with ethanol, drying of pectin in mechanical cabinet-type dryer at 60^{o}C for at least 30 minutes, and pulverization of pectin into 120 um particle size using electric pulverizer and astm sieve. The physico-chemical properties of pectin from mango peels met the specifications of US Pharmacopeia for pharmaceutical grade pectin. It has higher methoxyl content that shows good spreading quality and sugar binding capacity, firmer gel due to high degree of esterification. Pectin with at least 50% degree of esterification is used for food application. Higher galacturonic acid content of pectin from mango peels denotes its higher purity. The gel grade of pectin from mango peels was similar to that of pharmaceutical grade apple pectin indicating good functionality. Therefore, upscale pectin processing is technically feasible. It can be adopted for commercial scale production.

Keywords: Gel grade, Gelling agent, Mango peels, Pharmaceutical grade pectin

Submitted for review on January 17, 2022. Accepted for publication on October 14, 2022

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INTRODUCTION

Pectin is a group of complex carbohydrate derivatives mainly present within the primary cell wall and intercellular regions of plants (Voragen et al., 1995). They usually form a gelatinous substance when combined with sugar and acids.

Pectin has many applications including as functional ingredient in foods, cosmetics, and pharmaceuticals. The classical function of pectin is giving the jelly-like texture and consistency. It is used in yogurts, pastry glazes, stabilizer in drinkable blended milk-based drinks, and fruit juices (May, 1990). Pectin is also being used as a texturizing fat replacer to mimic the mouthfeel of lipids in low-calorie foods and shorter chain galacturonic acids and have been considered as clarifying agent in fruit juices (Braddock, 1999). Pectin is highly hydrophilic in nature. Hydrophilic matrices are generally used for the oral drug delivery and for the preparation of modified release formulation (Kudela, 1987). Pectin has also been investigated for its usefulness in the pharmaceutical industry. It has been considered in the class of dietary fiber known to have a positive effect on digestive processes and help lower cholesterol (Braddock, 1999). It is also used to stabilize liquid pharmaceutical emulsions and suspensions, and to increase the viscosity of certain drug preparations.

The Philippines is totally dependent on imported pectin. In 2019, the Philippines' total pectin importation from various origin amounted to 80,269kg with total customs value of US$ 65,708,792 (Department of Trade and Industry, 2019). These were mainly used in food processing, cosmetics, and pharmaceutical industries as thickening, gelling, and stabilizing agents.

Recent study conducted by Gragasin et al. (2019) proved that production of pectin from mango peels was found to be technically feasible and financially viable under laboratory scale. The study reported that about 21% recovery of high grade pectin can be isolated from dried mango peels or roughly 2% recovery from fresh mango peels. With an estimated annual mango waste peel of 23.4 million kgs, the Philippines can produce up to 468,000 kgs of mango pectin, which is more than threefold of the country's pectin importation. It was also reported that the mango pectin produced from mango peels is of superior quality and conforms to the US Pharmacopeia specifications in terms of physical and chemical properties.

Hence, a pilot-scale pectin processing system from mango peels needs to be established to verify its technical feasibility on a semi-commercial scale. The outcome of the present research serves as basis for eventual commercialization of the technology. Specifically, this research identified the processing equipment appropriate for pilot-scale pectin production from mango peels and evaluated the technical performance of the established pectin processing system.

METHODOLOGY

Identification and integration of appropriate equipment for pectin production from mango peels

Market research was conducted to determine the availability of appropriate equipment necessary for pectin production. Among the equipment/tools and machines identified were sorting table for the separation of seeds from peels, spinner, screw press, oven, pulverizer, cooker/jacketed kettle, stainless steel tanks, vacuum filtration system, trays, funnel, and distiller for ethanol recovery. Appropriate machineries which include locally fabricated cabinet tray type mechanical dryer, jacketed kettle, screw press, stainless tank, ethanol distiller were integrated into a pectin production line. With these equipment, the 2kgs output capacity pectin processing system as a protto type was set-up at the facility of a commercial mango processing plant located in one of the major islands in the Philippines.

Evaluation of the prototype processing system for pectin production from mango peels

The optimum parameters established in earlier study by Gragasin et al. (2019) was followed in establishing and evaluating the performance of the pilot-scale pectin processing system. Technical performance and efficiency of the 2kgs prototype pectin production system was evaluated based on pectin yield, physico-chemical properties of the produced pectin. Necessary modifications on the process were done until the ideal pectin yield and qualities were achieved.

Mango wastes collected from wastes bin area were sorted to remove the discolored and fermented peels. The peels were scraped with a knife to remove extra pulp for faster drying. Scraped peels were washed and pressed using a mechanical screw press to remove the excess water. Drying of mango peels was done at 70°C using a cabinet tray-type oven dryer. The dried mango peels were then pulverized, packed, and stored.

Pectin was extracted from mango peels following the established process by Gragasin et al. (2019) as follows; The powdered mango peels was solubilized with acidified water (pH 2.5) in a steam jacketed kettle. Solubilization was done for 60 mins at 90^{o}C for the first time and for 60 minutes for the second time. After cooling, the solubilized mango peels were pressed using mechanical screw press to collect the pectic liquor. The filtered pectic liquor was placed in a container and ethyl alcohol (1:2) was added to form pectin coagulum. The mixture was left overnight and filtered with muslin cloth bag the next morning. The collected pectin coagulum was dried at 60^{o}C using mechanical tray type dryer, pulverized to fine particles, sieved to about 120um then packed in aluminum pouch with plastic liner.

Recovery of pectin from dried mango peels using different parameters was determined by computing the ratio of pectin produced over the amount of the raw materials utilized and computed as follows:

$$\%\ \textit{Pectin recovery} = \frac{\textit{Weight of pectin}}{\textit{Weight of mango peels}} \times 100$$

The test for pectin identity and physico-chemical properties such as methoxyl content, galacturonic acid and degree of esterification were determined using the standard procedure of United States Pharmacopeia (USP) 1980. The viscosity, gel grade, gel strength, setting time, and temperature were also evaluated following the method of Rangana et al. (1986). Moreover, other characteristics such as dietary fiber, moisture, and ash content were analyzed following the AOAC methods of analysis (2016).

All analyses were done in two replications. The obtained data were analyzed using analysis of variance to determine the significant differences between extraction parameters. The comparison between the mean values were tested using Duncan's multiple range test at 5% level of significance.

RESULTS AND DISCUSSION

Lay-out of an ideal pectin processing plant

Figure 1 shows the ideal layout for a complete pectin processing system. The system was designed following the protocol of good manufacturing practices. This include a receiving area, sorting area, washing area, cold storage room for raw materials, drying room for mango peels, pulverization room for mango peels, dry storage, solubilization room for pectin extraction, precipitation room for pectin isolation, drying and pulverization room for pectin, packaging and storage room for final pectin product. A separate room for ethanol recovery also comprised the facility.

Pilot-scale processing system for production of pectin from mango peels

Drying of mango peels is a critical component of the process. The established drying parameters include drying the peels at 70°C for four to five hours using a cabinet tray-type dryer (Table 1, Figure 2). The dryer has 11 trays with a loading capacity of 750g/tray. The total loading capacity of the dryer was 18kgs per batch. The recovery of dried peels was 20% with 10-12% moisture content.

The drying characteristics of mango peels is shown in Figure 3. Results showed that the mango peels has initial moisture content of 80%. Moisture reduction was fast during the first three hours of drying time wherein about 20% moisture content (MC) was lost every hour for the succeeding first three hours. The desired MC of 10-12% was achieved between four to five hours when the mango peels were dried at 70°C using the cabinet tray-type dryer.

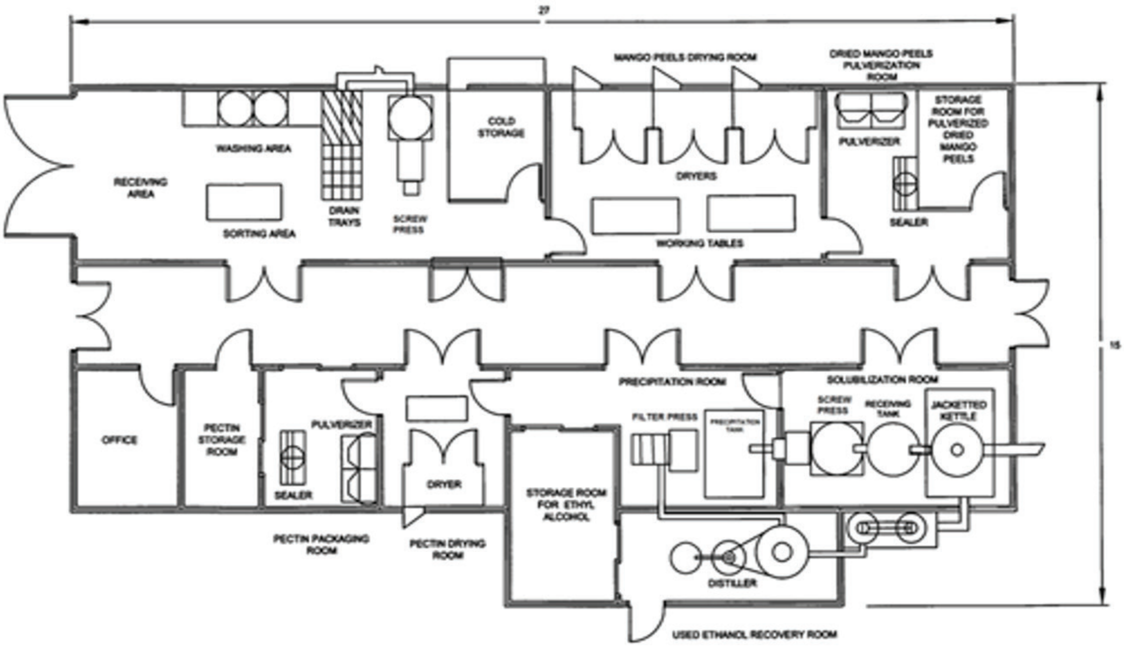

Figure 1. Ideal layout of a pectin processing plant

Table 1. Drying parameters established for dehydration of mango peels

Parameters	Established Data
Number of trays	24
Capacity per tray	750g
Loading capacity	18kg
Drying temperature	70°C
Drying time	4-5 hrs
% recovery	20%

Figure 2. Drying of mango peels using cabinet tray dryer

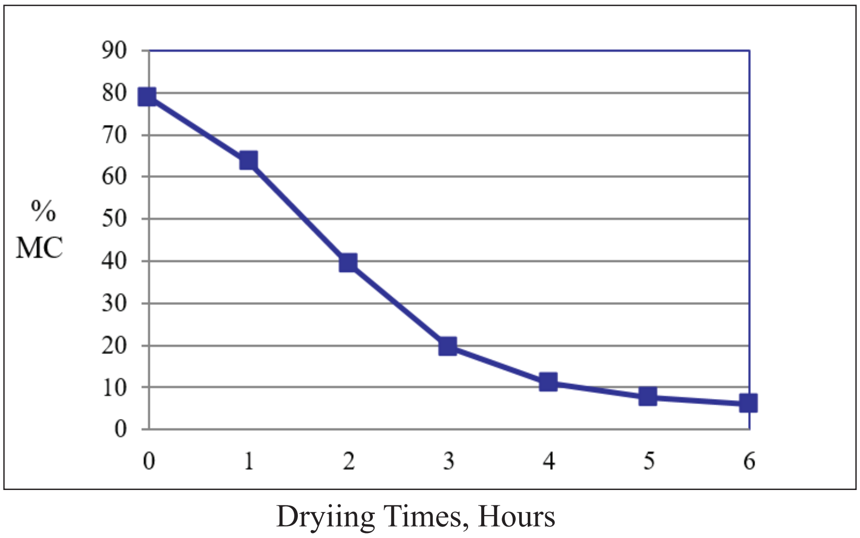

Figure 3. Drying characteristics of mango peels dried at 70°C using tray-type cabinet dryer

Solubilization of mango peels for pectin extraction using steam-jacketed kettle was done. The jacketed kettle used was connected to a steam line as source of energy or heat to run it. It took 15 minutes to boil the required volume of 80 liters acidified water. Solubilization of the peels for pectin extraction was done at 100^{o}C twice at 90 and 60 minutes, respectively. Then the pectic mixture was drained off through a spout attached to the jacketed kettle. The mixture was cooled down before proceeding to the next stage. The use of steam-jacketed kettle enabled faster solubilization process because the steam provided more stable heat making the process more efficient.

Pressing pectic liquor out of the pectic solution (mango peels + pectic liquor) was also critical in terms of recovery of pectin from mango peels. Mechanical press was very helpful for higher pectin recovery. The pectic mixture was fed into the feeder section that passed through the screw for pressing to separate the pectic liquor from the mango pulp. This stage was very critical since the recovery of pectic liquor affects the recovery of pectin.

Precipitation of pectin coagulum followed. Precipitation of pectin coagulum with ethanol required at least four to six hours to complete the reaction with a 1:2 ratio (pectic liquor:ethanol). The pectin coagulum was separated from the ethanolic liquor through filtration. In the absence of mechanical filtration system, muslin cloth bag served as filter to separate the pectic liquor from the pulp. The process required big volume of ethanol so the bulk of expenses was lodged at this step. Without the ethanol recovery system, the process will be very costly.

The established drying temperature for pectin coagulum was 60^{o}C for 30-60 minutes after the fresh pectin was thinly spread on the drying tray. The particle size of dried pectin is also critical because it affects the solubility of pectin. Pectin was pulverized to at least 120um using a laboratory stainless powdering machine. The pulverized pectin powder was sieved with 120um mesh size sieve to come up with uniform particle size. Then the pulverized pectin powder was stored in airtight, aluminized pouch to preserve its quality, safety and stability.

Further, used ethanol was recovered using the ethanol distiller. It has an efficiency of recovering 70-80% of the used ethanol and capable of distilling a total of 120 liters ethanol per batch. The recovered ethanol has 95% purity.

Properties of pectin from mango peels produced in a pilot processing system

Table 2 shows the amount of pectin extracted from mango peels at two production scale. Previous study at the laboratory by Gragasin et al. (2019) showed 21% pectin recovery from dried mango peels. On the other hand, the pilot scale experiment yielded 19% pectin recovery. It was quite lower because of the bigger volume of pectic material that were handled. It is hoped that this will be improved throughout the system by thoroughly pressing the solubilized pectic materials.

Table 3 shows the physico-chemical properties of pectin from mango peels and compared with the USP specifications. The properties of pectin from mango peels even surpassed the minimum specification of USP apple pectin. It has higher methoxyl content amounting to 10.82%, that shows good spreading quality and sugar binding capacity, firmer gel due to high degree of esterification equivalent to 64.58%.

The higher galacturonic acid content of pectin from mango peels with a value of 98.51 denotes its higher purity. The color of pectin from mango peels of grayish/light brown also met the specifications for color by USP.

Another interesting quality of pectin from mango peels was it contains high total dietary fiber amounting to 60-77% wherein 53% of which was in soluble form as shown in Table 4. It also contains 7% insoluble dietary fiber which provides volume and body to stool, thus, it is an aide to constipation (http://www.health.com/nutrition/types-of-fiber).

Gel grade of pectin means the weight of sugar wherein one part by weight of pectin will form a satisfactory jelly resulting to proper texture and consistency. The gelling properties of mango pectin was comparable with the USP grade apple pectin as shown in Table 5. Results showed comparable functional properties of mango pectin with apple pectin.

Though a little bit lower gel grade was noted in pectin from mango peels, it only means that slightly higher amount of pectin from mango peels is needed to reach the exact consistency or jelly-like property of USP apple pectin. The gel formed was firm which is also in agreement with its high degree of esterification. Yapo (2009) reported that the positive gel forming capabilities of pectin jellies is correlated with high esterification value.

Table 2. Pectin yield from mango peels in two production scale

Production Scale	% Yield
Laboratory Scale (Gragasin *et al.*, 2019)	21
Pilot-Scale	19

Table 3. Physico-chemical properties of mango pectin as compared with USP apple pectin

Sample	Degree of Esterification	Methoxyl Content	Galacturonic Acid	Color
Mango Pectin	64.58	10.82	98.51	Grayish to light brown
USP GRADE	Not specified	≥6.70 %	≥74.00%	Grayish to light brown

Table 4. Dietary fiber content of pectin from mango peels

Analyte	%
Total Dietary Fiber, %	60 - 77.4
Insoluble Dietary Fiber	7
Soluble Dietary Fiber	53

Table 5. Gelling properties of pectin from mango peels as compared with USP apple pectin

Sample	Gel grade	Setting time (mins)	Setting temp. (°C)
Mango Pectin	140-150	1:08	80
USP Apple Pectin	150	3	73

The research findings showed that the physico-chemical properties of mango pectin produced from pilot-scale production system met the USP Pharamacopeia specifications for pharmaceutical grade pectin indicating superior quality. The produced pectin has firmer gel due to its high degree of esterification, similar to those reported by other researchers (Yapo, 2009). Pectin with at least 50% degree of esterification can be used for food application (Ptichkina et al., 2008). It is also classified as high methoxyl pectin which is capable of forming gels in aqueous system with high soluble solids and low pH values (2.0-2.5). Another interesting property of the produced pectin from mango peels is its high content of soluble dietary fiber. Soluble dietary fiber forms a gel-like substance inside the digestive system in the presence of water. It binds substances like cholesterol and sugar thus preventing or slowing their absorption into the blood stream (http://www.health.com/nutrition/types-of-fiber).

Results also presented that pilot-scale pectin processing system from mango peels was found to be technically feasible based on the technical parameters that were established and the physico-chemical qualities of the produced pectin from mango peels. The most challenging part of the process is drying of the mango peels. Overlapping of the peels in drying trays must be prevented for complete drying.

The developed pectin processing system from mango peels can be promoted for large scale production and commercialization. Cost efficiency of this technology will be realized for bulk production for economies of scale. The industrial utilization of mango peels for production of high grade pectin will pave the ways for the country's economic opportunities through the creation of a new industry since the Philippines is totally dependent on imported pectin. Further, it will have great impact in solving the problem on solid wastes through the utilization of wastes generated from mango processing.

ACKNOWLEDGEMENT

The authors are grateful to the Philippine government for funding this research. The assistance of Engr. Don Ognayon and Ms. Sheryll May M. Villota in the analysis is greatly appreciated.

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SINGLE EFFECT EVAPORATION OF TENDER COCONUT WATER

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ABSTRACT

As a fundamental step in developing a vacuum evaporator for small scale processing of concentrated coconut water in the rural areas of the Philippines, the mechanism of evaporation under vacuum pressure was investigated in terms of volume reduction, sugar concentration and stability over the process time. The water from the young coconut was subjected to vacuum evaporation (50 mbar) for up to 90% moisture removal. Considering the coconut water is composed mostly of water and sugars, distilled water and sugar water solution (5%) samples were similarly subjected to vacuum evaporation alongside the tender coconut water. The water removal from these samples proceeded linearly within 35 minutes from an initial 100 ml volume. The experiments showed further that the evaporation of water from coconut water ($y=2.4349x+0.8344, R^2= 0.9941$) was significantly lower than both distilled water ($y=2.6739x+1.9138, R^2= 0.9966$) and sugar solution ($y=2.614x+2.9511, R^2=0.9917$). As the water is liberated from the samples, the sugar gets concentrated exponentially in the coconut water ($y=4.2396e^{0.0538x}, R^2=0.977$) and sugar solution ($y=4.5596e^{0.0567x}, R^2=0.9805$). In terms of stability, the experimental samples showed the water activity going down over the process time according to second degree polynomial fit: young coconut water, $y=-0.003x^2+0.0054x+0.9841, R^2=0.8972$; sugar solution, $y=-0.00009x^2+0.0018x+0.9537, R^2=0.9236$; These findings are useful in sizing and controlling the hardware components of the prototype vacuum evaporator for village level processing of coconut water concentrate.

Keywords: Vacuum evaporation, Coconut water concentrate, Young coconut water

Submitted for review on May 6, 2022. Accepted for publication on October 5, 2022

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INTRODUCTION

Coconut water is a commercially viable beverage in international trade with such recognizable brands as Kero Coco in Brazil, Vita Coco, Zico, Goya and ONE in the United States, among others (Berry, 2014; Hennessy, 2014; Liu, 2019). To continually expand its market, some inefficiencies in the supply chain of coconut water must be resolved.

Two notable bottlenecks are transportation and shelf-life. One way to address these issues is to produce concentrated coconut water by vacuum evaporation where whole, bulky nuts can be processed at the point of production, and only the dense, stable liquid product is transported for marketing and finally consumed after reconstitution with water. Some industry players like iTi Tropicals are optimistic coconut water concentrate could succeed as much as the pineapple given its high volume dilution factor (17.8) and significantly lower calories (40%) than many juice products in the market (Hennessy, 2014).

Coconut water is a refreshing, natural energy drink, containing about 95% water, sugars and a high amount of minerals which change over the maturity of the nut (Tan et al., 2014; Yong et al., 2009). Its maximum water and sweetness (6.15 °Brix, Malayan Tall) are attained at about seven to nine months. With its rich nutrients and low acidity (pH 4.6), it is favorable to the growth of microorganisms as soon as it gets exposed to ambient air. It contains potassium (274.32 mg/100ml), sodium (5.60 mg/100ml), magnesium (20.87 mg/100ml), calcium (15.19 mg/ml) and iron (0.308mg/100ml) which all increase with the maturation (12 months) of the nuts to 28, 552, 52, 58 and 442 %, respectively. The sugars are mostly fructose (32.52 mg/ml) and glucose (29.96 mg/ml) with a smaller amount of sucrose (6.36 mg/ml). Over time (12 months), the latter rises by more than double (14.37 mg/ml) while the first two sugars decrease in amount by 34 and 36 %, respectively.

There is a critical food processing challenge in balancing sterility, palatability and preservation of nutrients. The same hurdle exists in coconut water processing to attain fresh-like attributes in the finished product. Vacuum evaporation allows for the removal of water from the food at a low temperature, thereby minimizing the degradative effects of thermal treatments on the processed output.

Single effect evaporation is the process of subjecting a product to a single stage treatment from start to finish at constant pressure and temperature (Bylund, 2015; Hackett, 2018). In large commercial systems, energy efficiency is improved significantly by using multiple effect vacuum evaporation where separate the product is brought to separate treatment chambers in series at descending boiling temperature or pressure. The greater the evaporator effects, the higher the steam economy, up to a certain extent. In a triple effect and 6-effect evaporator, the steam economy advantages are three-fold (3.1x) and five-fold (5.4x), respectively, compared to a single effect system (Bylund, 2015; Hackett, 2018).

A recent study on the vacuum evaporation of coconut sap was conducted to produce sugar (Asghar et al., 2020). Using a laboratory rotary vacuum evaporator (Ika RV-10 Digital, Shanghai, China), the coconut sap (100 ml) in a rotary flask was heated at three different water bath temperatures (65, 75, 85 °C) to attain product evaporation temperatures of 50, 60 and 70 °C, respectively under the corresponding pressures of 160, 250 and 395 mbar. The total soluble solids (TSS) measurements were done by stopping the process every 5 min from the start and every 2 min towards the end, until the 65 °Brix was attained. The samples were kept refrigerated (2 °C) prior to analysis.

In the United States, a patent was issued to Coco Fountain LLC, Princeton, New Jersey for a stable coconut water concentrate which was touted as shelf-stable for up to one year, with endpoint soluble solids of 70 °Brix, a water activity of 0.70 and a dilution ratio of 20-30:1 (Manen, Gert van; Giampetro, 2018). However, it appears that the raw material, at 60 °Brix, is not a fresh coconut water, and as such, it must have been processed earlier. The opportunity still exists in developing a small-scale coconut water concentration system for raw coconut water from rural farms.

To concentrate coconut water, the desirable final soluble solids level is about 60 to 65 °Brix, at which state the product is regarded as self-preserving. When the concentrated product is stored at -18 °C, it is useable for up to two years (Liu, 2019).

In the food industry, the sugar content may be measured in varying ways depending on context and the accuracy required. The standard means of sugar content determination was derived from the physics of density and refractometry. The unit of measure, Brix, refers to the percentage by weight of sucrose in a water solution and its corresponding refractive index, based on the table promulgated by the 16th Session of the International Commission for Uniform Methods of Sugar Analysis (ICUMSA) 1974. The notation Brix degrees (°Brix) is technically valid only for pure sucrose solution. For other sugars, several conversion tables are prescribed based on the premise that there is a direct relationship between density and Brix. In other digital instruments, the reference values are built-in, including temperature compensation (Mettler Toledo, 2014).

When product stability is aimed at, it refers to the ability of food samples to resist deterioration. It can be measured objectively in terms of several attributes such as color, acidity, turbidity and water activity, among other parameters. An example of a recent paper (Kumar et al., 2022) using the term stability similarly described the qualities of tender coconut water from various processing techniques. Water activity, aw, is a unitless measure of water availability in food for microbial and enzymatic activity based on the ratio of the vapor pressure in the food material with that of surrounding air (Fennema, 2010; USFDA, 2014).

The general regulatory requirement for food safety is aw $\leq$ 0.85 (USFDA, 2014) although food-specific recommendations are also available from other authors (Forsythe, 2000; Jay, James M., Loessner, Martin J. and Golden, 2005).For most juice concentrates and syruping sugars, the desirable water activity levels are 0.87 $\leq$ aw $\leq$ 0.80 and aw $\leq$ 0.70, respectively. Food stability and food safety are related in the sense that significant microbial and enzymatic activities in food result to adverse food quality changes including toxin contamination at the extreme end.

The fundamental design considerations for vacuum evaporator are: 1) how to evaporate water from the sample and 2) when to stop. Essentially, the first issue pertains to the pressure and temperature requirement for the product to meet the target processing capacity when scaled up from the experimental model to the industrial deployment. It must consider the operating range of commercially available components of the hardware such as actuators and sensors. Granted the desirable output of the vacuum evaporator is a product with soluble solids of 60 to 65 °Brix, this parameter is not directly measurable in the evaporation chamber without disrupting the process itself.

For this reason, process automation can proceed in practical terms by exploring other process end-point parameters such as volume, time, viscosity and electrical conductivity. The other parameters like color and turbidity may be relevant but they are as intrusive as the refractive index to the evaporation process. For simplicity, volume and time are good starting points of this investigation but their usefulness can only be established after verifying a strong correlation -- preferably linear – with the concentration of total soluble solids.

To establish the fundamental functional basis of a vacuum evaporator, this study was conducted to: 1) determine how water is liberated from coconut water under vacuum pressure; 2) find out how sugar concentration rises with the removal of water from coconut water; and, 3) determine the product stability as coconut water loses moisture.

METHODOLOGY

Procedure of Investigation

This study was conducted on March 1 to April 15, 2022 at the Philippine Center for Postharvest Development and Mechanization (PHilMech), Muñoz Science City, Nueva Ecija, Philippines. It was carried out following the general procedure shown in Figure 1 below:

Preliminary experiments were conducted on the range of vacuum evaporation settings which can be scaled up into a small village level processing plant with raw input capacity of less than 5,000 nuts per day. The vacuum pressure was aimed within the pump rating of 1 hp and batch processing time of less than 1 hour. The vacuum evaporation of water at 90mbar and 40 °C process temperature was considered as a starting point as prescribed in the operating manual of the laboratory rotary evaporator.

From these initial trials, the smallest manageable sample volume (100 ml) was determined to allow fast replication while keeping sufficient residual volume for subsequent product property measurements. The process endpoint was set at around 90% moisture removal, within 40 minutes process time, whichever comes first. The interval of product measurements was set at 10 min.

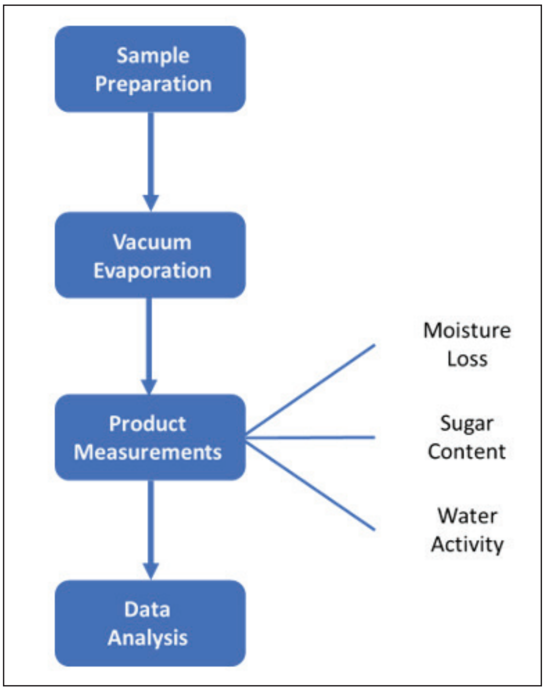

Figure 1. Procedure of investigation.

Preparation of Experimental Samples

The young coconut samples (locally termed as 'buko' in the Philippines) were taken from the lot of seven to nine month-old nuts as sold in the local market of San Jose City, Nueva Ecija, Philippines. The coconut water, 100ml per replicate, was collected in a beaker, filtered and immediately subjected to vacuum evaporation. In the case of the sugar solution sample, 5g of commercial white sugar was dissolved into 95ml distilled water. Initial sugar content and water activity levels were recorded for each of the four replicates. Each replicate was 100 ml volume.

Vacuum Evaporation

The vacuum evaporation of coconut water was carried out using a laboratory evaporation system (Buchi Labortechnik, Flawil, Switzerland; 220VAC, 60Hz, 210W) consisting of a temperature controlled water bath (Buchi B100, 1,700W, 20-95°C), evaporator – condenser (Buchi Rotavapor R100), vacuum pump (Buchi V100) and recirculating chiller (Buchi F105, 850W, 2.5L/min, -10 to 25°C) and a control panel (Buchi I100) where temperature and pressure setpoints can be entered.

For all experimental samples, the vacuum evaporation was done under the following constant set points: water bath temperature, T_b, = 65 °C; vacuum evaporation pressure, P_e = 50 mbar; condensation temperature, T_c = 15 °C.

The evaporation water drops by gravity into a dedicated collecting flask after the vapor from the evaporating flask condenses upon contact to a spiral cooling tube along the slightly tilted vacuum chamber. The collecting flask for condensed water is removable from the rotary evaporator set up and its contents may be measured by weight and volume.

Shown in Figure 2 below is the control volume representing the vacuum evaporation set up. The raw material, m_p, was placed in a flask and submerged in a hot water bath m_b. This bath is open mouth and hence, it also loses mass over time to the atmosphere. Given the heat and pressure, an increasing fraction of the feed material m_p evaporates into the next heat exchange chamber as a vapor m_v where it condenses into the bottom collector as a liquid m_c.

The entities m_{ci} and m_{co} are mass quantities referring to the incoming and outgoing cooling liquid, respectively, to facilitate the condensation of the vapor m_v. These cooling mass (m_{ci}, m_{co}) and heating mass entities (m_b,m_l) will be tackled in another paper on energy modeling where they are more relevant. It should be noted that these heat exchange mass entities are contained in their own conduits, preventing them from physically mixing with the feed material in all its phase changes.

This aspect of the study is mainly governed by the mass conservation which is given in the equation below:

$$m_p - (m_v + m_c + m_s) = 0$$

where:

m_p = mass of the product at the feed chamber,g
m_v = mass of the vapor at the evaporation-condensation chamber,g
m_c = mass of the condensate,g
m_s = mass of the vapor at the suction line,g

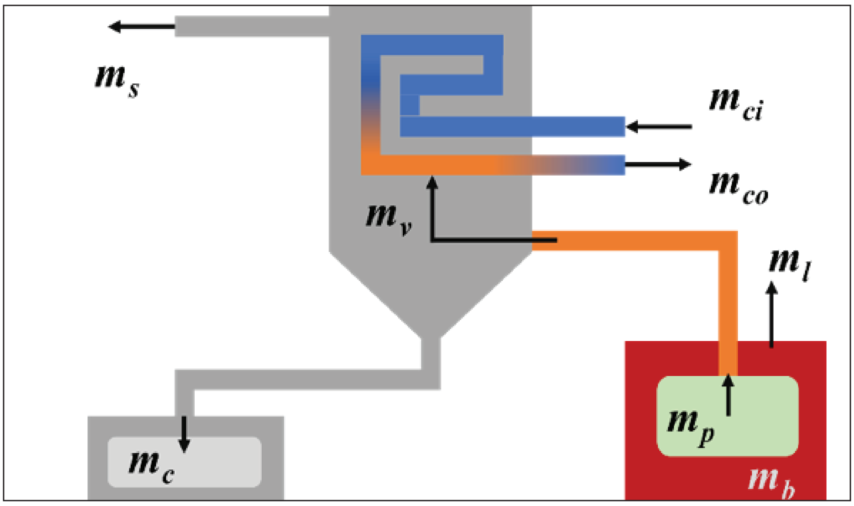

Figure 2. Control volume of the experimental single effect vacuum evaporation set up showing mass entities relevant for conservation of mass.

At the start of the vacuum evaporation, the mass of the product, m_p, at the feed chamber was 100g and as such, all other masses were zero. At each process intermediate measurement point (time, t=10,20, 30) until the process endpoint (t=35 min), the sum of the feed mass, m_p, and the condensate mass, m_c, was 99.5 g, suggesting that a) the mass of the vapor at the evaporation-condensation column, m_v, was effectively condensed, thus, $\sum(m_v + m_s)=0$ and, b) the process settings such as evaporation temperature, vacuum pressure and cooling temperature were adequate for this experiment. The residual error of 0.5g in the mass balance can be attributed to the residual droplets adhering to the flask wall and to the consistency (accuracy and precision) of weighing.

Determination of Total Soluble Solids

The total soluble solids which represent the sugar content or sweetness of the experimental samples (Mettler Toledo, 2014) were measured using an optical refractometer (N-1α, Atago, Japan; Brix 0-32%) at each time point of the vacuum evaporation. Four replicates were carried out.

The sample for sugar content determination was collected from the residual volume in the evaporating flask, after cooling to laboratory room temperature (T = 20 °C). The measurements were done on the same day, after vacuum evaporation, without prior refrigerated storage of the sample. Droplets of this sample were placed on the clean specimen glass of the portable optical refractometer and the corresponding visual readings were recorded.

The instrument itself (Atago N-1α) shows a percentage scale (% Brix), not degrees (°Brix), and as such, it must be faithfully recorded as such. The difference between them has been presented in the earlier part of this paper. At this stage, this paper does not intend to reconcile or refute varying measures of sugar content in other papers.

Water Activity Measurement

The water activity of the experimental samples was measured using a digital water activity meter (4TE, Aqualab, USA; 220VAC, 60Hz, 40W) every 10 min interval until the process endpoint (80% moisture removal) of the vacuum evaporation. Four replicates were done.

As in the sugar content measurement above, the samples for water activity measurement were obtained from the evaporation flask, cooled to room temperature, then measured on the same day, without refrigerated storage, by dropping adequate amounts into the sample holder of the water activity meter. The water activity readings (unitless) were given automatically by the measuring device in its electronic display.

RESULTS AND DISCUSSION

Vacuum Evaporation

Shown below (Fig 3) is the progressive removal of water from the experimental samples under vacuum pressure. Generally, the evaporation proceeded linearly for all samples: distilled water, sugar solution (5%), and coconut water. It took roughly 35 minutes to remove around 80% of water in all samples.

The evaporation of water from coconut water ($y=2.4349x+0.8344, R^2= 0.9941$) was significantly lower than both distilled water($y=2.6739x+1.9138, R^2=0.9966$) and sugar solution ($y=2.614x+2.9511, R^2= 0.9917$) over the process time. Given the vacuum evaporation conditions, the rate of evaporation of water and sugar solution was faster by 8.94% and 6.85%, respectively, than coconut water. The distilled water evaporates 2.24% faster than sugar solution.

Total Soluble Solids

As the water is liberated from the samples, the product became noticeably sweeter which means the total soluble solids were mostly sugars. These soluble solids were concentrated exponentially in the coconut water ($y=4.2396e^{0.0538x}, R^2 =0.977$) and sugar solution samples ($y=4.5596e^{0.0567x}, R^2 =0.9805$) over time (Fig 4). Expectedly, the plot for the distilled water remained flat.

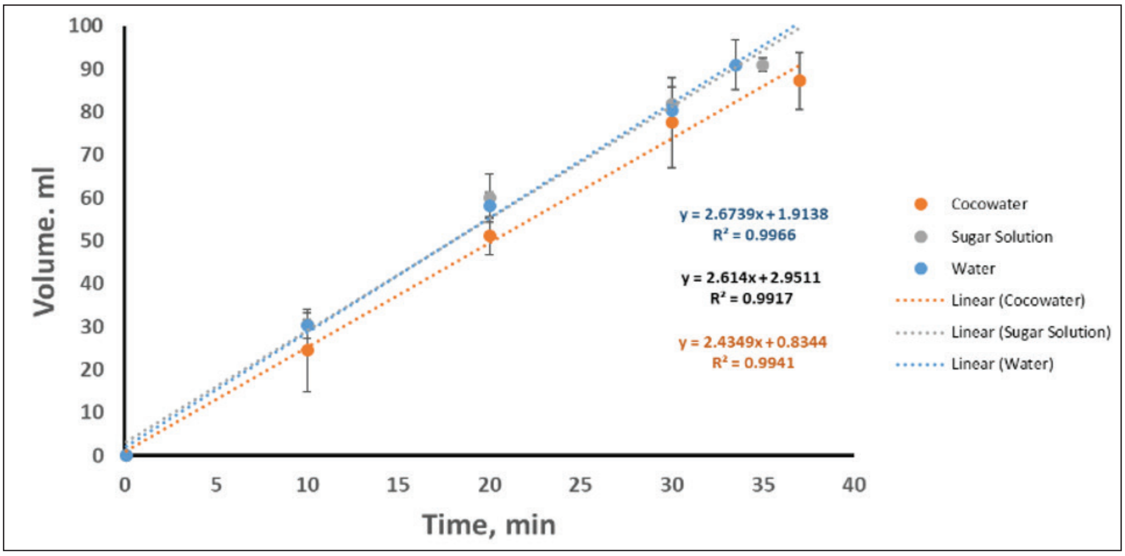

Figure 3. Evaporation of water under vacuum pressure for distilled water, sugar solution (5%) and coconut water. Error bars = ± 2 SE.

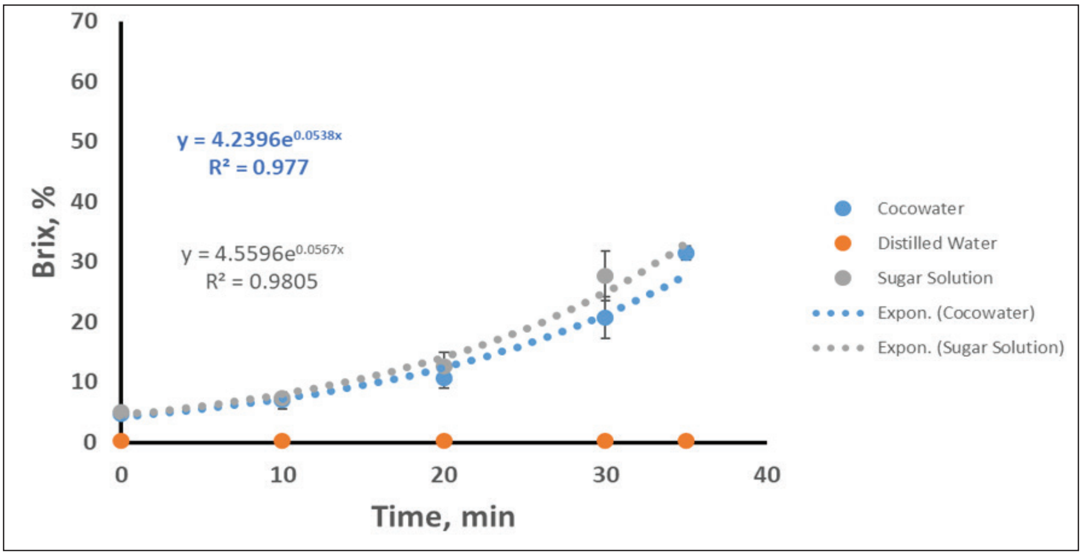

Figure 4. Concentration of soluble solids in the coconut water, sugar solution (5%) and distilled water samples during vacuum evaporation. Error bars = ± 2 SE.

Coconut water gets concentrated slower by five percent than the sugar solution sample within the 35-minute process time. From an initial sweetness of around 4.7 % Brix, the coconut water became sweeter up to 31.5 % Brix after losing 80 % water. This change represents around seven-fold increase.

The units of measure % Brix and °Brix are equal only if the same sucrose solution is measured. Elsewhere in this paper where °Brix is mentioned, it is because the sources themselves declared such notation from their own independent experiments using different measuring instruments. From Coconut Handbook (Liu, 2019) however, it is implied that the 60-65 °Brix is equivalent to the same % Brix. Coconut water however, is certainly not pure sucrose, even after evaporation. The constitution of major sugars in coconut water has been thoroughly documented in reputable papers (Santoso et al., 1996; Tan et al., 2014; Yong et al., 2009).

Sucrose is inherently small in quantity in tender coconut water compared to the other major sugars (fructose and glucose). It is roughly 1 to 10% of the total sugars depending on variety and other factors.

In this paper however, the other kinds of sugar content measuring instruments were unavailable, hence, never used. At the next stages of the project such as hardware development and product quality standardization, as may be required by the commercial buyers or regulatory entities, a calibration curve will be developed, among other initiatives, to reconcile objectively sugar concentration levels from different methods and measuring devices. For this paper, it has been consistently stated that the methods and results provide the sugar content in percentage Brix, not °Brix. This paper is not an isolated case using optical refractometer and percentage Brix as a unit of measure (Chowdhury et al., 2009). The evaporation curve obtained is most useful in machine design, such as sizing of heater, vacuum chamber, heat exchanger, condensation system, and so on. It should be noted that the evaporation end point in this study was 80% moisture removal.

As such, it does not necessarily mean that a result of 31.5% Brix coconut water concentrate is less sweet than the other external assertions of 60-65 °Brix. This can be reconciled in another paper but for now, this paper is consistent in its methods all the way to prototype hardware design.

Water Activity

In Figure 5 below, the water activity of sugar solution (5%), distilled water and young coconut water during vacuum evaporation.

The water activity of the experimental samples go down over the process time according to second degree polynomial fit: young coconut water, $y=-0.003x^2+0.0054x+0.9841, R^2=0.8972$; sugar solution, $y=-0.00009x^2+0.0018x+0.9537, R^2=0.9236$; As for the distilled water, the water activity remained constant at y=0.32;

The water activity of 0.90 is reasonable for the purpose of this study considering that 80% of the water has been liberated already, the sugar concentration increased seven-fold, and the technical consideration that product stability does not depend solely on water activity (Jay, James M., Loessner, Martin J. and Golden, 2005). In commercial operations, the concentrated product is normally pasteurized first, chilled and subjected to multiple effect evaporation, thereby providing hurdle treatment for better stability.

The water activity ranges in other fruit juice concentrates differ with coconut water because of the other factors at play towards overall product stability such as water to solubles ratio, acidity, enzyme and microbial inactivation treatments, storage temperature, packaging material, among other things.

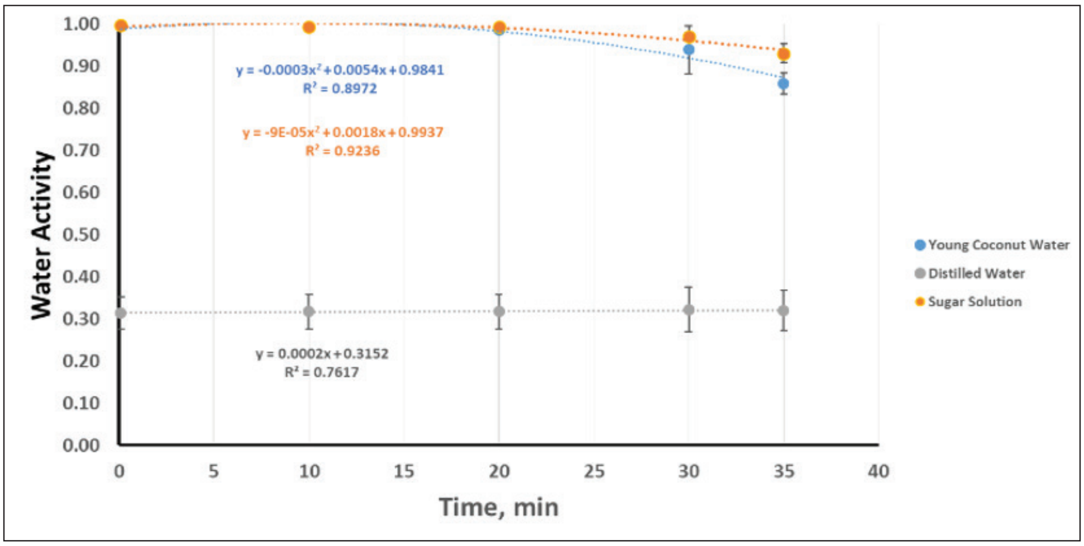

Figure 5. Water activity of sugar solution (5%), distilled water and young coconut water during vacuum evaporation. Error bars = ± 2 SE.

Implications to Hardware Design

The evaporation and concentration curves suggest that it is desirable to evaporate and condense the excess moisture and from there, control the process mainly through the volume accumulation in the condensation chamber with the use of a non-contact liquid level sensor. The other parameters and sensors may be added later for optimization purposes. The prototype single effect vacuum evaporator requires the following components:

1. Feed tank, pump and monitoring system
2. Evaporation chamber
3. Vacuum pump
4. Heater and monitoring system
5. Discharge tank, pump and monitoring system
6. Condensing tank, pump and monitoring system
7. Sensors (pressure, temperature, level) and control system
8. Electric power supply

Another approach to improving process efficiency and scalability is to alter the design altogether into a multiple effect evaporator where the heat exchange fluid can be reused. Such multiple effect evaporation system can increase steam economy by nearly three times for triple effect and up to as high as 30x steam economy for mechanical vapor recompression (Hackett, 2018). About 80 to 100 kg of water can be removed from a 1 kwh input and thus, processing costs can be reduced by half compared to a conventional six effect evaporator with a thermocompressor (Bylund, 2015).

When compared to other techniques, vacuum evaporation was shown to produce superior product quality at a lower energy cost. In processing syrup from coconut sap, this study (Asghar et al., 2020) showed that vacuum evaporation consumed only 42.17% energy compared to open heat evaporation which is common in small scale village level processing. At the same time, vacuum evaporation produced superior color than both microwave and open heat evaporation. This implies good prospects on the feasibility of vacuum evaporation even for small scale processing.

The viscosity of coconut water can change significantly by three-folds (3.36x) as the soluble solids gets concentrated (Manjunatha & Raju, 2013). This means pump load gets bigger and flow rate tends to slow down.

CONCLUSION

Based from the experimental findings above, the following conclusions are drawn:

1. The evaporation of water under vacuum from young coconut water is slower than both distilled water and 5% sugar solution;
2. The rate of sugar concentration in coconut water is significantly slower than the sugar solution sample;
3. The coconut water sample approached the shelf-stable water activity level faster than the sugar solution;
4. The linearity of moisture removal over the process time suggests the automation of certain hardware components like the vacuum pump, heater and discharge pump may be carried with simpler controls like liquid level sensor and timer switch.

ACKNOWLEDGMENT

Credits are due to Dante M. Niegos and Miguelito V. Valdez for their technical assistance in the laboratory work.

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THE VIABILITY OF HIGH-TEMPERATURE STORAGE FOR SMALLHOLDER ONION FARMERS IN NUEVA ECIJA, PHILIPPINES

Rodelio G. Idago[1], Edgar D. Flores[2], Hernaiz G. Malanon[3] and Domingo R. Miranda[4]

ABSTRACT

This paper discusses the technical, financial and economic viability of high-temperature storage (HTS) as an alternative storage of bulb onion for smallholder farmers in Nueva Ecija, Philippines. The HTS is a generic type of non-refrigerated storage (NRS) system that applies storage temperature slightly higher than ambient condition designed for medium-duration storage. The study revealed that percentage storage losses in HTS is 11.52% and 38.92% in 70 and 140 days, respectively and increases progressively to 85.25% in 224 days. The optimum storage duration under HTS is 112 days given current price, storage costs and losses. Putting up HTS as private investment will be financially viable at storage fee of PhP70/bag. At this rate however, farmers may not avail of its service because of marginal increase in income creating little incentive for its sustained use and adoption. Putting up HTS as public investment is economically viable with an ERR of 33.59% and 11.40% under partial and full subsidy, respectively. The economic gains would come from reduced storage losses. Providing HTS under public investment scheme can provide farmers incremental income of Php61,576 to Php92,364 per season by storing and selling 50-75% of their harvest creating opportunity for local producers higher economic returns from their produce.

Keywords: Peak production, Losses, Market glut, Incremental income, Economic return

Submitted for review on June 17, 2021. Accepted for publication on October 4, 2022

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INTRODUCTION

Vc Alliums are essential vegetable crops in the Philippines and Allium cepa L. or bulb onion place the highest significance in terms of production and economic value (BPI, 2013). In 2019 the Philippines recorded a total production of 172,000 MT valued at Php6,743.9M. Onion is widely grown in the regions of Central Luzon and Ilocos contributing to 49% and 31%, respectively of the national production. In Central Luzon the province of Nueva Ecija contributes the bulk of production which is over 90% (PSA, 2019).

Onions are grown during the months of October to February while reaching its peak harvest season on March to April. During these peak months average farmgate price however is at its lowest as influenced by the dynamics of supply and demand and without any viable alternative such as storage appropriate for smallholder producers leave these value chain actors limited option but to sell their harvest at current price. In some occasions this market glut is further exacerbated by the untimely influx of imported supply. The onion market channel involves a complex chain of supply chain actors, and off-farm these are strongly participated by local traders, assemblers, wholesalers, retailers and some sub-layers and intermediaries in between (Calica et al., 2015). Most of the excess supply during peak harvest are deposited in cold storage facilities in anticipation of higher price and withdrawn during the lean months of August to December.

In the Philippines, the use of cold storage remain the chief practice of storage lasting from six to nine months (Castillo et al., 2008; Idago et al., 2015). Based on the value chain study of Calica et al. (2015) the use of cold storage is a domain of the financers and traders that procure the largest share of supply during peak season. This constitute the supply which are normally withdrawn after five to six months depending on the current price (Idago et al., 2015). While the rates of storage fees charged by cold storage operators are high these value chain actors are able to make profit with their economies of scale. One of the common arrangements in the services of cold storage service providers is a straight/ fixed contract for six months which will be charged regardless of whether the onion is withdrawn from the storage even earlier. Beyond six months additional storage fees applies. Therefore, there is already a minimum storage cost ranging from Php220-250/bag of 27kg upon the use of cold storage.

Under this rates and arrangements the use of cold storage is practically beyond reach of smallholder local onion farmers considering the average volume they handle in a season. Hence, a storage system that can be practically applied by smallholder farmers will be desirable to get the most out of their produce.

Bulb onion remains dormant for four to six months (BPI, 2013) and a number of studies suggest that bulb onion can be effectively stored under ambient and high temperature storage conditions for a period of two to four months (Dabhi, et al.,2008; Dela Cruz, et al., 2019; Endalew et al., 2014; Idago et al., 2015; Jallorina, et al., 2012; Opara, 2003). Endalew et al., (2014) underscored that bulb onion shelf life can be prolonged in naturally ventilated structure as compared to traditional in house floor storage. Jallorina et al. (2012) highlighted that bulb onion can be effectively stored in near ambient conditions of 35C with 0.04m/s air velocity for 4 months. Dabhi et al. (2008) and Opara (2003) suggested that onion can be effectively stored in non-refrigerated condition. These findings were also corroborated by the studies of Idago et al., (2015) and Dela Cruz et al., (2019) that the shelf life of onion can be prolonged in non-refrigerated conditions using the high-temperature structure for four months and nine months for bulb onion and shallot, respectively. These studies support that an alternative storage system, in the form high-temperature storage, can be effectively applied for smallholder farmers. However, the level of its viability needs further investigation as there is scarce information in relation to its technical and financial performance under Philippine conditions at the farmers' level of utilization.

This paper intends to: 1) assess the technical and financial viability of adopting high-temperature storage at the farmers level, and; 2) assess its economic viability as a form of government intervention in support to the local onion producers.

METHODOLOGY

Conceptual Framework

The conceptual framework of the study is presented in Figure 1. The technical viability of the HTS was assessed by evaluating the storability of bulb onion in HTS designed and developed by PHilMech. The shelf life of bulb onion and rate of storage losses - sprouting, rotting and weight loss, were used as indicators of technical viability.

The storage losses are also used as input in the financial analysis in determining the marketable onion after storage. Average onion price, storage costs and the cost of HTS were used to assess the financial viability which was done from two perspectives, that is: 1) from the point of view of a farmer adopting the HTS using different levels of volume, analysed using partial budget analysis; and 2) from the point of view of a private investor investing in HTS charging different rates of storage fee, analysed using investment analysis.

The economic viability was assessed by accounting for the costs and benefits treating the HTS as a public investment, analyzed using cost benefit analysis. The economic analysis was done under two scenarios, that is: 1) partially subsidized; 2) fully subsidized. Synthesizing the results of the aforementioned analyses determined the technical, financial and economic viability of HTS as an alternative storage for smallholder onion farmer.

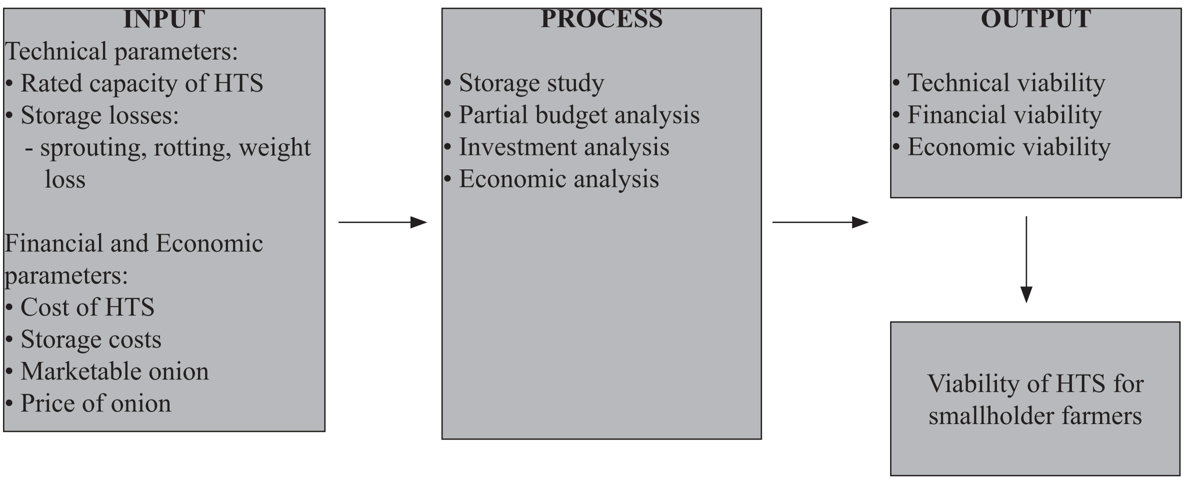


Figure 1. Conceptual framework of the study

Bulb Onion Samples and Experimental Design

The study used the Red Pinoy cultivar, the most widely grown bulb onion, as samples for the storage study. In the storage study 36 red bags of 25kg each presorted marketable bulbs were used as storage samples. The study used repeated measure experimental design, with each bag of onion samples as experimental unit, measuring storage losses at 14 days interval throughout the 224 days storage period. Storage conditions such as temperature and relative humidity (RH) were monitored using data loggers (Thermco Products Inc., model CT 309; 4 channels K-type thermocouple; Operation temp. 0C-5^{0}C; accuracy-.±0.1%C; resolution 0.1C; made in USA)

Technical Performance of HTS

The technical performance of the HTS was assessed based on how long the shelf life of onion is extended and the percentage cumulative storage losses over the storage period. Storage losses measured by the project included percentages of physiological weight loss, bulb rot and sprouting intensity. These technical parameters were computed using the formula described and presented below.

Percentage weight loss (PWL)

Weight loss refers to reduction in weight due to shrinkage, water loss and other physiological changes of the bulb onion. The percentage weight loss (PWL) was computed using the formula:

$$PWL = \frac{wi - wf}{wi} \times 100$$

where:

wi= initial weight
wf= final weight

Percentage bulb-rot (PBR)

Bulb rot refers to decaying and rotten onion bulb. The percentage bulb rot (PBR) was computed using the formula:

$$PBR = \frac{wr}{wi} \times 100$$

where:

wr = weight of rotten bulb
wi= initial weight

Percentage sprouted bulbs (PSB)

Sprouted bulb refers to bulb onion with leaves emerging from the bulb neck. Percentage sprouted bulb (PSB) was computed using the formula:

$$PSB = \frac{ws}{wi} \times 100$$

where:

ws= weight of sprouted bulb
wi = initial weight

Storage Costs

Storage costs refers to costs incurred in preparation to and during storage which include preliminary curing and cutting of leaves, cleaning on-field, hauling, sorting, bagging/crating, and regular cleaning in storage. During storage period the labor cost on regular cleaning represents the bulk of storage costs. Depreciation of the HTS was included as part of the indirect storage costs.

Average Onion Price, Marketable bulb, Net profit and Profit Margin

The average onion price from 2016 to 2020 was determined using the data from the Philippine Statistics Authority to establish the average onion price for the last five years. Marketable bulb refers to the good onion bulb recovered after storage which is basically the difference between the initial weight at day 0 and the storage losses at withdrawal period. Marketable bulb (MB) was computed using the formula:

$$MB = IW - TL$$

where:

MB = marketable bulb, kg
IW = weight of stored onion at day 0, kg
TL = (BR+ WL + SB), in kg
BR = bulb rot;
WL= physiological weight loss;
SB = sprouted bulb

The net profit (NP) is the difference between the total revenue and total costs determined using the formula:

$$NP = TR - TC$$

where:

NP = net profit, Php
TR = total revenue, Php
TC = total cost, Php

On the other hand, total revenue (TR) was computed using the formula:

$$TR = MB \times P$$

where:

TR = total revenue, Php
MB = marketable bulb, kg
P = selling price, Php/kg

Profit margin was computed using:

$$PM = \frac{Np}{R} \times 100$$

where:

PM = profit margin, %
NP= net profit, Php
R = revenue, Php

Methods of Analyses

Storage losses

The storage losses were analyzed using descriptive statistics taking the average of the repeated measures from 36 bags which served as experimental units. Every after measurement samples were returned to the storage to observe the progress of losses over the storage study duration. The losses were recorded and tabulated at 14 days interval and presented in percentages.

Partial budget analysis

Partial budgeting is an instrument that measures the effects of marginal changes on overall profitability and, in particular, choosing between technologies and enterprises (SEARCA; undated). This analysis measures the change in income as a result of the proposed intervention. In this study a comparison between the application of HTS and the traditional practice of selling harvest at current price. In the partial budget analysis the change in income (I) is computed using the formula:

$$I = (Ra + Cr) - (Rr + Ca)$$

where:

I = incremental income, in Php
Ra = added revenue, in Php
Cr = reduced cost, in Php
Rr = reduced revenue, in Php
Ca = added cost, in Php

Financial Analysis

The financial viability of HTS was assessed from the point of view of private investor operating the HTS for rent charging the farmer-client a certain storage fee similar with the business model of how commercial storage facilities operate. Profitability parameters used are benefit-cost ratio (BCR), net present value (NPV), payback period (PP) and internal rate of return (IRR) computed using the following formula:

$$BCR = \frac{\sum_{t=0}^{n} \frac{Bt}{1+r^t}}{\sum_{t=0}^{n} \frac{Ct}{1+r^t}}$$

where:

BCR = benefit cost ratio
Bt= benefits at time period t, Php
Ct = costs at time period t, Php
r = discount rate, %
n = project life, yrs

$$NPV= \sum_{t=0}^{n} \frac{Bt}{1+r^t} - \sum_{t}^{n} \frac{Ct}{1+r^t}$$

where:

NPV = net present value, Php
Bt = benefits at time period t, Php
Ct = costs at time period t, Php
t = number of time periods, yrs
r = discount rate, %
n = project life, yrs

$$IRR = \sum_{t=0}^{n} \frac{Cft}{1+r^t} - C_0$$

where:

IRR = internal rate of return, %
Cft = net cash inflow during time period t, Php
r = discount rate, %
t = number of time periods, yrs
C_0 = initial investment cost, Php
n = project life, yrs

Economic Analysis

Cost benefit analysis was used to assess the economic viability of putting up HTS as an alternative storage for small-holder onion farmers treated as public investment. In the economic analysis the study used the shadow exchange rate (SER) method (Boardman, et al. 1996) to compute for the efficiency prices since the HTS is indirectly traded item, or some of the materials used in its parts are imported items. The SER is computed using the formula:

$$SER = OER\ (1 + fep)$$

where:

OER = official exchange rate, in pesos
fep = foreign exchange premium, in percent

The economic viability indicators used were economic rate of return (ERR) and net present value (NPV). Decision rule is that the project is economically viable if NPV is positive which implies that discounted benefits outweighs discounted cost and ERR is at least equal to the social discount rate. NPV and ERR were computed using the following formula:

$$Discounted\ cost = \sum costs / (1+i)^n$$
$$Discounted\ benefits = \sum benefits / (1+i)^n$$

where:

n = time period, in years
i = interest rate, in percent

$$NPV = \sum benefits/ (1+i)^n - \sum costs / (1+i)^n$$
$$ERR, 0 = NB0\ \frac{NB_1}{(1+i)^1} + \frac{NB_2}{(1+i)^2} + \frac{NB_3}{(1+i)^3} + \frac{NB_n}{(1+i)^n}$$

where:

NBn = net benefit occurring at period n
n = time period, in years
i = social discount rate, in percent

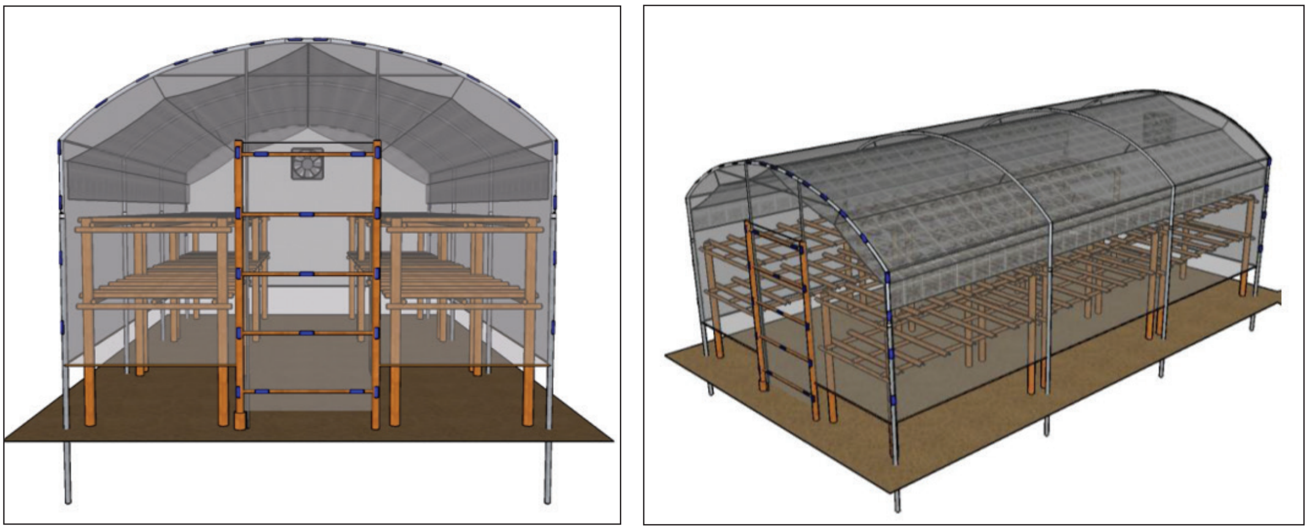
RESULTS AND DISCUSSION

Description of the HTS

The HTS structure (Figure 2) is a tunnel type structure covered with 4 mils thick UV-stabilized plastic. The dimension is W=4m x L=15m x H=2.5m with structural frames built using GI pipes similar to basic greenhouse structure. It is provided with an exhaust fan for air circulation. The heat source is solar energy that effect the elevated temperature inside the storage structure which can be 4-6C higher than ambient. This storage condition accelerates curing of bulb onion that contributes to longer shelf life. Regular cleaning and inspection of rotten and sprouted bulb is done manually to prevent spread of infection on the stock. During intense summer heat a second layer of shade net is installed to regulate the temperature. With solar energy as the only heat source, the temperature at night is the same with ambient condition. The rated capacity of the HTS is 7-8 tons which can accommodate 75% of the average harvest of an individual onion farmer. The design can also be modular, extending the length of the tunnel, to accommodate larger volume.

Storage Losses

Percentage storage losses such physiological weight loss, bulb rot and sprouted bulb increases with storage period (Figure 3). Sprouted bulb was only observed on the 84th day onwards while bulb rot and physiological weight loss manifested as early as after 14 days onwards. The total accumulated storage loss increased dramatically on the 98th day and reached over 85% on the 224th day.



(a) (b)

Figure 2. Front elevation (a) and perspective view (b) of HTS structure

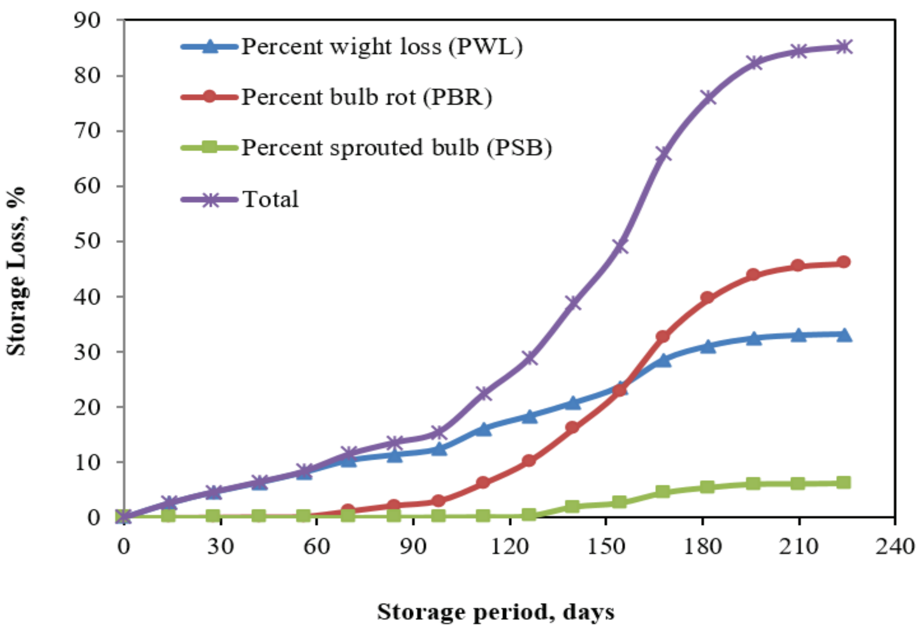


Figure 3. Percentage mean physiological, sprouting, and bulb rot losses of bulb onion stored under high temperature storage

Storage condition

The average temperature and relative humidity inside the HTS follows a similar pattern with the prevailing ambient condition. The range of temperature is 27-39°C. The relative humidity (RH) inside the HTS has a mean value of 77% as compared with ambient at 80%. The relative humidity ranges from 65-93% with higher values observed towards the 112th days since this period onwards coincide with the onset of rainy season in the study area.

Optimum Storage Duration in HTS

The optimum storage duration under HTS is determined based on the following information: 1) marketable bulb, which decreases with storage period; 2) price, which generally increases over the time after the peak harvest period, and; 3) the storage costs, which increases with storage duration. Given this information the total revenue, total costs, net profit and profit margin were determined across the storage period.

Theoretically, the optimum storage duration corresponds to the length of storage period that provides the highest net profit and profit margin. In this case, while profit can already be realized at day 28, it is best to withdraw the stored onion on the 112th day as it provides the highest net profit and profit margin of Php249.62 and 30.18%, respectively (Figure 4). Therefore, the optimum storage period under HTS is 112 days or about four months. Beyond 126 days there is no incentive but only losses as illustrated by negative values of net profit and profit margin.

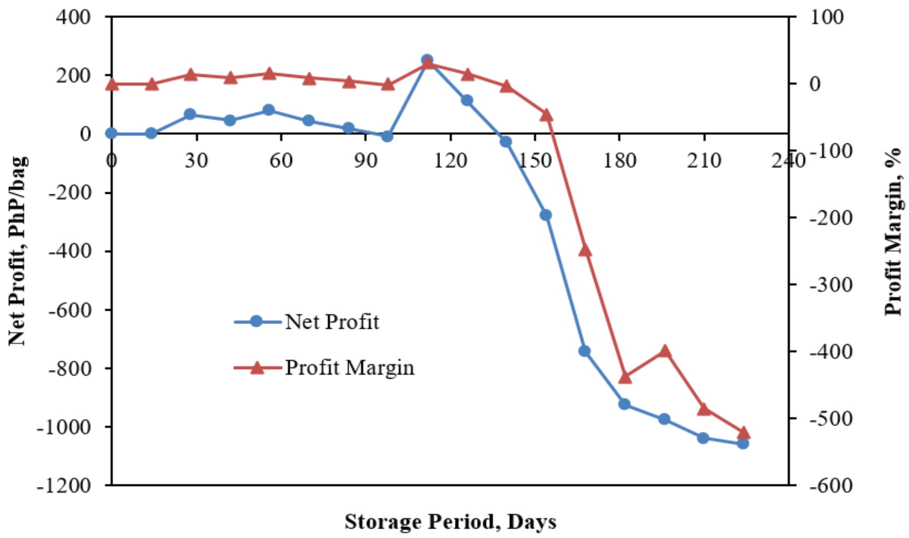


Figure 4. Net profit and profit margin from bulb onion stored in HTS given marketable bulb

Financial Viability of HTS

In the financial analysis , it is assumed that a private investor will invest on HTS and charge a corresponding storage fee. With an investment cost of Php196,500.00 corresponding to the cost of HTS structure (Table 1) charging a storage fee of Php60/bag does not provide reasonable rate of returns as indicated by the financial indicators which is almost at breakeven point. Setting the storage fee at Php70/bag suggests that the investment can be recovered in less than six years with a BCR of 1.42 indicating that there is a net returns of Php0.42 for every peso invested, and a net present value of Php81,771 (Table 2). This suggests that operating the HTS for hire should charge Php70/bag to be financially viable.

Table 1. The cost of putting up HTS structure with capacity of 7,500 kg; 60 m^2 area.

Particulars	**Quantity**	**Unit Cost (P)**	**Financial Cost (P)**
1. UV stabilized+ plastic, 4mil thick, 2.8m wide	1 roll	16,530.00	16,530.00
2. GI pipes(GI pipe standard; GI pipe bended; GI pipe structural base; sliding door set; front frame assy; back frame assy; sliding door set; deformed steel bar anchor bended	lot	79,230.00	79,230.00
3. Greenhouse accessories+: shade net tensioner; black woven shade net; strap; spring clip; plastic net clamp; fine net joint sewing; insert GI pipe nipple; turn buckle; lock strips; locking profile with zigzag wire	lot	16,530.00	16,530.00
4. Multi-layer steel rack	2 sets	31,000.00	62,000.00
5. Labor cost of installation	lot	41,040.00	41,040.00
		Total	**196,500.00**

Table 2. Financial viability of HTS under different rates of storage fee.

Storage Fee Php 60/bag				Storage Fee Php 70/bag			
Benefits		**Costs**		**Benefits**		**Costs**	
Period (Yrs)	Amount (Php)	Period (Yrs)	Amount (Php)	Period (Yrs)	Amount (Php)	Period (Yrs)	Amount (Php)
1-10	76,320	1	26,817	1-10	89,040	1	26,817
		2-4	67,932			2-4	67,932
		5	85,617			5	85,617
		6-10	3,237			6-10	3,237
Net present value=Php9,900				Net present value=Php81,771			
Benefit Cost Ratio=1.05				Benefit Cost Ratio=1.42			
Internal Rate of Return=12.9%				Internal Rate of Return=19.62%			
Payback period=6.29 yrs				Payback Period=5.79yrs			

Discount rate =12%

Financial Attractiveness of HTS from Farmers Viewpoint

Given a storage fee of Php 70/bag, will it be financially attractive from farmers viewpoint to avail of the HTS services? This was evaluated by performing partial budget analysis. In the partial budgeting, it is projected that half of the farmer's harvest equivalent to 5,300 kg will be marketed immediately to cover for the cost of production and other immediate financial obligations such as loan and need of cash. Based on survey of onion farmers majority finance their production with or in combination with loans from traders either in cash or production inputs. With interest rates ranging from 1.5 to 5.0% per month, this needs to be settled immediately within the agreed maturity period normally covering one cropping cycle equivalent to four months.

The remaining 5,300 kg will be stored in HTS in anticipation for higher price. In the application of HTS, added cost will be incurred which will comprise of 1) the cost of production of onion computed at Php 16/kg; 2) harvesting cost at Php 20/bag; 3) hauling cost from field to storage, Php 7/bag; 4) red bags 5) the labor cost for regular cleaning and mixing of stored onion, 6) opportunity cost; 7) storage fee at Php 70/bag. There is also reduced returns due to income foregone from immediate marketing of the harvest. On the other hand, the major source of added returns will be coming from the sales of onion after storage whose selling price has more than doubled in less than four months. With the use of HTS there is an incremental income Php 2,216.00 (Table 3). Given this marginal incremental income the HTS will not be patronized and therefore will not be financially viable as a private investment. Putting up the HTS, however as public investment will effectively discount storage costs and this would result to a higher incremental income of Php 61,576.00 (Table 4) which can lead to farmers adoption of HTS. With the adoption of HTS established under public investment modality there is potential to increase farmers income ranging from Php 30,788 to Php 92,364 depending on the percentage of harvest stored (Table 5).

Table 3. Partial budget analysis of storing 50%of harvest in HTS operated by a private operator charging Php 70/bag versus immediate marketing after harvest.

PROPOSED TECHNOLOGY STORAGE IN HTS STRUCTURE		VS. IMMEDIATE MARKETING	
Added Costs (A)		**Added Returns (B)**	
1. Production cost (5,300 kg[a] x Php 16/kg[b])	84,800	Sales of stored onion after 4 months (4,134 kg[d] at P42.69/kg[e])	Php 176,480
2. Harvesting cost (212 bags[c] x Php 20/bag)	Php 4,240		
3. Hauling cost (212 bags x Php 7/bag)	Php 1,484		
4. Red bags (212 bags x Php 10/bag)	Php 2,120		
5. Regular cleaning of stored onion (Php 8/bag x 212 bags x 2times/ month x 4 months)	Php 13,568		
6. Opportunity cost (4%) (84,800 x 0.04)	Php 3,392		
7. Storage fee (P70/bag/month x 4 months 212 bags)	Php 59,360		
Reduced Returns		**Reduced Costs**	
Income foregone from immediately selling after harvest	Php 5,300[f]	Nil	
Subtotal A = Php 174,264		Subtotal B = Php 176,480	

[a]10,600 kg/ha x 0.50 = 5,300 kg
[b]average production cost (PSA 2019)
[c]5,300 kg ÷ 25kg/bag = 212 bags
[d]5,300 kg x 0.78 recovery after 4 months = 4,134 kg
[e]wholesale price
[f]gross sales - production cost
(5,300 kg x Php 17/kg farmgate price) – Php 84,800 = Php 5,300

Table 4. Partial budget analysis of storing 50% of harvest in HTS treated as public investment versus immediate marketing after harvest.

PROPOSED TECHNOLOGY STORAGE IN HTS STRUCTURE		VS. IMMEDIATE MARKETING	
Added Costs (A)		**Added Returns (B)**	
1. Production cost (5,300 kg[a] x Php 16/kg[b])	84,800	Sales of stored onion after 4 months (4,134 kg[d] at P42.69/kg[e])	Php 176,480
2. Harvesting cost (212 bags[c] x Php 20/bag)	Php 4,240		
3. Hauling cost (212 bags x Php 7/bag)	Php 1,484		
4. Red bags (212 bags x Php 10/bag)	Php 2,120		
5. Regular cleaning of stored onion (Php 8/bag x 212 bags x 2times/ month x 4 months)	Php 13,568		
6. Opportunity cost (4%) (84,800 x 0.04)	Php 3,392		
Reduced Returns		**Reduced Costs**	
Income foregone from immediately selling after harvest	Php 5,300[f]	Nil	
Subtotal A = Php 114,904		Subtotal B = Php 176,480	
Estimated change in income (B less A) = **Php 61,576**			

[a]10,600 kg/ha x 0.50 = 5,300 kg
[b]average production cost (PSA 2019)
[c]5,300 kg ÷ 25kg/bag = 212 bags
[d]5,300 kg x 0.78 recovery after 4 months = 4,134 kg
[e]wholesale price
[f]gross sales - production cost
(5,300 kg x Php 17/kg farmgate price) – Php 84,800 = Php 5,300

Table 5. Incremental income from adopting HTS over immediate marketing under different modalities of establishment and operation.

Percent of harvest Stored in HTS	Modality of establishment	
	Private investment	Public investment
25	Php 1,106	Php 30,788
50	Php 2,216	Php 61,576
75	Php 3,318	Php 92,364

Economic Viability of HTS

If HTS is not financially viable as shown from the previous section, this part of the paper intends to answer the question whether HTS is a viable investment from societal viewpoint.

Using benefit cost analysis, the economic costs and economic benefits associated with the establishment and use of HTS were quantified. Direct transfer payments such as interest on loan were eliminated since it does not represent the use of real resources. Streams of costs and benefits were projected over 10 years corresponding to the economic life of the HTS structure.

The economic gains would come from the reduced storage losses. Economic costs would come from the cost of the HTS structure, depreciation, repair and replacement of parts, wage in regular cleaning of stored onion during the storage period.

The costs of HTS structure was adjusted since some parts of the HTS are traded items and adjustments were made using shadow exchange rate (SER) method. The foreign exchange premium used for the computation of SER is 20% (NEDA, 2017).

From the financial cost of Php 196,500.00, the adjusted economic cost of HTS becomes Php222,032.00 (Table 6).

Projecting the streams of costs and benefits under different levels of subsidy resulted to NPV of Php 27,757 to Php 269,719 and an ERR of 11.40% to 33.59% (Table 7). These were computed using discount rate of 10% as recommended by NEDA (2017). The reults suggest that HTS is economically viable public investment.

Table 6. Financial and economic costs of HTS structure with capacity of 7,500 kg; 60 m^2 area.

Particulars	Quantity	Unit Cost (Php)	Financial Cost (Php)	Economic Cost (Php)
1. UV stabilized+ plastic, 4mil thick, 2.8m wide	1 roll	16,530.00	16,530.00	19,836.00+
2. GI pipes(GI pipe standard; GI pipe bended; GI pipe structural base; sliding door set; front frame assy; back frame assy; sliding door set; deformed steel bar anchor bended	Lot	79,230.00	79,230.00	79,230.00
3. Greenhouse accessories+: shade net tensioner; black woven shade net; strap; spring clip; plastic net clamp; fine net joint sewing; insert GI pipe nipple; turn buckle; lock strips; locking profile with zigzag wire	Lot	16,530.00	16,530.00	19,836.00+
4. Multi-layer steel rack	Lot	62,000.00	62,000.00	62,000
5. Labor cost of installation	Lot	41,040.00	41,040.00	41,040.00
		Total	**196,500.00[a]**	**222,032.00**

Traded item+, adjusted to efficiency price using shadow exchange rate method at 20% foreign exchange premium; Source: NEDA, 2017.

Table 7. Economic analysis of putting HTS by the government under different levels of subsidies.

Full subsidy				**Partial Subsidy**			
Benefits		**Costs**		**Benefits**		**Costs**	
Period (Yrs)	Amount (Php)	Period (Yrs)	Amount (Php)	Period (Yrs)	Amount (Php)	Period (Yrs)	Amount (Php)
1-10	88,362	1-4	7,373	1-10	88,362	1	6,231
		5	27,943			2-4	16,516
		6-10	7,373			5	6,231
Net present social value=Php 27,757				Net present social value=Php 269,719			
ERR=11.40%				ERR=33.59%			

Social discount rate = 10% (NEDA, 2017)

CONCLUSION AND RECOMMENDATIONS

The result of the study suggests that HTS is a viable storage option for small-holder onion farmers who may opt to temporarily store a portion of their harvest during peak season in anticipation of better price. Given the trend in market price, storage costs and rate of storage losses under HTS, the recommended storage duration is less than four months. Putting up HTS as a private investment will be financially viable at storage fee of Php 70/bag. At this rate of storage fee however, farmers may not avail of its services because there is only marginal increase in income therefore creating little incentive for its sustained use and adoption.

While HTS is not financially attractive as a private investment, putting up HTS as public investment is economically viable with an ERR of 11.40% to 33.59% under full and partial subsidy, respectively. The economic gains would come from reduction in storage losses.

Providing HTS under public investment scheme can provide farmers incremental income of P61,576 to P92,364 by storing and selling 50-75% of their harvest providing local producers higher gains from their produce. In terms of its potential contribution in equally spreading local supply, the HTS together with cold storage facility, can help address skewed local supply during peak production. That is, HTS can be used to store onion supply for period not exceeding 4 months and beyond through the application of cold storage facility.

Based on the findings, the study recommends that the HTS be piloted at the farmers level of operation to identify the remaining technical and socioeconomic gaps that needs to be addressed for its adoption and commercialization.

ACKNOWLEDGMENT

The authors are thankful to: 1) Mz. Zeren Lucky Cabanayan for sharing her expertise in setting up experimental design and statistical analysis; 2) Mr. Rolando P. Paragas for safely transporting the project team in the project sites during the conduct of the study; 3) Dr. Renita SM. Dela Cruz for providing the technical and administrative guidance; 4) PHilMech for funding the project.

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DESIGN AND DEVELOPMENT OF CACAO HULLER USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Hull is the most contaminated part of a Cacao bean, most of the mycotoxins especially Ochratoxin A was found in this bean part. Ochratoxin A (OTA) is a toxic fungal metabolite classified by the International Agency for Research on Cancer (IARC) as a possible human carcinogen. Hence, the removal of the shell/husk will significantly reduce OTA levels in cacao products. World Health Organization (WHO) specifies that the shell and germ must be less than 5% m/m of the cocoa mass (cocoa liquor). The machine's hulling condition was optimized using Response Surface Methodology following the Box Behnken Design. Three factors were used in the study viz. air velocity at large nib blower, air velocity at small nib blower and clearance of breaking rollers. The PHilMech developed roasted cacao bean huller is a 3-1 machine. It can perform the hulling process, separate large nibs and small nibs, and sort cacao beans before roasting. It consists of 4 major components: breaking rollers, sieves, blowers and a prime mover. The optimum air velocity on large nib blower, small nib blower and clearance at breaking roller are 4.36-10.37 m/s, 2.83-7.20 m/s and 2-4 mm, respectively. The highest purity of large nib and small nib obtained were 97.13% and 95.99%. While the highest recovery index of the developed cacao huller is 0.845.

Keywords: Cacao huller, Optimization, Response surface methodology, Purity, Nib recovery index

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Submitted for review on January 7, 2022. Accepted for publication on November 8, 2022

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INTRODUCTION

Hull is the most contaminated part of a Cacao bean. Most of the mycotoxins especially ochratoxin A was found in this bean part (Codex Alimentarius, 2014). Ochratoxin A (OTA) is a toxic fungal metabolite classified by the International Agency for Research on Cancer (IARC) as a possible human carcinogen (group 2B).

The Joint Food and Agriculture Organization (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) established a Provisional Tolerable Weekly Intake (PTWI) of 100ng/kg bodyweight for OTA (PNS 2014). Hence, the removal of the shell/ husk will significantly reduce OTA levels in Cacao products. World Health Organization (WHO) specifies that the shell and germ must be less than 5% m/m of the cocoa mass (cocoa liquor).

De-hulling roasted cacao beans involve cracking and winnowing step. In the Philippines, the cracking was performed using the available corn grinder and the winnowing was done using circular baskets or "bilao." The hygienic de-hulling machine that cracks and eventually cleans the cacao nibs should be developed to increase the production and quality of the cacao nibs.

OBJECTIVE

General Objective

The general objective of the study is to design and develop Cacao huller to ensure the quality of Cacao nibs.

Specific Objectives

1. To design and fabricate Cacao huller using locally available materials; and
2. To optimize the hulling process of roasted Cacao beans using the developed Cacao huller.

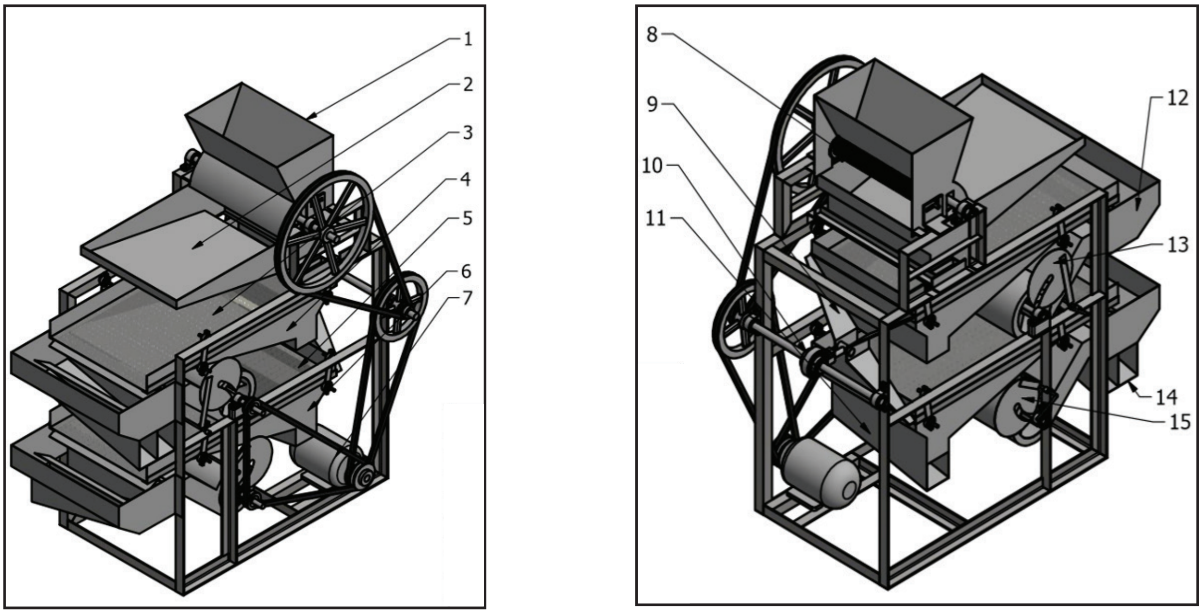
METHODOLOGY

Preparation and Collection of Samples

Cacao bean samples used in the experiment were hybrid UF18 variety collected from Farmers Development Cooperative plantation located at Cadallan, Davao City. The samples were fermented for six days using a wooden fermentary box and sundried for five days with a moisture content ranging from 6.35-6.88%. The beans were categorized as class 1A based on its average bean count ranging from 60.67-65.67 beans/100 grams (PNS, 2011). The beans were also categorized as fairly good fermented in terms of fermentation index because it consists of 42% well-fermented beans (fully brown color) based on Malaysia standards for cacao beans (Khairul B. et al., 2013).

Design and Fabrication of Cacao Huller

An AutoCAD-finished working drawing/ plan of cacao huller was prepared to serve as a guide in the fabrication of the machine (Figure 1). The machine was fabricated using locally available supplies and materials.



No.	Description
1	Cracker Chute
2	Conveying Chute 1
3	Sieve 1
4	Conveying Chute 2
5	Sieve 2
6	Conveying Chute 3
7	Prime Mover
8	Cracking Rollers
9	Sieve Holder
10	Off-centered bearing
11	Outpute Chute 3
12	Outpute Chute 1
13	Blower 1
14	Outpute Chute 2
15	Blower 2

Figure 1. AutoCAD-finished working drawing/ plan of cacao huller

Test Runs and Debugging

After fabrication, preliminary test runs were carried out to determine the operational status and possible technical problems of the machine. Repair and debugging of malfunctioned parts/ components were also conducted prior to laboratory testing.

Hulling Process Optimization

Laboratory testing and evaluation of the developed cacao huller was conducted at the PHilMech fabrication shop to establish its operating conditions. The roasted cacao beans obtained from the optimum condition of cacao bean roaster was used in the optimization experiment of roasted cacao bean huller. One kg of roasted cacao bean samples was prepared and subjected in hulling test at each hulling condition. Clearance and air velocity was set and measured before starting each hulling test. All products from the large nib and small nib outlet were collected and analyzed in the laboratory.

Purity

It defines the weight of cacao nibs free from foreign matter to the total weight of uncleaned cacao beans expressed in percentage. The collected samples from different outlets were weighed and analyzed in the laboratory. Nib, hull and other impurities were separated manually. After separation, the weight of nibs for each outlet was recorded. According to PAES 2018, the formula used to compute the purity of products collected from different outlets at each hulling test as shown below:

$$P = \frac{W_n}{W_t} x\ 100$$

where:

P = purity (%)
W_N = weight of nibs (g)
W_t = total weight of the collected product (g)

Nib Recovery Index

It was defined as the ratio of the total weight of the cacao nibs collected at cacao nib outlet to the input cacao nibs. The nib recovery index was computed using the formula as follows (PAES 2018):

$$R_i = \frac{W_{cn}}{I_{cn}}$$

Where:

R_i = nib recovery index
W_{cn} = total weight of collected nibs (at large nib outlet+nibs at small nib outlet)(g)
I_{cn} = input cacao nibs (g)

Input cacao nibs

It was defined as the theoretical amount of cacao nibs in the input dried cacao or roasted cacao beans, expressed in kilogram (kg). One hundred grams of roasted cacao beans were manually dehulled to determine the total weight of cacao nibs in the roasted cacao bean samples. The formula used as shown below:

$$I = \frac{W_m}{N} x\ W_{rc}$$

Where:

I_{cn} = input cacao nibs
W_m = weight of Cacao nibs obtained from manual dehulling
N = weight of samples (100 grams)
W_{rc} = weight of roasted cacao beans (1000 g)

Experimental Design and Statistical Analysis

The machine's hulling condition was optimized using Response Surface Methodology following the Box Behnken Design. Three factors were used in the study viz. air velocity at large nib blower, air velocity at small nib blower and clearance of breaking rollers.

The optimized condition was selected based on the result of different responses viz. purity at large nib outlet, purity at small nib outlet, and nib recovery index. The RSM was performed using the three factors with three levels (+1 high, 0 middle, -1 low); the actual values are shown in Table 1. The 15 experimental runs with its corresponding actual conditions are shown in Table 2. Analysis of variance (ANOVA) and regression analysis was used for fitting the models and also to examine the statistical significance of the model terms. The significance of all the fitted equation was determined using the F – values.

Visualization of interactions between factors and responses was achieved using the response surface plots generated using the Design Expert Software version 11 (Balasubramanian, 2012).

Table 1. Actual values of independent variables used in the experiments

Name	Units	Low	High
Air velocity at large nib blower	meter per second	4.36	10.37
Air velocity at small nib blower	meter per second	2.83	7.20
Clearance of Breaking Rollers	millimeter	2.00	4.00

Table 2. Experimental runs used in the optimization process

Run	Air Velocity at large nib blower (m/s)	Air Velocity at small nib blower (m/s)	Clearance of Breaking Rollers (mm)
1	10.37	5.015	4
2	7.365	5.015	3
3	7.365	5.015	3
4	7.365	7.2	4
5	7.365	7.2	2
6	7.365	2.83	4
7	7.365	5.015	3
8	4.36	5.015	4
9	4.36	5.015	2
10	7.365	2.83	2
11	10.37	5.015	2
12	10.37	2.83	3
13	10.37	7.2	3
14	4.36	2.83	3
15	4.36	7.2	3

RESULTS AND DISCUSSION

Description of the machine

PHilMech developed cacao bean huller is a 3-1 machine as shown in Figure 2. It can perform the hulling process, separate large nibs and small nibs, and sort cacao beans before roasting. It consists of four major components: cracker, grader, winnower and prime mover. During operation, roasted cocoa beans are fed into the cracking rollers. The cracking of roasted beans was done using the two rotating metal rollers below the cracking chute.

Cracked beans (nibs and hull) was conveyed into the perforated sheet to sort the nibs and hull according to size, large nibs and hull will remain at the upper sieve while the smaller is fall into another sieve to separate fine nibs/ hull that may bring health problem issues when blown in the surroundings. After passing into the sieve, the mixture was conveyed into the blower area. Since the hull is lighter than the nib, it will be blown outside the system, while the nibs are falling into the nib output chute.

Hulling Process Optimization

Large Nibs

Hull is the most contaminated part of the cacao beans (Codex Alimentarius, 2014). When the nibs are still mixed with the hull after the hulling process, the quality of nibs and its by-products will decrease (Nguyen 2019). The highest purity of large nibs obtained using the developed produced cacao huller was 99.63%. This is in accordance with the PNS for cacao huller with a minimum purity of 97 %.

The air velocity at large nib blower and roller breaking clearance had a significant effect on the purity of products at large nib outlets. It was expected because the fabricated machine performs nib separation before the winnowing process. Using the values of significant coefficients, the model for purity at large nib outlet of roasted cacao bean huller was established as follows:

*Purity at Large Nib Outlet = 36.0882 + 11.207 * Air velocity at large nib blower + 5.19164 * Breaker clearance + -0.560557 *Air velocity at large nib blower * Breaker clearance + -0.475437 * Air velocity at large nib blower2*

Figure 3 showed the response surface plot for purity at a large nib outlet of roasted cacao bean huller. From the plot, it can be seen that an increase in both significant factors resulted in increasing in purity at a large nib outlet. The reason for the increase of purity at large nib outlet with increasing breaker clearance because when there is a greater clearance between breaking rollers many large nibs will fall through the large nib outlet. Since the hull is less dense than nibs, an increase in air velocity at large nibs blower will decrease the amount of hull mixed with the nibs resulting from increasing in purity. The same result was found in the study conducted by Firmanto (2016), where lesser hulls found with an increase in blower's air velocity.

Figure 2. PHilMech developed cacao huller

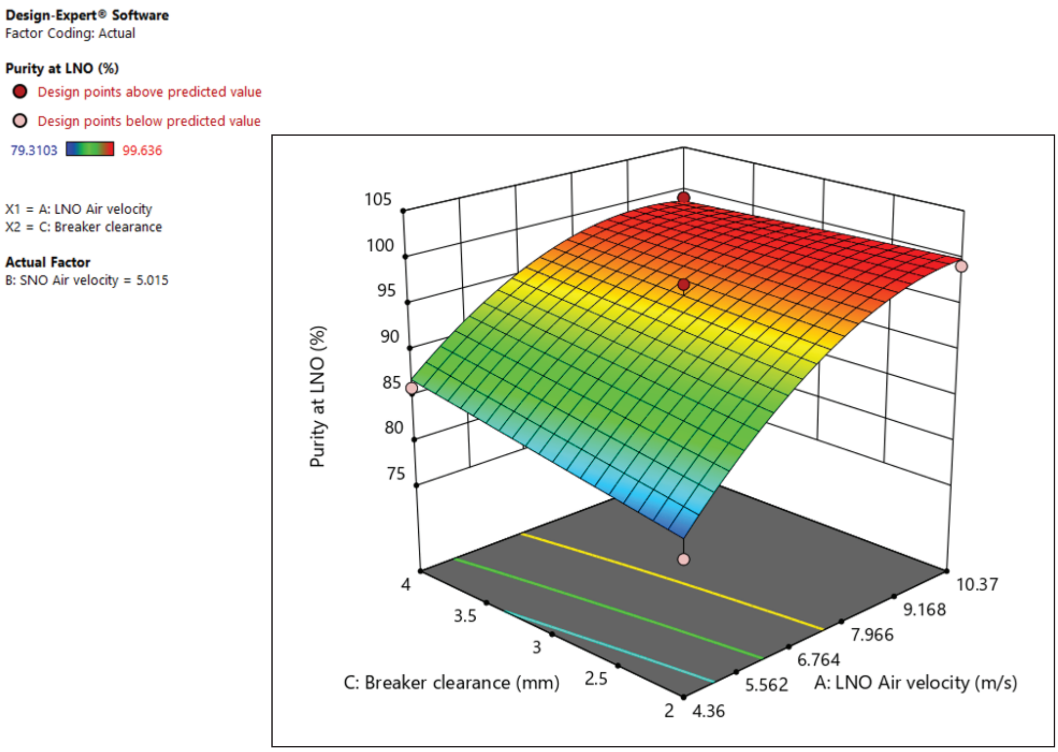


Figure 3. Response surface plot for purity at large nib outlet of roasted cacao bean huller

Small Nibs

The produced nibs and hulls with smaller dimensions were fallen into another section of the machine where another winnowing takes place. The purity of the product from this section was ranging from 90.75 to 97.51%. Due to nib separation, only air velocity at small nib blower and roller breaking clearance were expected to have a significant effect. Using the values of significant coefficients, the model for purity at small nib outlet of roasted cacao bean huller was established as follows:

$$\text{Purity at small nib outlet} = 92.2345 + 0.989588 * \text{SNO Air velocity} + -1.02428 * \text{Breaker clearance}$$

It can be seen that an increase in air velocity at a small nib blower will increase the purity of collected products from small nib outlet plots (Figure 4). On the other hand, an increase in breaking roller clearance will slightly decrease the purity of the product from a small nib outlet.

Nib Recovery Index

The obtained nib recovery index of roasted cacao bean huller obtained was ranging from 0.688 to 0.8635. The air velocity at large nib blower and breaker clearance had a significant effect on the nib recovery index. Using the values of significant coefficients, the established model as shown below.

$$\text{Nib Recovery Index} = 0.261527 + 0.0563521 * \text{LNO Air velocity} + 0.241037 * \text{Breaker clearance} + -0.00479624 * \text{LNO Air velocity}^2 + -0.0331352 * \text{Breaker clearance}^2$$

Figure 5 showed an increase in air velocity in the large nib blower decreases the nib recovery index of cacao bean huller. This significant decrease was caused by the increase in blown nibs caused by an increase in air velocity at large nib blower. While a significant increase was found in the nib recovery index as the breaker clearance increases.

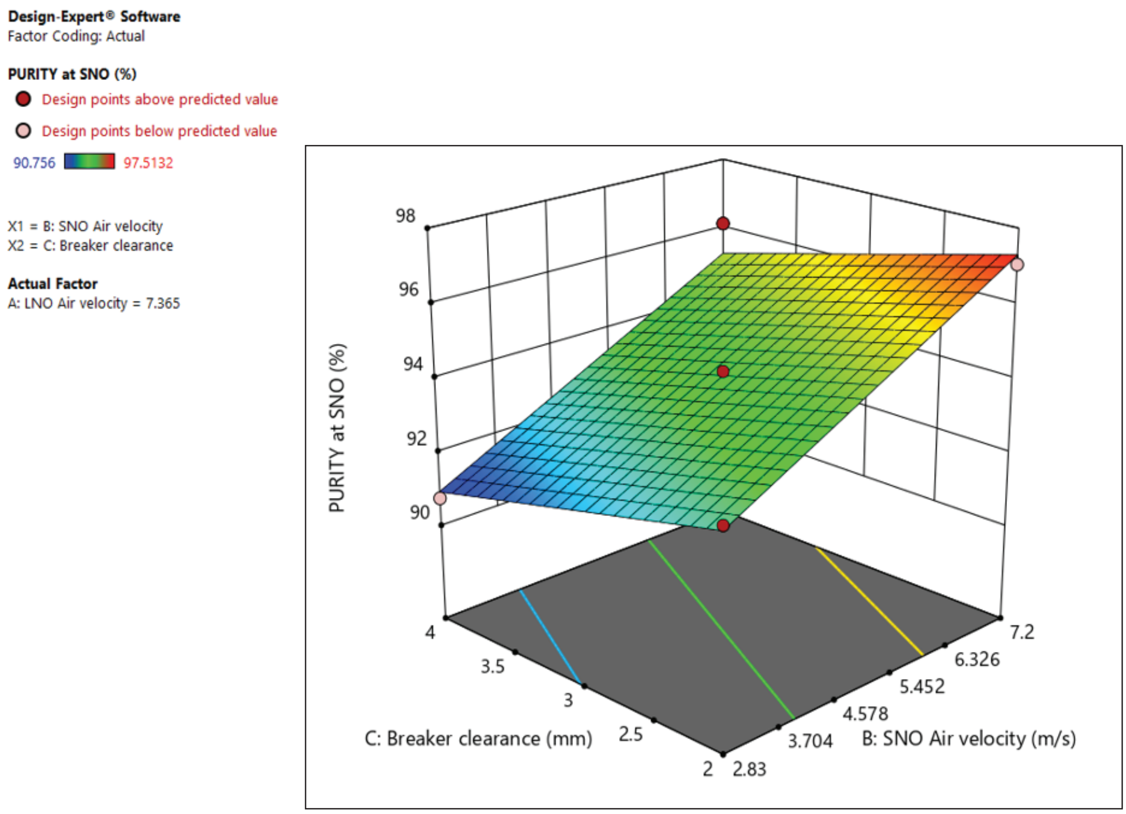


Figure 4. Response surface plot for purity at small nib outlet of roasted cacao bean huller

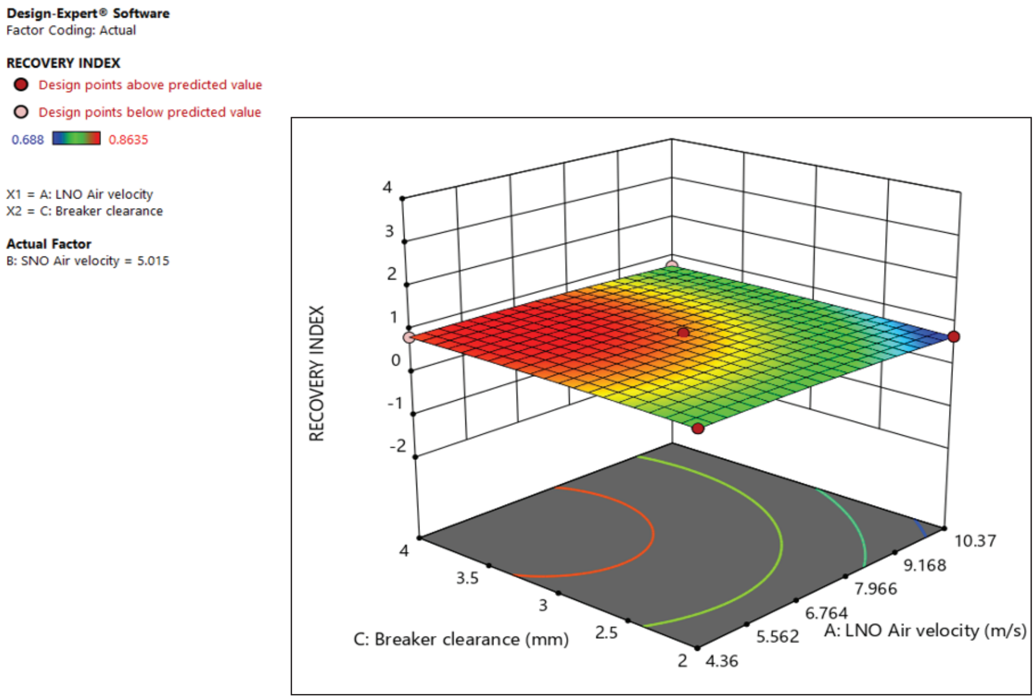


Figure 5. Response surface plot for nib recovery index of roasted cacao bean huller

Table 3. Optimization and Validation of cacao bean huller

Constraints	Goal	Lower Limit	Upper Limit	Importance	Predicted	Actual Values
Air Velocity on Large Nib Blower	In range	4.36	10.37	3	-	-
Air Velocity on Large Nib Blower	In range	2.83	7.2	3	-	-
Clearance at Breaking Rollers	In range	2	4	3	-	-
Purity at Large Nib Outlet	Maximize	79.3103	99.636	3	97.131	96.3885
Purity at Small Nib Outlet	Maximize	90.756	97.5132	3	95.991	94.884

Optimization and Validation Process

The parameters viz purity at large nib outlet, purity at small nib outlet and nib recovery index was optimized using the developed model. The maximum range was set to all responses and the condition that obtained the highest desirability was chosen as the optimum condition. After determining the optimum condition, validation was performed to check the efficiency of developed models. Table 3 shows that the optimum air velocity on large nib blower, small nib blower and clearance at breaking roller are 4.36-10.37 m/s, 2.83-7.20 m/s and 2-4 mm, respectively. The highest purity of large nib and small nib obtained were 97.13% and 95.99%. While the highest recovery index of the developed cacao huller is 0.845.

CONCLUSION

The PHilMech developed roasted cacao bean huller is a 3-1 machine. It can perform the hulling process, separate large nibs and small nibs, and sort cacao beans before roasting. It consists of four major components: breaking rollers, sieves, blowers and a prime mover. The optimum air velocity on large nib blower, small nib blower and clearance at breaking roller are 4.36-10.37 m/s, 2.83-7.20 m/s and 2-4 mm, respectively. The highest purity of large nib and small nib obtained were 97.13% and 95.99%. While the highest recovery index of the developed cacao huller is 0.845.

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OPTIMIZATION OF PECTIN EXTRACTION FROM CACAO POD HUSK

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ABSTRACT

The cacao (*Theobroma cacao L.*) pod is generally composed of husk and mucilaginous pulp surrounding the bean. About 90% of the pod is discarded as waste and remains underexploited. The pod husks are traditionally disposed to rot in the farms resulting in a waste management problem, especially because the demand for chocolate increases. An economical and environment-friendly way to deal with this is to extract pectin from the pod husks. The main objective of the study was to develop an extraction process that will provide the highest pectin yield and determine its physico-chemical properties, pectin identification test, methoxyl content, galacturonic acid content and gel strength. The cacao clones used in the study were BR 25, F1, and UF18. The husks of each clone were hydrolyzed using three different acids (i.e., citric acid, hydrochloric acid (HCl), and tartaric acid). Results showed that the highest pectin yield obtained was using tartaric acid, followed by citric acid and hydrochloric acid across cacao variety with a mean value of 12.28, 2.23, and 1.54, respectively. Likewise, the color of the extracted pectin had brown with different saturation and lightness. Tartaric acid had the lightest color, while hydrochloric acid had the darkest color. The TA-hydrolyzed pectin has the smallest particle sizes but with the highest specific surface area. This implies that the pectins mentioned above may have higher efficiency to serve as a gelling agent than other extracted pectins. The methoxyl content, galacturonic acid, and gelling strength of cacao pod husk based pectin range from 6.98%-10.82%; 86.20%-97.33% and 0.02-0.05Newton, respectively.

Keywords: Optimization, Pectin, Cacao pod husk, Hydrolysis, Acids

Submitted for review on January 7, 2022. Accepted for publication on November 10, 2022

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INTRODUCTION

Cacao (*Theobroma cacao L.*) next to coffee and tea is a very important beverage crop. It is one of the most important crops and a major agricultural commodity traded worldwide. It is considered a cash crop for growing countries and a key import for processing and consuming countries. It is also consumed as chocolate confectionery, chocolate coated products such as biscuits, ice creams, or other food products containing cocoa powder including, cakes, snacks, etc.

The World Cocoa Foundation reported that cacao's world production continues to increase in absolute terms from 3.66 million metric tons in 2007-2008 to 3.98 million metric tonnes in 2011-2012, respectively (Word Cocoa Foundation, 2012). Africa has been projected to remain the principal cocoa producer with a 73 % market share or a total of 2.8 million metric tons concentrated mainly in Ghana and the Ivory Coast. Asia and Oceania, on the other hand, contributed about 14 % of the total world production of about 623,000 tons, the bulk came from Indonesia (500,000 tons). Brazil, Ecuador, and other Latin Americas produce the remaining 13% (563,000 tons). Likewise, the cocoa price has also increased over the past five years, with an average of $ 2,342 per ton.

With the increasing consumption of chocolates worldwide, the global demand for this commodity exceeded the global supply. Netherlands is the top importer valuing to 2.076 billion USD in 2009 (FAO, 2012). Also, demand is growing more rapidly in Asia, where strong economic growth, particularly in India and China, results in more people being able to afford luxury foodstuffs such as chocolate (Sunstar, 2012).

Cruz et. al., (2012) stated that cocoa beans are primarily used in chocolate processing. However, the entire processing operation generates a substantial quantity of pod husk approximately between 70 to 75% of the whole weight of cacao or 700-750 kg of pod husk is generated for every ton of cacao fruit (With the country's current cacao production, around 3,382 metric tons of pods are wasted every year. Traditionally in practice, the cacao processors prefer to collect the cacao beans only and leaving the cacao pods in the field unutilized. This generates foul odors and becomes inoculum of black pod rot, pathogens, etc. (CocoaPhil, 2013).

The Philippines' cocoa production shows the potential for expansion since the country is ideal for cacao growing, particularly in Mindanao. As of 2015, the Philippines produced 6,023 metric tons of cacao, the bulk of the Davao Region with 3,127 metric tons (BAS, 2016). However, by 2020 and beyond, the cacao major industry stakeholders in the country are targeting to supply 100,000 metric tons of dried cacao beans to exporters of cacao products (Philippine Cacao Road Map, 2016). It is estimated that from the targeted production, the cacao industry can generate pod husks of about 633 million kg (Caparino et. al., 2016).

Utilization of these materials as a source of pectin will add value and, at the same time, address the problem of waste disposal. Pectin from cacao pod husks was characterized as high-methoxyl (HM) pectin and highly acetylated. Its degree of esterification is comparable to that obtained for mango peel pectin and yellow passion fruit rind pectin (Koubala et al., 2008; Yapo et al., 2006). Pectins are a family of complex, acid-rich polysaccharides from plant cell walls. They are widely used as gelling and stabilizing agents in the food, pharmaceutical, and cosmetic industries. Also, pectin intake has several positive effects on human health, including reduced serum cholesterol, reduced serum glucose, reduced cancer incidence, and improved immune response, amongst other effects (Gragasin et al., 2012; Wusigale and Yangchao (2020). Adi-Dako et al. concluded that cacao pectin has a requisite microbial quality and physico-chemical parameters as a multi-functional excipient in the pharmaceutical, food, and allied industries (Adi-dako et al., 2016). On the other hand, pectin's production process from the cocoa husk is economically viable for use in the food industry (Marsiglia-Lopez et al., 2017).

Utilizing three different acids (tartaric acid, citric acid and hydrochloric acid), this project aimed to develop an extraction process that will provide the highest pectin yield from three varieties of cacao pod husk and determine its physico-chemical properties, pectin identification test, methoxyl content, galacturonic acid content and gel strength.

The main objective of the study was to develop an extraction process that will provide the highest pectin yield and determine the quantitative properties of the pectin.

METHODOLOGY

Raw and Other Materials

The fully mature cacao pods were obtained from the Bud wood garden of CocoaPhil, Davao City (Figure 1). The cacao pods with a smooth surface and no signs of pest-induced pod rot or mechanical damage were collected for experiments. Then, the pods were washed and brushed to remove dirt, debris, and insects followed by soaking in 300 ppm (v/v) sodium hypochlorite for 15 mins. The disinfected cacao pods were split open using a pod's splitter to extract the wet beans. After extraction of wet beans, the pod husk was sliced and dried to reduce the moisture content down to 8-10% to facilitate the grinding process. The washing of pods until drying of slice pod husk was conducted at CocoaPhil processing center at Davao City while the grinding of dried pod husk up to analysis of pectin was conducted at BioProcess Engineering laboratory.

a b c

Figure 1. Cacao varieties: a) BR25, b) F1 and c) UF18

Pectin Extraction

The pectin extraction process for cacao pod husk followed by the optimized method is shown in Figure 2. The acid extractants used in the experiments were citric, hydrochloric, and tartaric acid solutions. The solution's final pH was set to 2.0, the heating time was 60 minutes, and the heating temperature was 100 °C.

Fully matured fruit

↓

Cleaning of fruit

↓

Removal and collection of peels

↓

Shredding

↓

Drying at 50-60 °C or until the moisture content is 8-10%

↓

Pulverization

↓

Boil the acidified water (pH 2.0)

↓

Add the dried powder in the acidified water in 1:25 ratio at 100 °C for 60 mins

↓

Cool the mixture down to 60 °C

↓

Filtration (Hand squeezing)

↓

Precipitation overnight

↓

Washing with 95% ethanol twice

↓

Oven drying until the moisture content of 8%

↓

Pulverization

↓

Store in an airtight container

Figure 2. Cacao pectin extraction process flow

References: Gragasin et al., 2012; Tang and Wong, 2011; Vriesnan and de Oliveira, 2017 and Khan et al., 2015

Pectin recovery

The percent recovery of pectin from cacao pod husk was determined by computing the pectin ratio produced with the raw material utilized.

Physico-chemical properties

The physicochemical properties of the cacao pod husks powder (CPHP) were analyzed. The analyses involved were moisture content, water activity (aw), color, pH, total soluble solids, and viscosity. The last three analyses were conducted before and after heating the sample mixture of CPHP and extractant. The initial measurement was done after the samples were agitated for 60 s and allowed to settle for 60 mins. Then, the samples were heated at 95-100 °C for 60 mins and allowed to settle and cool down. The final measurement was done when the samples had an internal temperature of 25°C.

The crude samples collected after extractions were tested first for pectin identification following the methods of USP Pharmacopoeia (USP 2005). The identified pectin samples were then tested for percent recovery, physical, and chemical properties. Cost analysis was also conducted to determine how much to produce pectin from cacao pod husk.

Color. The color was measured using a colorimeter (Erichsen Spektromaster 565-45 and Konica Minolta Inc, Chromameter CR-400). Data were recorded as L* for "lightness", a* for "+red/-green", and b* for "+yellow/-blue" with two decimal places.

Particle size (μm). The particle size of the extracted pectin was determined using the particle size analyzer (Mastersizer 3000, Malvern). Three repeatability results of dv (10), dv (50), and dv (90) per sample were recorded.

Specific surface area (m^2 kg^{-1}). The total surface area of the extracted pectin per unit of mass was determined using the particle size analyzer (Mastersizer 3000, Malvern).

Pectin Identification

Test A. About 1 g extracted sample from the CPH powder was dissolved in 9 ml distilled water, placed on a steam bath, and replaced water loss caused by evaporation. The mixture was heated until a solution was formed. The formation of stiff gel on cooling indicated a positive result of possible pectin identity.

Test B. The extracted sample was mixed with distilled water in a 1:100 ratio. To a solution of known amount, an equal volume of 95% ethanol was added. Formation of a translucent, gelatinous precipitate indicated a positive result of possible pectin identity; otherwise, gum.

Test D. The extracted sample was mixed with distilled water in a 1:100 ratio. A 5 ml of a solution, 1 ml of 2 N sodium hydroxide (NaOH) was added and allowed to stand at room temperature for 15 minutes. Formation of a gel or semi-gel suggested a possible pectin identity; otherwise, tragacanth.

Test E. From the previous test (Test D), a sample with a positive result was acidified with 3 N hydrochloric acid (HCl), shaken, and heat to boiling. The positive result showed an appearance change from voluminous, colorless, gelatinous precipitate to white and flocculent after boiling. The positive result indicated the presence of pectic acid.

Chemical Analyses

Assay for methoxy groups. Five grams of identified pectin sample was stirred with 5 ml HCl and 100 ml of 60% (v v^{-1}) ethanol for 10 mins. The mixture was poured in a sintered glass filter and washed six times with 15 ml HCl and 60% (v v^{-1}). Final washing was done using 20 ml of 95% (v v^{-1}) ethanol and dried at 105 °C for 60 mins. The dried sample was cooled, and the final weight was recorded.

Exactly one-tenth of the dried sample's total net weight, representing 500 mg of the original unwashed sample, was transferred to a 250 ml conical flask and moistened with 2 ml of 95% (v v^{-1}) ethanol. About 100 ml of carbon dioxide-free water was added, inserted the stopper, and occasionally swirled until the pectin was completely dissolved. The solution was titrated with 0.5 N (VS) with five drops of phenolphthalein TS as an indicator. The result was recorded as the initial titer (V_1). About 20 ml of 0.5 N NaOH was added, gitted vigorously, and allowed to stand for 15 mins. Approximately 20 ml of 0.5 N HCl was added and stirred until the pink color disappeared. The solution was titrated until faint pink color persisted after vigorous shaking. The result was recorded as the saponification titer (V_2). The degree of esterification, degree of carboxylation, methoxyl content, and galacturonic acid content were computed using Equations 1 to 8.

The degree of esterification (DE) was computed using Equation 1, where V_t was the total titration of the initial titer (V_1) added to the saponification titer (V_2).

$$DE = \frac{V_2}{V_t} \times 100$$

The degree of carboxylation (DC) was computed using Equation 2, where DE was the degree of esterification.

$$DC = 100 - DE$$

The methoxyl ($-OCH_3$) content of pectin was computed using Equations 3 to 6, where V_2 was the saponification titer, and 15.52 mg was the amount of methoxyl ($-OCH_3$) per 1 ml 0.5 N NaOH used in the V_2.

$$Methoxyl\ units = V_2 \times 15.52\ mg$$
$$Carboxyl\ units = DC \times 176$$
$$Total\ weight = methoxyl\ units + carboxyl\ units$$
$$\%\ Methoxyl\ content = DE \times \frac{31}{Total\ weight} \times 100$$

The galacturonic acid ($C_6H_{10}O_7$) content of the cacao pectin was determined using Equations 7 and 8, where Vt was the total titration. Each of 0.5 N NaOH used in the total titration in the assay for methoxy groups was equivalent to 97.07 mg of $C_6H_{10}O_7$.

$$Galacturonic\ acid\ content = 97.07\ mg \times V_t$$
$$\%\ Galactronic\ acid = \frac{Galacturonic\ acid\ content}{Weight\ of\ the\ sample, mg} \times 100$$

Experimental Design

The experiment was laid out in 2-factorial experimental designs. The factors were cacao variety (BR25, F1, and UF18) and extractant acids (citric, hydrochloric, and tartaric). The gathered data was analyzed using the Analysis of Variance (ANOVA) table. The significant differences among treatments were compared using Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Description of Cacao Pod Husk Powder (CPHP)

Table 1 shows the physicochemical properties of cacao pod husks powder of BR25, F1, and UF18 CPHP. F1 variety had the lightest color, followed by BR25 and UF18.

Description of Acid Extractants

Three extractant acids were used in the experiments, namely: citric (CA), hydrochloric (HA), and tartaric (TA) acid. Table 2 shows the descriptions of the physical and chemical properties of the acids.

Pectin Yield, %

Table 3 shows the average yield of pectin from cacao pod husk using citric acid, hydrochloric acid, and tartaric acid. The highest pectin yield obtained was using tartaric acid followed by citric acid and hydrochloric acid with a mean value of 12.28, 2.23, and 1.54, respectively. The lower pectin yield extracted using hydrochloric might be due to the higher pectin hydrolysis, leading to the production of soluble and smaller pectin molecules, which could not be precipitated by alcohol (Kalaphaty and Proctor, 2001). Likewise, Chandel (2015) investigated the effects of the acid, such as hydrochloric, citric, acetic, malic, phosphoric, and tartaric on the yield and physicochemical properties and characteristics of pectin from apple pomace. The results showed that tartaric acid resulted in higher yield than hydrochloric acid. This is similar to Desniorita et al. (2019) and Laksmono et al. (2018) study with a value of 2.33% and 5.29%, respectively.

Table 1. Physicochemical properties of cacao pod husk powder

Properties	BR 25	F1	UF 18
Color: L* (Lightness)	61.22 ± 0.36	62.50 ± 0.37	55.98 ± 2.27
Color: a* (+Red/ - Green)	8.19 ± 0.31	8.03 ± 0.08	8.45 ± 0.17
Color: b* (+Yellow/ -Blue)	20.00 ± 1.15	20.47 ± 0.58	19.68 ± 0.86
Moisture content (%)	9.59 ± 0.15	8.32 ± 0.08	9.35 ± 0.08
Water activity	0.62 ± 0.00	0.62 ± 0.01	0.67 ± 0.01
pH at 4% solids	5.83 ± 0.12	6.00 ± 0.17	5.80 ± 0.10
TSS at 4% solids	0.53 ± 0.15	0.20 ± 0.10	0.37 ± 0.12
Viscosity at 4% solids	1040 ± 124.90	790 ± 17.32	810 ±30.00

Table 2. Physical and chemical properties of the acids

Properties	Citric acid	Tartaric acid	Hydrochloric acid
Chemical formula	$C_6H_8O_7$	$C_4H_6O_6$	HCl
Molar mass, g·mol^{-1}	192.12	150.087	36.46
Specific gravity, g·ml^{-1}	N/A	N/A	1.18
Appearance	Crystalline white solid	White powder	Transparent liquid
Type of acid	Triprotic Organic acid	Diprotic Organic acid	Monoprotic Mineral acid
Acidity	pKa_1 = 3.13 pKa_2 = 4.76 pKa_3 = 6.40	pKa_1 = 2.89 pKa_2 = 4.40	pKa = -6.3
Acid Dissociation constant	Ka_1 = 7.5 x 10-4 Ka_2 = 1.7 x 10-5 Ka_3 = 4.0 x 10-7	Ka_1 = 1.80 x 10-3 Ka_2 = 1.03 x 10-4	

Table 3. Effect of cacao variety and acid extractant on the yield of pectin, %

Cacao Variety	Extractant			AVERAGE
	CA	HA	TA	
BR25	3.09	2.42	7.30	4.27^c
F1	2.59	1.11	14.85	6.18^a
UF18	1.00	1.08	14.68	5.59^b
AVERAGE	2.23^b	1.54^c	12.28^a	

Means not sharing letters in common differs significantly at 0.05 level of significance by DMRT.

The acceptable colors of pectin are white, yellowish, light greyish, or light brownish powder. The color of commercial apple pectin is yellowish with red specks, while the extracted pectin from cacao had brown with different saturation and lightness (Figure 3). Regardless of cacao variety, the pectin derived from TA-hydrolyzed CPHP was the brightest white with the slightest tint of red and yellow. On the other side, the darkest colored pectin was derived from HA-hydrolyzed CPHP. This indicates that the type of acid greatly influences the color of the extracted pectin. In connection with the acid type, the pectic liquor's pH also contributed to the color of the extracted pectin. As already discussed, the pH of the pectic liquor produced from HA, CA, and TA-hydrolyzed CPHP was 5.30-5.50, 3.97-4.10, and 3.77-3.87. The lower the pH, the lighter the color of the pectin became. Likewise, TA-hydrolyzed pectin was paler than the control, while CA-hydrolyzed pectin was most vivid, except for UHP. The TA-hydrolyzed pectin had the lightest color, while the HA-hydrolyzed pectin was darkest. This indicates that the acid extractant or the pH of the pectic liquor prior to ethanol precipitation greatly affects the color of the extracted pectin.

a) BR2B: Citric Acid

b) BR2B: Hydrochloric Acid

c) BR2B: Tartaric Acid

d) F1: Citric Acid

e) F1: Hydrochloric Acid

f) F1: Tartaric Acid

g) UF18: Citric Acid

h) UF18: Hydrochloric Acid

i) UF18: Tartaric Acid

Figure 3. Color of extracted pectin using different extractants and cacao variety

Pectin Identification

It is essential to conduct a pectin identification test to the acid-hydrolyzed crude extracts in order to determine if it will form a stiff gel when a 10% wv-1 solution was heated, distinguish pectin from tragacanth and other gums, and detect the presence of pectic acid, an indicator of pectin demethylation. The pectin ID tests employed followed the standard procedures of US Pharmacopeia.

Pectin ID Test A. A 10% wv-1 solution was prepared by dissolving the powdered sample in distilled water; then, the solution was heated and cooled down. The control, commercial apple pectin, was able to dissolve. This was because pectin almost completely dissolves in 20 parts of water, resulting in a viscous, opalescent colloidal solution [15]. The positive result showed a stiff gel upon cooling. This was observed in the commercial apple pectin. On the other hand, the treatments reacted differently.

Since all treatments contained insoluble impurities, it was expected that all would not dissolve in water. Some treatments became very thick and moist, while others remained watery with minimal particulate swelling. The samples treated with hydrochloric acid became thick and stiff with paste-like appearance; samples treated with citric acid became lumpy and moist, and samples treated with tartaric did not change its consistency. It was still watery, and the texture of the particulates was like sandy or gritty.

Pectin ID Test B. A 1% solution wv-1 of crude extract and distilled water was prepared. Positive control exhibited a formation of translucent, gelatinous precipitated with an equal volume of ethanol. The test revealed that all samples precipitated. This implies that all treatments were possibly pectin but not most gums.

Pectin ID Test D. The setup was prepared by adding a 2N sodium hydroxide to crude extract solution and allowed to stand at room temperature for 15 mins. The positive control showed a formation of the translucent gel. The test results revealed that all treatments formed a translucent gel in different proportions. Some samples had a high amount of gel formed, while others had a few. This indicates that all samples were possibly pectin but not tragacanth.

Pectin Test E. The samples used in Test D with a positive result were acidified with 3 N hydrochloric acid, which then formed a voluminous, colorless, gelatinous precipitate. A positive result showed a conversion of gel into white and flocculent upon boiling, indicating pectic acid's presence. However, the positive control remained gel, while all treatments became brownish and flocculent after boiling.

Particle size of the cacao pod husk based pectin

One of the most important physical properties of the pectin powder is the particle size. It has a direct influence on other properties such as dissolution, texture and feel, appearance, flowability and handling, viscosity, and packing density and porosity. The extracted pectin powder samples were dispersed in 95% ethanol and measured using the wet method. Some of the samples were cohesive and tended to stick to the surface of the container; this may result in biased measurements. In the case of commercial apple pectin, the dry method was used because it contained additives that may have reactions with different dispersants.

It is a general knowledge that the organic particles are three-dimensional objects with irregular shapes, so a single value cannot fully describe it. Thus, the various dimensions measured by laser diffraction were converted into equivalent spherical diameter because a sphere has a single dimension. This followed the Mie theory, which presumes that the particles measured are perfect spheres. As the particles flow randomly in the dispersant, the light scattering device averaged the various dimensions, producing a distribution of sizes. The volume of every particle size class was consolidated, which resulted in a volume weight distribution. The percent volume of particles within the size class was plotted as a frequency curve (Figure 4).

The smooth bell curve represented the distribution of the particle sizes that started at zero, then goes through the maximum and then returns to zero. Other supporting parameters were also noted, such as the width of distribution, specific surface area, volume mean diameter, surface area mean diameter, and volume of particles with the particle size of less than 120 µm. The TA-hydrolyzed pectins have the smallest particle sizes but with the highest specific surface area. This implies that the aforementioned pectins may probably have higher efficiency to serve as a gelling agent as compared to other extracted pectins.

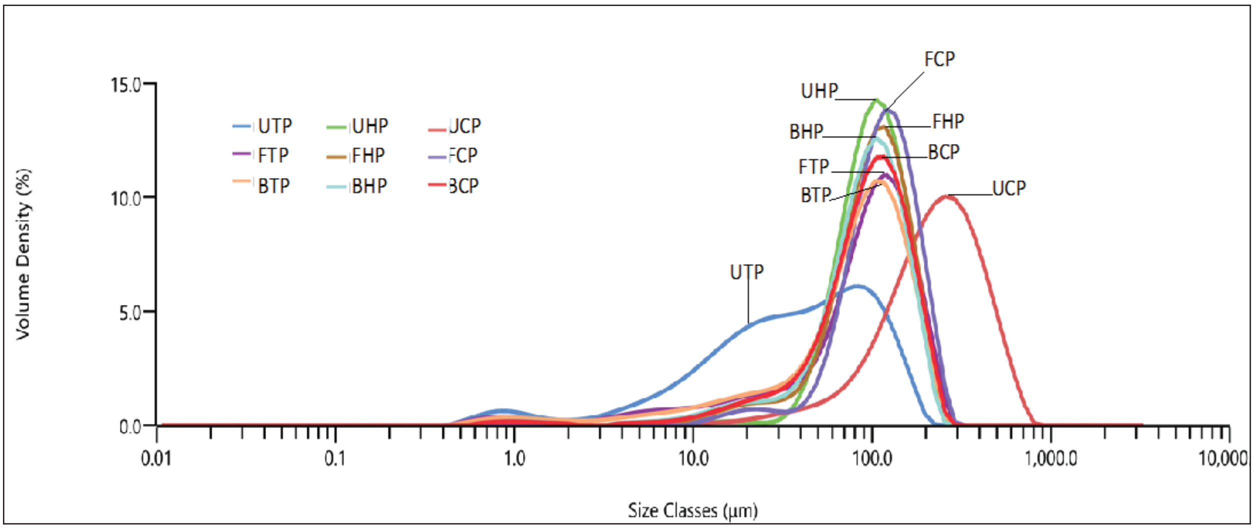

Figure 4. Frequency distribution of crude pectin particle sizes and equivalent sphere representation of the specific surface area

Chemical Analyses

Tables 4, 5, and 6 show the methoxyl content, galacturonic acid, and gelling strength of cacao pod husk-based pectin. The methoxyl content, galacturonic acid, and gelling strength of cacao pod husk based pectin range from 6.985% - 10.82%, 86.20% - 97.33% and 0.02 Newton - 0.05 Newton, respectively. The setting temperatures and time for cacao pod husk pectin range from 50.7 ˚C -63.3 ˚C and 8.08 minutes - 11.25 minutes. All pectin samples passed the USP pectin minimum specifications of 6.7% (methoxyl content) and 74% (galacturonic acid) (Tang and Wong, 2011). Likewise, the gelling strength of the standard apple pectin is 0.06 Newton.

Among the extracted pectin from cacao pod husk, the pectin extracted using tartaric acid has the highest methoxyl content (9.70%) while the pectin extracted using citric acid has the highest galacturonic acid (94.78%) content and gelling strength (0.04 Newton). Across the cacao varieties, UF18 has the highest methoxyl (8.96%) content while F1 has the highest galacturonic acid (93.30%) content and gelling strength (0.05 Newton). In the study of Pandit et al., (2015), at optimum conditions, the microwave extraction of pectin from mango peels contained galacturonic acid and methoxyl content of 57.2 % and 8.2 %, respectively.

The results of Rodsamran & Sothornvit, (2019) showed that pectin from lime peel using microwave extraction had a methoxyl content and galacturonic acid content of 8.74–10.51% and 79.29–95.93%, respectively. Another study by Kulkarni & Vijayanand, (2010) extracted pectin using passion fruit peel, their results showed pectin extracted from the dried peels had a methoxyl content of 9.6 % and galacturonic acid content of 88.2 %. When comparing to other acids, the study of Van Hung et al., (2021) stated that the galacturonic acid content of the extracted pectin from pomelo peels using citric acid was 76.5%–85.0%, acetic acid was 65.1%–68.2% and lactic acid 60.4%–65.8%. This shows that the cacao pod husk is a better source of pectin when compared to other agricultural wastes.

Table 4. Effect of cacao variety and acid extractant on the methoxyl content of pectin, %

Cacao Variety	**Extractant**			**AVERAGE**
	CA	**HA**	**TA**	
BR25	6.98	8.66	8.47	8.04^{c}
UF18	7.90	9.17	9.82	8.96^{a}
F1	7.18	8.24	10.82	8.75^{b}
AVERAGE	**7.35^{c}**	**8.69^{b}**	**9.70^{a}**	

Means not sharing letters in common differs significantly at 0.05 level of significance by DMRT.

Table 5. Effect of cacao variety and acid extractant on the galacturonic acid of pectin, %

Cacao Variety	**Extractant**			**AVERAGE**
	CA	**HA**	**TA**	
BR25	96.46	86.20	87.63	90.10^{c}
UF18	94.26	91.23	90.65	92.05^{b}
F1	93.62	97.33	88.96	93.30^{a}
AVERAGE	**94.78^{a}**	**91.59^{b}**	**89.08^{c}**	

Means not sharing letters in common differs significantly at 0.05 level of significance by DMRT.

Table 6. Effect of cacao variety and acid extractant on the gelling strength of pectin, N

Cacao Variety	Extractant			AVERAGE
	CA	HA	TA	
BR25	0.03	0.02	0.02	0.02[a]
UF18	0.05	0.03	0.02	0.03[b]
F1	0.05	0.04	0.05	0.05[c]
AVERAGE	**0.04[a]**	**0.03[b]**	**0.03[b]**	

Means not sharing letters in common differs significantly at 0.05 level of significance by DMRT.

CONCLUSION

The highest pectin yield obtained was using tartaric acid, followed by citric acid and hydrochloric acid across cacao variety with a mean value of 12.28, 2.23, and 1.54, respectively. Likewise, the color of the extracted pectin had brown with different saturation and lightness. Tartaric acid had the lightest color, while hydrochloric acid had the darkest color.

The pectin ID tests showed that all the extracts from cacao pod husk are pectin. The TA-hydrolyzed pectin has the smallest particle sizes but with the highest specific surface area. This implies that the aforementioned pectins may probably have higher efficiency to serve as a gelling agent as compared to other extracted pectins.

Among the extracted pectin from cacao pod husk, the pectin extracted using tartaric acid has the highest methoxyl content (9.70%) while the pectin extracted using citric acid has the highest galacturonic acid (94.78%) content and gelling strength (0.04 Newton). Across the cacao varieties, UF18 has the highest methoxyl (8.96%) content while F1 has the highest galacturonic acid (93.30%) content and gelling strength (0.05 Newton).

The extraction of pectin from cacao pod husks would help reduce the cost of cocoa products and add profit to the farmers and processors. Moreover, it would manage the disposal of this waste.

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EFFECT OF GAMMA IRRADIATION ON THE SENSORY QUALITY OF STORED BROWN RICE AS INFLUENCED BY AGE OF PADDY, PACKAGING AND STORAGE PERIOD

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Alma A. De Leon[4], Jessica M. Rustia[5], Geraldine G. Gantioque[6] and Joel G. Juvinal[7]

ABSTRACT

Rice is considered as one of the staple foods of the Filipinos. With the recent consumer preference to eat healthy foods, demand for brown rice or unpolished whole grain rice is increasing because of its nutritive value. However, brown rice contains high oil content that shortens its shelf-life and making the grains rancid because of the formation of free fatty acids causing rancidity and spoilage. A suitable and cost- effective treatment to preserve the quality and extend the shelf-life of brown rice is needed to assure its steady supply both in the local and international markets.

The efficacy of irradiation treatment in extending the shelf life of brown rice was investigated in the present study in terms of its sensory qualities. Low amylose rice cultivars from two weeks and eight weeks old SL7 and RC160 packed in polyethylene and super bags exposed to radiation treatments of 0.5 kGy and 1.0 kGy were used as experimental samples.

Overall, the acceptability of brown rice was affected by the following: (1) age of paddy from where it was produced wherein the two - week old paddy was more preferred, (2) irradiation dose in combination with packaging – irradiated brown rice at a dose of 0.5kGy packed in polyethylene was more preferred.

Addressing the short shelf-life of brown rice will increase its availability and utilization, thus, it will contribute to the staples sufficiency program of the Department of Agriculture wherein brown rice consumption has been identified as one of the mechanism.

Keywords: Brown rice, Gamma irradiation, Amylose, Irradiated brown rice, Sensory quality

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Submitted for review on March 23, 2022. Accepted for publication on December 19, 2022

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INTRODUCTION

Rice is considered as one of the main staple food of the Filipinos. With the recent consumer preference to eat healthy foods, demand for brown rice or unpolished whole grain rice are increasing because of its nutritive value. Brown rice is produced by removing husk or hull using mortar and pestle or rubber roll huller. Brown rice still retains its nutrient-rich bran and germ. It has a mild nutty flavor, chewable and more nutritious than white rice. Brown rice required longer cooking time or more difficult to cook than well-milled white rice and has harder texture due to the presence of fiber in the bran thus making slower absorption of liquid into the kernel.

Brown rice contained high oil content that shortens its shelf-life and making the grains rancid. The hulling process breaks up the bran cells, releasing lipase enzyme that breaks down the oil in the bran producing free fatty acids that cause rancidity and spoilage. At most, brown rice has a shelf-life of only about three to four months which could only be extended if packed with special packaging or processing (Garcia, et al., 2013). In their study, Garcia, et al., 2013 proved that combination of saturated steaming and fluidized bed drying extends the shelf-life of brown rice for up to six months.

In many countries, freezing or refrigeration and the use of air-tight containers under nitrogen atmosphere condition have been applied with varying degrees of success. However, these methods have several disadvantages with regards to their application such as reduction in the quality and prohibitive cost of treatments which add to the cost of processed brown rice. With problem on storage, producing brown rice at big volume without readily available market is too risky on the part of producers and sellers.

A suitable and cost-effective treatment to preserve the quality and extend the shelf-life of brown rice is needed to assure its steady supply both in the local and international markets. Irradiation is an effective non-thermal process to preserve food products. Roy (1997) reported that at irradiation dose of 10kGy, the nutritional quality of the food is generally unaffected. Many studies have shown that bacterial pathogens in food products are inactivated by irradiation (Follett, 2004; Ahmed, 2001). Thus, irradiation treatment can improve the microbiological safety and shelf-life of a number of food items.

Food irradiation activities in the Philippines started 35 years ago with the main thrust to accelerate commercial application of the technology. Lustre, et al. (1995) reported that irradiation has a role to play in reducing the post-harvest losses in food commodities such as onions and garlic; in ensuring the safety of food ingredients such as spices, dehydrated vegetables, herbs and frozen foods, and in providing less harmful method for the quarantine treatment of fresh fruits and vegetables for export. PNRI reported a significant reduction in microbial contamination and shelf-life extension of irradiated foods.

METHODOLOGY

Preparation of experimental samples

Low amylose content brown rice of RC 160 and SL 7 varieties having low amylose content were used as experimental samples. Rice varieties of low amylose content were selected as experimental materials because these are best for brown rice production due to their soft texture (PhilRice, personal communication). Brown rice of RC 160 variety were procured from PhilRice which were dehulled from two-week and two-month old paddy to determine the effect of the age of paddy on brown rice quality. SL 7 paddy were procured from a trader. The two-week and two-month old

SL 7 paddies were dehulled using PHil-Mech Compact Rice Huller.The produced brown rice samples were packed in polyethylene bags (PE) and superbag (SB, hermetic bag provided by Grain Pro Corp.) at 1kg/bag.

Irradiation Treatment and Experimental Design

Brown rice both from the two-week old and eight-week old paddies were subjected to gamma irradiation at doses of 0.5 and 1.0 kGy at Cobalt Radiation Facility, PNRI, Diliman, Quezon City. These irradiation doses were based on the study conducted by de Guzman et al. (1996) where they reported that irradiation dose of 1.0 kGy was sufficient for decontamination of brown rice from molds and yeasts with no significant effects on its physico-chemical and nutritional properties.

Two hundred forty packs of brown rice were packed each in polyethylene and Super Bag at 1kg/pack or a total of 480 packs comprised the whole set-up. Each 10 packs were placed in ordinary plastic sacks prior to irradiation treatment. Two sacks containing 10 packs of brown rice each were placed inside the tote box, a metallic box having the dimensions of 50 x 70 x 90 cm. These tote boxes served as container of brown rice samples during irradiation treatment. Tote boxes that contain the brown rice samples were carried by conveyor belt to the irradiation treatment chamber.

A total of 48 sacks were irradiated (24 sacks per age of paddy) for two doses (0.5 and 1.0 kGy). Co-60 was the radiation source having an activity of 80.23 kCi. Chemical dosimeters were strategically placed inside the tote boxes to monitor the minimum and maximum absorbed radiation doses (Figure 1). Non-irradiated brown rice served as control samples.

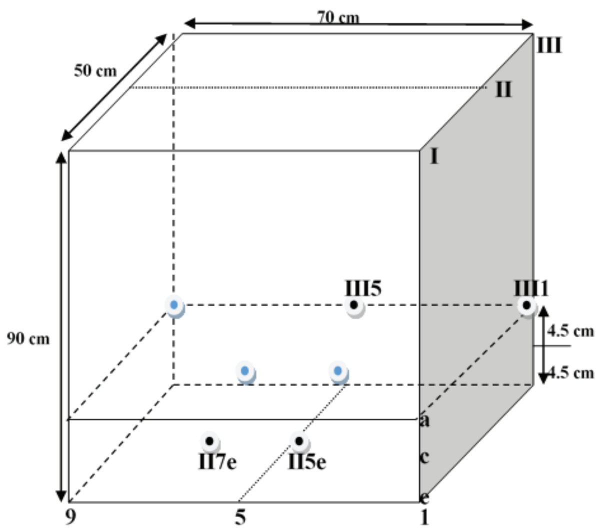

Figure 1. Position of dosimeters for dose mapping (blue and black) and actual irradiation (black) of brown rice in the tote box.

Immediately after irradiation treatment, all samples were brought back to PHilMech, Nueva Ecija and stored under ambient condition (26±1 oC). The temperature and the relative humidity in the storage room were monitored.

Sampling Design

Irradiated and non-irradiated brown rice were sampled on a monthly basis starting from the beginning of storage until eight months to determine the effect of irradiation on the quality of stored brown rice (Table 1). Split-plot Randomized Complete Block Design was used as experimental design.

The experimental design is as follows:

Table I. Experimental and sampling design.

Experiment No.	Treatment/Irradiation Dose (kGy)	Age of Experimental Stock (Weeks)	Type of Packaging	Storage Period (Months)
1	0.5	2	Regular plastic	8
2	0.5	2	Superbag	8
3	0.5	8	Regular plastic	8
4	0.5	8	Superbag	8
5	1	2	Regular plastic	8
6	1	2	Superbag	8
7	1	8	Regular plastic	8
8	1	8	Superbag	8
9	Control or Non-irradiated	2	Regular plastic	8
10	Control or Non-irradiated	2	Superbag	8
11	Control or Non-irradiated	8	Regular plastic	8
12	Control or Non-irradiated	8	Superbag	8

Consumer Acceptability Testing of brown rice samples

Brown rice were withdrawn every month and cooked for evaluation.The sensory qualities of both irradiated and non-irradiated stored brown rice were surveyed through the conduct of product testing interviews using the survey form. 50 common respondents were utilized throughout the test trials.

The responses gathered include the following:

1. Overall Acceptability (GAP) of the product
   - rating scale of 1-9

2. Intensity of liking (LIKING) for each of products sensory characteristics (Odor for positive perception, Off odor for negative perception, Tenderness, Cohesiveness, Color, Taste for positive perception, Off taste for negative perception, and Rough ness)
   - rating scale of 1-9

STATISTICAL ANALYSIS

Data were analyzed statistically by analysis of variance and comparison among means at 95% confidence level.

RESULTS AND DISCUSSION

For purposes of discussion, the following abbreviations were used:

A - Age of paddy
V - Variety
ST - Storage Time
SB - Super Bag
I - Irradiation dose
P - Packaging
PE - Polyethylene bag

Overall Acceptability

Close examination of the significant interaction of AIP x ST revealed that all treatment combinations were equally liked at T0, T2, T4, T5 T6 and T7. However, at T1, non-irradiated brown rice from eight week old paddy and packed in super bag (8 Weeks-Control-SB) was significantly the most liked. On the third month of storage (T3) irradiated brown rice from two week old paddy and packed in either PE or SB were the most liked. On the last month of storage, non-irradiated brown rice from two week old paddy and packed in SB (2 weeks-Control(C)-SB) as well as the brown rice irradiated at 0.5 kGy from two week old paddy and packed in PE got significantly the highest general acceptability mean score.

Overall, the acceptability of brown rice was affected by the following: (1) age of paddy from where it was produced wherein the two week old paddy was more preferred, (2) irradiation dose in combination with packaging – irradiated brown rice at a dose of 0.5kGy packed in polyethylene was more preferred.

Odor Acceptability

Results showed a significant interaction between A and ST ($p < .0001$) on the odor of brown rice (Fig.3). Mean odor scores at T3, T5 and T8 of brown rice dehulled two weeks after harvest were significantly higher than those dehulled after eight weeks. On the other hand, brown rice dehulled eight weeks after harvest had significantly higher mean score than those dehulled two weeks at T4, T6 and T7.

Figure 4 also revealed that A*V*I significantly ($p=0.0089$) affected the odor acceptability scores. For those brown rice dehulled two weeks after harvest, RC160 had the highest odor acceptability score if the strength of irradiation given to them was 0. 5 kGy. On the other hand, for those brown rice milled eight weeks after harvest, SL7 that received 0.5 kGy was the most liked and as the irradiation strength was increased to 1.0 kGy the two varieties were equally liked.

Age (A) at which palay was hulled significantly ($p=0.0037$) affected the mean odor acceptability of brown rice. Age however significantly ($p=0.0424$) interacted with variety. Seemingly depending on V, the effects of A on odor acceptability scores changed (Figure 5). Odor of SL7 was more acceptable when brown rice was milled eight weeks after harvest than brown rice milled after two weeks. For RC160, A of palay before hulling did not affect the odor acceptability scores. SL-7, therefore, was more sensitive to treatments than that of RC-160 in terms of odor acceptability.

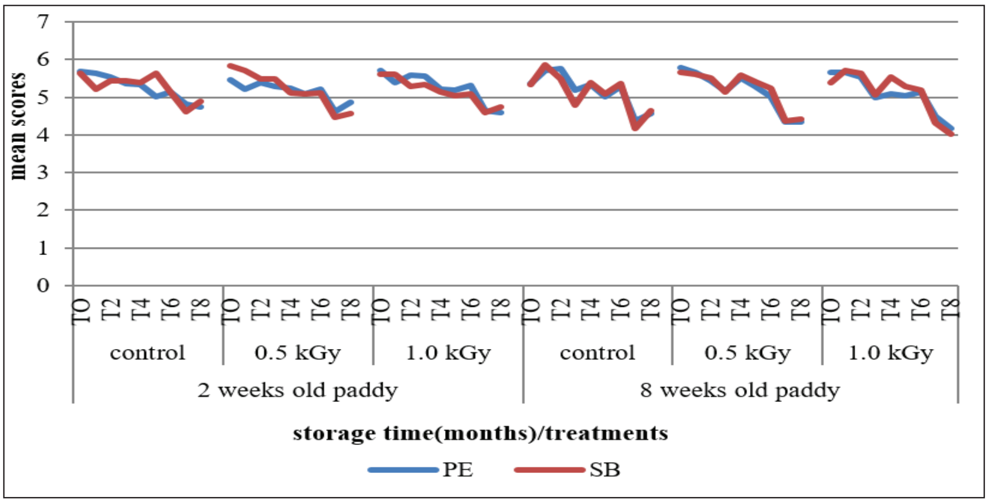

Figure 2. Overall acceptability (interaction of age, irradiation dose, packaging and storage period) of irradiated and non-irradiated SL-7 brown rice variety from 2 weeks old and 8-weeks old paddy packed in PE and SB at different storage times.

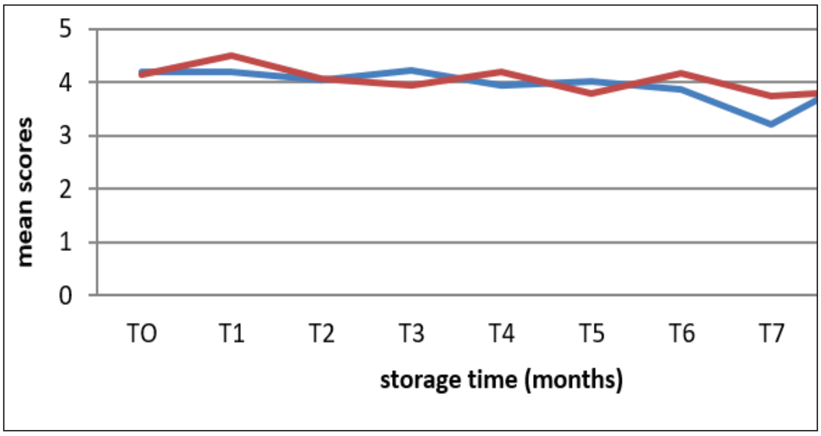

Figure 3. Effect of age and storage time on the odor of brown rice from 2 weeks and 8 weeks old paddy.

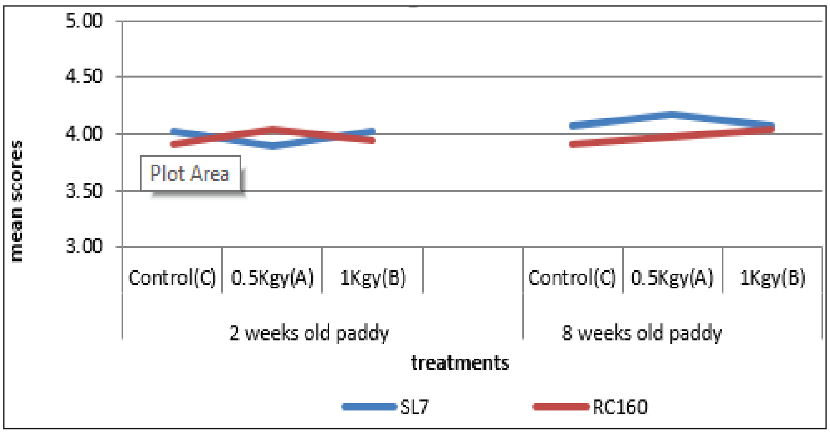

Figure 4. Effect of age (A), variety (V) and irradiation (I) on the odor of brown rice from 2 weeks and 8 weeks old paddy.

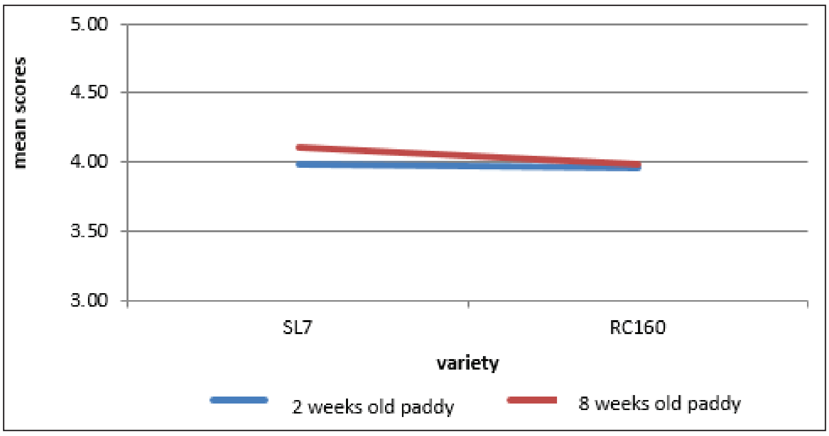

Figure 5. Effect of age (A) and variety(V) on the odor of brown rice SL-7 and RC-160 from 2 weeks and 8 weeks old paddy

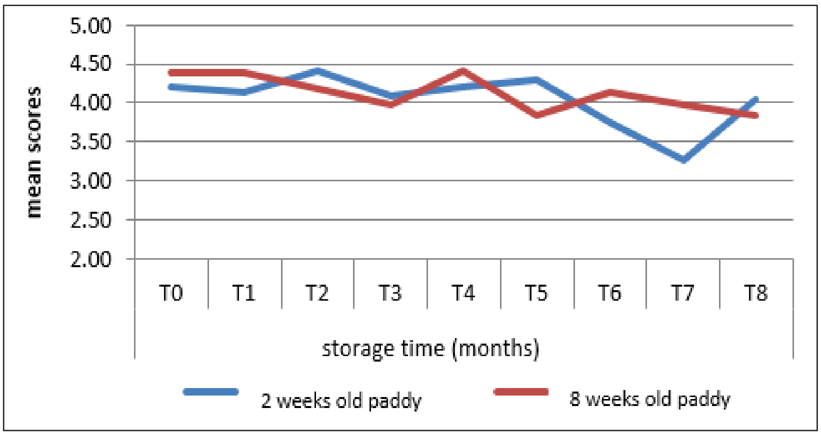

Figure 6. Effect of age(A) and storage time(ST) on the taste acceptability of brown rice from 2 weeks and 8 weeks old paddy

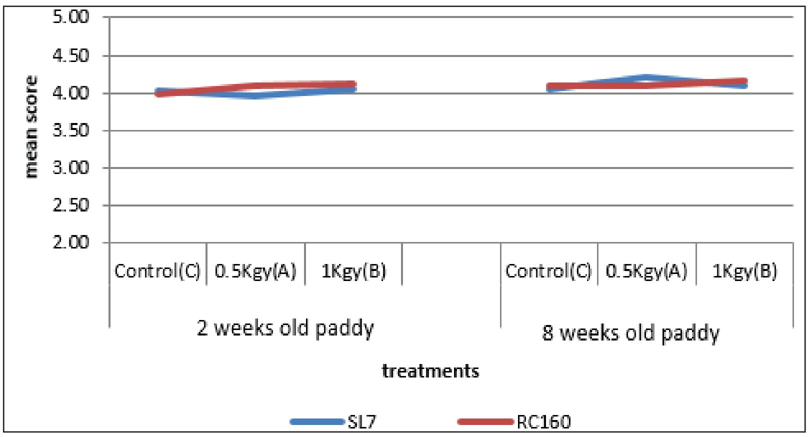

Figure 7. Effect of age (A), variety (V) and irradiation (I) treatments on the taste acceptability of brown ricefrom 2 weeks and 8 weeks old paddy

Taste

Generally, the mean scores of taste decreased with storage time regardless of the A of paddy from where the brown rice are produced. However, it was more pronounced in brown rice from eight weeks old paddy. At T1, T4, T6 and T7 mean scores of brown rice dehulled 2 weeks after harvest were significantly higher than those dehulled eight weeks after (Fig.6). On the other hand, brown rice dehulled eight weeks after harvest had significantly higher mean score than those dehulled two weeks after at T2, T5 and T8.

Taste liking scores of SL7 was at its peak when the palay was dehusked eight weeks after harvest and was given a 0.5 kGy irradiation dose (Fig.7). On the other hand, taste of RC160 was most liked when the palay was dehusked two weeks after harvest and was given a 0.5 kGy irradiation dose.

Tenderness

Comparison of means revealed that at T3, T4, and T7 mean scores of brown rice dehulled two weeks after harvest were significantly higher than those dehulled eight weeks after (Fig.8). On the other hand, at T0, T2, T5, T6 and T8 the brown rice were equally liked regardless of the age of palay.

With regards to packaging at T0, T2, T3, T7 and T8 those packed in SB were more liked than those stored in PE (Fig.9). Apparently in terms of tenderness RC 160 was more liked than SL 7 across the eight month-storage-period (Fig.10).

Brown rice that were given 0.5kGy irradiation strength, packed in SB and stored for one month was the most liked (Fig.11). Also during the last four months of storage (T5 to T8), brown rice that were given 1.0 kGy irradiation strength and were packed in SB had higher liking tenderness score than those packed in PE.

Roughness

It is apparent that throughout the eight month storage period (T0>T8), SL7 brown rice packed in PE, milled after eight weeks after harvest and treated with 1.0 kgy irradiation strength was significantly the most liked in terms of roughness while 8 weeks_RC160_Control_SB was the least liked (Fig.12). Roughness was affected by the age of paddy from where brown rice was produced, variety, radiation dose and packaging.

Cohesiveness

Comparison among means for the significant A*V*ST interaction revealed that SL7 hulled eight weeks after harvest had the most liked texture in terms of cohesiveness during T0>T3 and T6>T8 (Figure 13). At T4 and T5 SL7 hulled two weeks after harvest had the most liked.

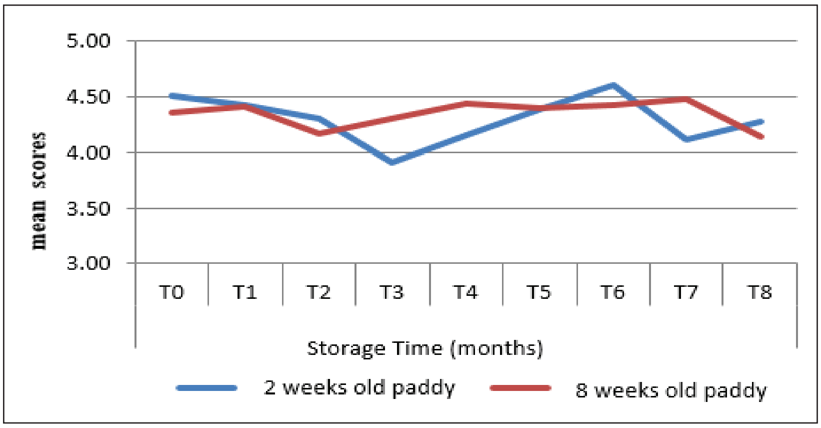

Figure 8. Effect of age (A) and storage time (ST) on the tenderness of brown rice from 2 weeks and 8 weeks old paddy.

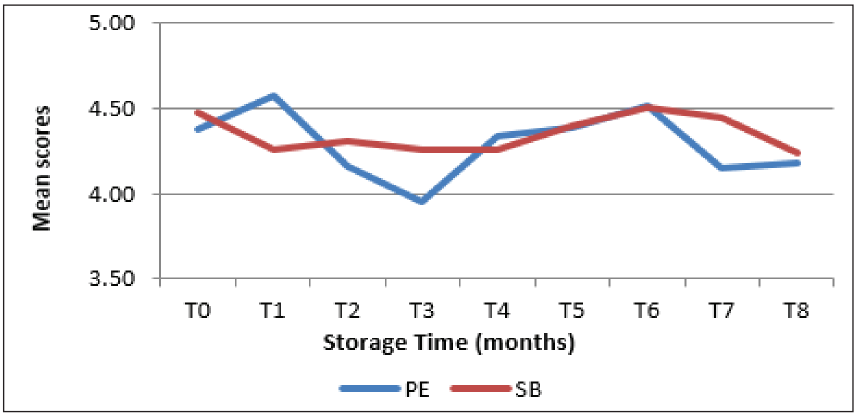

Figure 9. Effect of packaging (P) and storage time(ST) on the tenderness acceptability of brown rice packed in SB and PE.

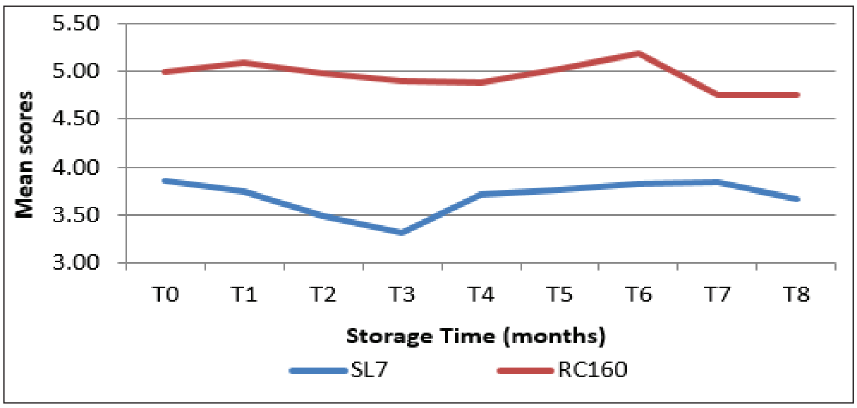

Figure 10. Effect of variety (V) and storage time(ST) on the tenderness of brown rice stored at different times.

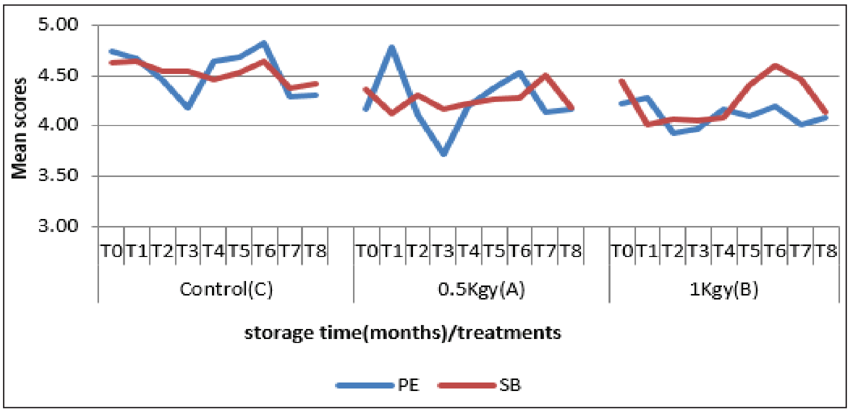

Figure 11. Effect of irradiation (I), packaging (P) and storage time (ST) on the tenderness acceptability of brown rice packed in PE and SB.

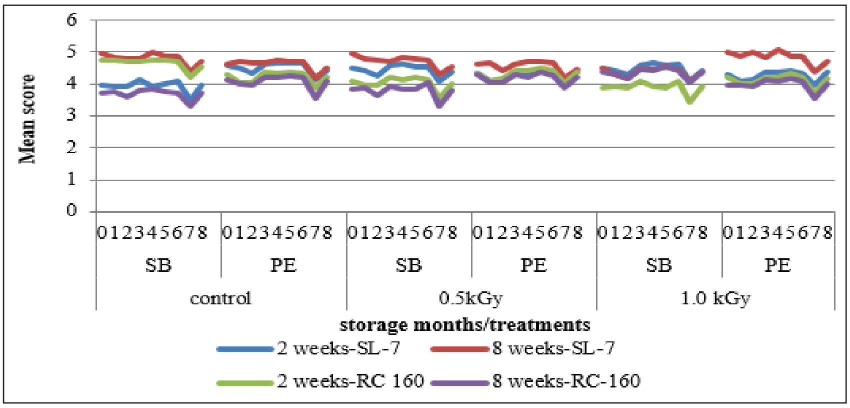

Figure 12. Comparison among means on the effect of age, variety, irradiation, packaging and storage on the roughness of brown rice from 2 weeks and 8 weeks old paddy

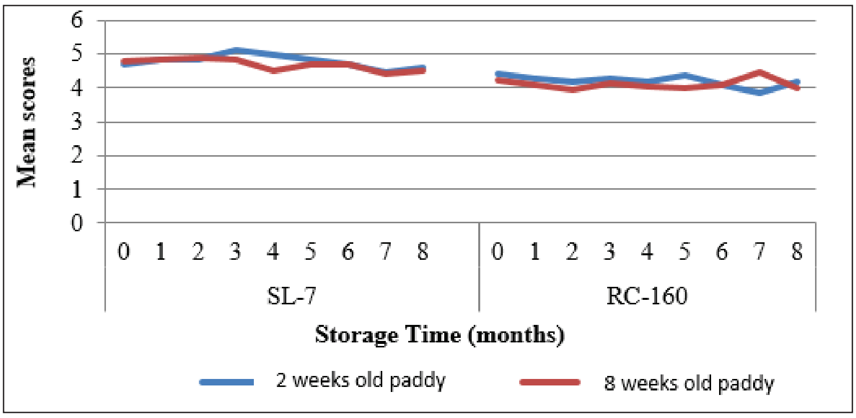

Figure 13. Effect of age (A), variety (V) and storage time (ST) on the cohesiveness of brown rice from 2 weeks and 8 weeks old paddy

Comparison among means for the significant A*P*ST interaction showed that significant differences were found at the 4th (T4) and 7th (T7) months of storage (Fig.14). During the fourth month of storage, brown rice hulled two weeks after harvest and stored in PE was significantly the most liked, and during the seventh it was brown rice stored also in PE but dehulled eight weeks after harvest.

Close examination revealed that with the exception of the initial evaluation (T0), SL7 brown rice stored in PE bags was significantly the most liked and it was not significantly different for SL7 brown rice stored in SB during the eight-month-storage period (Fig.15).

Off Taste

Comparison among means for the significant A*ST interaction showed that at T1, T3 and T6 through T8 palay milled two weeks after harvest had higher mean scores compared to those dehulled 8 weeks after harvest (Fig.16).

Seemingly RC 160 dehulled two weeks after harvest exhibited an off taste score increased with increasing irradiation strength while the score of the one dehulled eight weeks after had its highest score when treated with 0.5 kGy irradiation strength (Fig.17). For SL7 it was the brown rice dehulled eight weeks after harvest whose score increased with increasing irradiation strength.

Off Odor

Comparison among means for the significant A*ST interaction revealed that at T1, T2 T4 and T6, there were no significant difference between brown rice dehulled two weeks and eight weeks after harvests (Fig.18). However, at T3, T5 and T8 off odor mean scores of samples milled eight weeks after harvest was significantly higher than two weeks old paddy.

Seemingly difference between mean scores of SL7 dehulled two weeks and eight weeks after harvest were minimal but for RC160 mean difference between the two-week and eight-week samples widened. The eight-week RC160 brown rice mean score was higher than the 2-week RC160 brown rice (Fig.19).

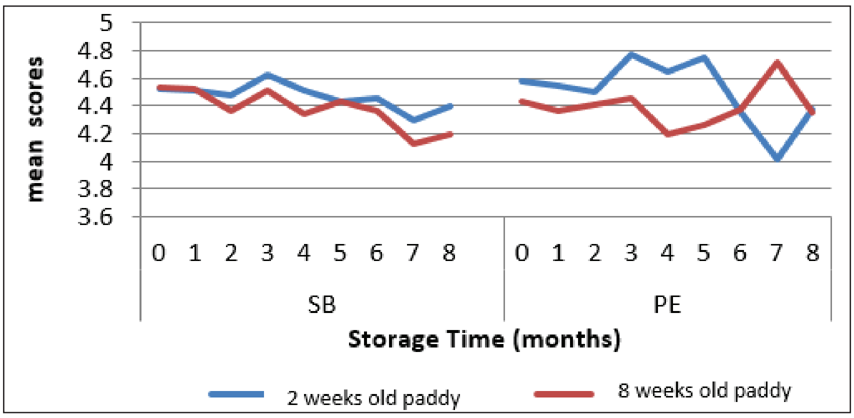

Figure 14. Effect of age (A), variety (V), irradiation (I), packaging (P) and storage time (ST) on the roughness of brown rice from 2 weeks and 8 weeks old paddy.

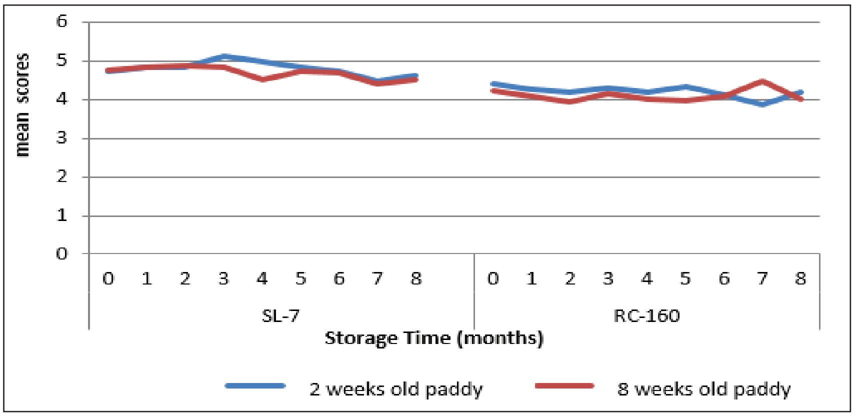

Figure 15. Effect of age (A), variety (V) and storage time (ST) on the cohesiveness of brown rice from 2 weeks and 8 weeks old paddy

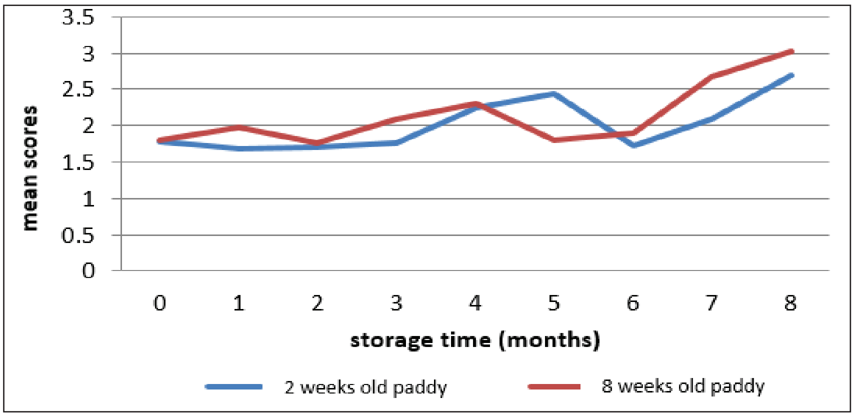

Figure 16. Interaction on the effect of age (A) and storage time (ST) on the off taste mean score of brown rice from 2 weeks and 8 weeks old paddy

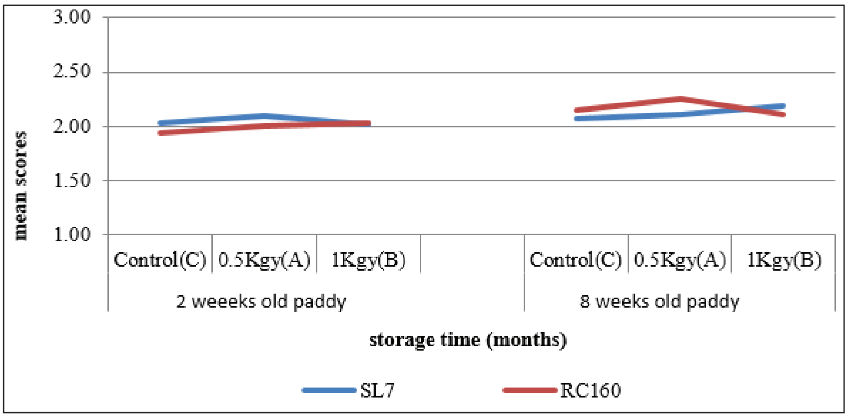

Figure 17. Effect of age (A), variety (V), Irradiation doses (I) on the off taste scores of irradiated and non-irradiated brown rice from 2 weeks and 8 weeks old paddy

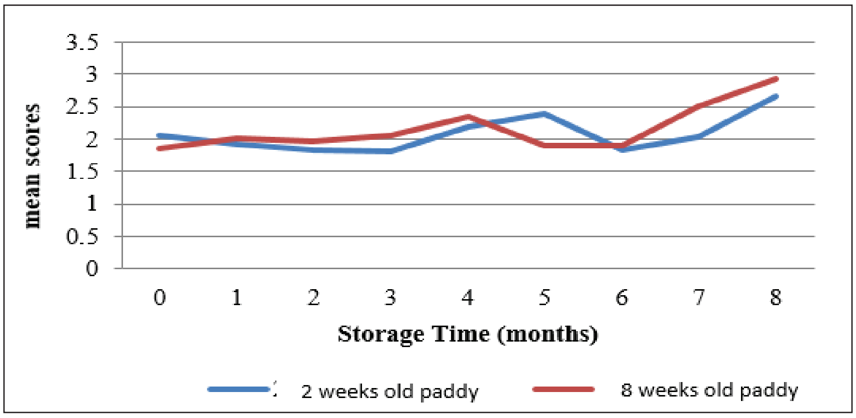

Figure 18. Interaction on the effect of age (A) and storage time (ST) on the off-odor acceptability of brown rice.

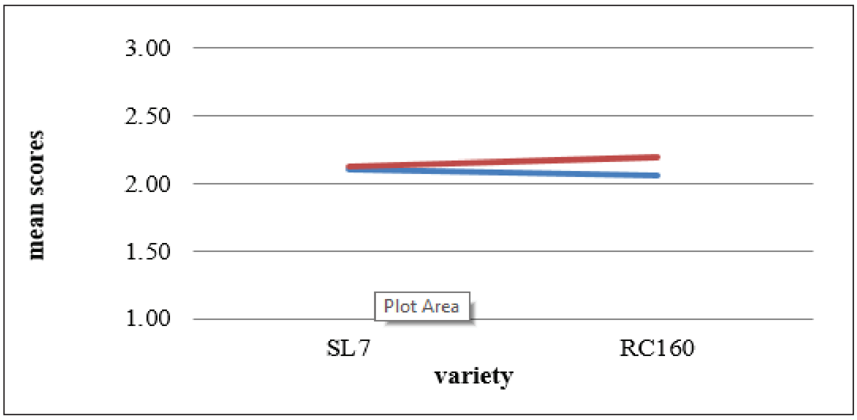

Figure 19. Effect of age and variety on off-odor acceptability of SL-7 and RC-160 brown rice.

CONCLUSION

Overall, the acceptability of brown rice was affected by the following: (1) age of paddy from where it was produced wherein the two- week old paddy was more preferred, (2) irradiation dose in combination with packaging – irradiated brown rice at a dose of 0.5kGy packed in polyethylene was more preferred.Therefore, gamma irradiation at 0.5 kGy is effective in extending the shelf-life of brown rice without affecting its sensory qualities. Hence,it is suitable in preserving the quality and extending the shelf-life of brown rice.

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