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CONTENTS

DESIGN AND DEVELOPMENT OF PROBE METER FOR MOISTURE DETECTION OF PADDY GRAINS

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ABSTRACT

A prototype unit grain probe moisture meter was developed for fast and easy moisture content measurement of paddy grains in bags while doing other quality assessment. The prototype unit was composed of a standard grain probe, a 100-gram capacity test chamber, a menu panel for control and measurement and a handle for ease of sampling. The prototype unit probe moisture meter was micro-controller based, with 7-segment light emitting diode (LED) display and adopted a capacitive sensor oscillator circuit. Results of calibration experiments showed linear relationship between frequency readings and standard oven moisture content measurements from paddy samples. Using linear regression technique, a calibration model was established with a relatively high coefficient of determination (R^2) of 0.94 and a relatively low standard error of estimate (SEE) at 0.80. Model validation tests showed excellent results with residuals mean square value of 0.68.

Keywords: Capacitance, Moisture Meter, Oscillation, Paddy, Probe

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INTRODUCTION

In grain handling, it is very critical that moisture content be within the acceptable limits. If grains contain too high moisture content, spoilage may occur and may incur significant losses. Similarly, it is important to monitor the moisture content while the grains are still in storage to avoid spoilage and further adulteration. Likewise, grain sampling is an essential and critical part of quality inspection process. (De Lucia and Assennato, 1994). A hand probe is the only effective method of obtaining a representative sample from grain at rest in a truck bin or other container (Armitage et al, 2007).

The most popular and widely-used method of determining moisture content are empirical methods. These methods do not give a true objective measurement, but estimate the degree of moisture by subjective sensory perception (touch, sight and smell) of some of the grain's characteristics. Farmers and agents are in the habit of nibbling grains, or scoring them with a thumbnail, or crushing them between their fingers, to evaluate their hardness and consistency and thereby to estimate their moisture content. Others rely on the good or bad smell that comes from a handful of grains; still others base their evaluations on the dull or sharp rattle produced by shaking a few grains in a metal box. Some assess the fluidity of the grain by trying to push an open hand into a fairly big grain mass contained in a bag or in a thick layer of bulk grain (FAO, undated).

Standard and reference methods for determining moisture content in grain and seed involve tedious laboratory procedures and long oven-drying periods and generally require more time for sample preparation. Over the years, indirect or secondary method of measuring moisture content have been studied and used to provide rapid techniques for grain and seed moisture testing (Nelson, 1991). The developed moisture meters were based on the relationship between electrical properties of moisture in the grain such as resistance and capacitance (Briggs, undated). But the more popular among the two is the use of capacitance measurements for its accuracy and reliability (Nelson et.al, 1991).

Capacitance is a measure of the amount of electric charge stored (or separated) for a given electric potential. Capacitance exists between two conductors insulated from one another. The dielectric (capacitance) technology used in many grain moisture meters is based on the principle that a functional relationship exists between the moisture content of grain and its dielectric constant. As grain increases in moisture content (water), its dielectric constant increases (Lee, 2006; Ventakesh et al, 2005). A dielectric constant can be determined by measuring the capacitance of a capacitor (two conductors or plates) with air between the plates, then measuring the capacitance with a dielectric material (e.g. grains, seeds) between the plates. The ratio of these measurements is used to determine the dielectric constant (Nelson et.al, 1991).

In the Philippines, farmers and traders rely heavily in empirical method of moisture content determination in lieu of costly, imported moisture meters. While this practice was a popular choice, this method besides being subjective, do not give a true objective measurement and is prone to abuse to the disadvantage of the farmers. In the late 1990s, PHilMech initially developed and commercialized Shega III, a capacitance-type grain moisture meter. Although the instrument showed promising results, recent studies suggest to further improve the technology to keep abreast with the latest trends in electronics and to cater to the changing needs of the grain industry. Inherent to having grains in bags; a typical grain handling operation in the Philippines is not possible without the use of a sampling probe, locally known to the industry as *buriki*. It is a tool used to collect grain samples from randomly selected bags for quality analysis including moisture content. It is also used to facilitate periodic monitoring of stored grains. (Ramos, 2014).

This project was proposed to incorporate a moisture sensing device to existing *buriki* to facilitate moisture content measurement while collecting grains for other quality assessment.

The developed technology offers an objective and faster determination of moisture content especially during field procurement. It also eliminates double handling in the traditional practice of composite sampling moisture content determination. It is made portable which can be brought handy in the field without difficulty. This technology is not intended to compete with sophisticated and highly accurate moisture meters but bids a less expensive alternative to imported electronic moisture meters ranging from US$ 450.00 to US$ 11, 000.00.

METHODOLOGY

Inventory and characterization of existing buriki

Actual identification and assessment of existing *buriki* was done in the pre-selected grain producing provinces in the Philippines. Majority of the *buriki* identified were commercially available in the local markets and mostly found in buying stations, warehouses, rice mills and hauling trucks. Size, including weight, length, diameter and thickness of the inventoried *buriki* were measured and recorded. From among the identified probes, the most popular and widely-used in terms of length, diameter and material served as basis in the development of the prototype unit grain probe moisture meter. The probe is made detachable and replaceable to cater to those with other preferences like milled rice and corn.

Design concept

Overall design considerations on the assembly of the probe moisture meter was a combination of the potential users' preferences and results of evaluation for existing *buriki* units. Consultations with pre-identified electronic companies were also explored to assess the technical and commercial viability of the design.

Figure 1 shows the CAD-generated perspective and actual prototype unit grain probe moisture meter. The fabricated prototype unit was composed of a standard grain probe attached to a 100-gram capacity test cell and grain compartment with two-parallel plates; selector and power switches for overall control and measurement and a handle for ease of sampling. It was micro-controller based with a 7-segment LED read out panel. It has a total length of about 630 mm, 42 mm width and aggregate weight of 730 grams without load. Production cost of the prototype unit was about US$ 100.00 for labor and materials.

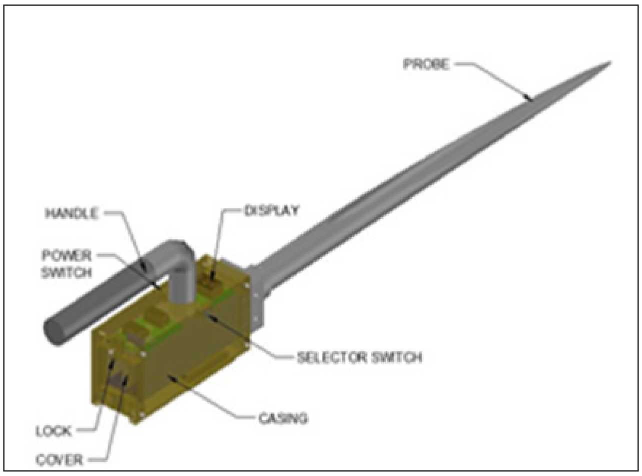

Figure 1. CAD-generated perspective view and actual prototype unit grain probe moisture meter

Circuit design

The final prototype system is described in a functional block diagram in Figure 2. Stainless steel parallel plates separated by a computed distance and encased in an acrylic plastic acts as sensor and test chamber. The grains to be measured were placed in the test chamber and acted as the dielectric medium of the parallel plate capacitor of the prototype unit grain probe moisture meter.

The prototype unit grain probe moisture meter adopted a capacitive sensor oscillator circuit. The main advantage of the oscillator was that an analog to digital converter was not required. Another key attribute of oscillators was that it produces accuracy and resolution that was much better than an analog output voltage circuit. It used precision resistors in determining the capacitance of the paddy samples placed inside the test cell.

The oscillator circuit was connected to a microcontroller to measure the frequency generated. The microcontroller would convert the frequency reading into moisture content values based on the calibration equation (Eq. 1) developed. The computed moisture content values were transmitted to an LED display. The supply voltage for the circuit was provided by a 3.7 Lithium-ion rechargeable battery.

Model calibration and validation process

Calibration equation for the prototype unit grain probe moisture meter was derived from frequency outputs measured from paddy samples with known moisture contents. Freshly harvested paddy of long and medium grain varieties were cleaned with varying moisture contents from 8% to 24%. Pre-conditioning was done by air-drying the grain samples to its desired moisture contents. Initial laboratory experiments on oven drying moisture content determination were based on PAES 203:2000 using ground samples. But due to voluminous paddy samples needed to be prepared; limited time and seasonality of paddy samples, unground samples was used for the whole calibration process based on ASAE S352.2 (2000) procedures. Pre-conditioned samples were placed in plastic containers and kept in room condition and individually withdrawn during each calibration tests.

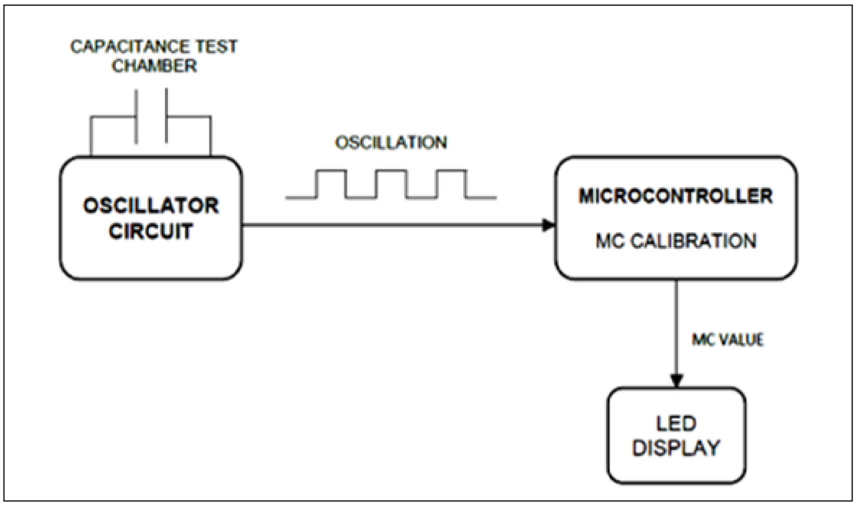

Figure 2. Functional block diagram

The developed model was later upgraded considering higher moisture contents up to 30% to address moisture content measurements during wet season harvest and as per recommendations of selected cooperators. The performance of the upgraded calibration model was tested and validated to be relatively adequate and was discussed in a separate related paper. Discussions in this paper is limited to the first prototype unit considering the moisture content up to 24%.

Shown in **Figure 3** was the actual laboratory set-up during the calibration process. Resulting frequency readings using the developed circuit were generated using an oscilloscope. A total of 238 data points from varying moisture content levels were generated from the calibration tests conducted. Based on the experimental data generated, regression analysis was conducted to develop different calibration models. The model which generated the highest coefficient of determination (R^2) was selected as the working model of the prototype system. The selected model was then used to convert frequency readings into its predicted moisture content values.

For model validation tests, a total of 77 data points were generated and subjected to comparative analysis. The moisture contents between the standard oven method and the prototype grain probe moisture meter were compared and analyzed statistically.

Moreover, effects of temperature and purity of the samples in the performance of the probe moisture meter were also observed. Since no conditioning chamber was available to vary the temperature, the observations were limited to actual temperature readings at the time of each testing. Density differences were tested for moisture content readings from long and medium sized paddy samples. No significant effect in the performance of the grain probe moisture meter was however, observed. A simple, inverted-cone grain spreader was designed for equal distribution of grain samples before it goes through the test chamber.

Figure 3. Calibration tests conducted for grain probe moisture meter

RESULTS AND DISCUSSION

Physical attributes of existing probes

There were two types of probes used in the field. The smaller ones which were intended for milled rice and the other type were used for both paddy and corn. The type of probe used for both paddy and corn came in various sizes – ranging from 422 mm to 825mm in length and from 20.4 mm to 35.4mm in diameter, depending on its purpose and preferences of agents. Weight varied from 300 grams to 750 grams without load. The tool can collect from 25 grams to 75 grams of grains per insertion and was always dependent on the manner and depth of sampling. Summary of physical attributes are summarized in **Table 1.**

Calibration tests

The calibration data points generated for paddy of mixed long and medium grain varieties during the laboratory experiments are shown in **Figure 4**. Results showed that frequency values increased as the moisture content values of paddy grains using oven method decreased. The relationship appeared linear over the data points generated. Using linear regression methods, calibration models were generated and the best calibration model was established and is shown below:

$$MC = 49.64 - 0.1204\,F \;\ldots \qquad (1)$$

where:

MC is the moisture content, %

F is the frequency measured, kHz

The equation had a relatively high coefficient of determination (R^2) of 0.94 and with a relatively low standard error of estimate (SEE) at 0.80 ranging from 0.58 to 0.93. As shown in the figure, it can be said that the calibration equation as fitted over the frequency and moisture content data points is relatively adequate.

Validation Tests

Laboratory tests using new set of paddy samples were done to validate the performance of the prototype grain probe moisture meter.

Presented in **Figure 5** is the validation data points for paddy generated from 77 readings of paddy grains with varying moisture contents. The tests yielded a relatively good fit over data points. This was an indication that the calibration model established for the prototype grain probe moisture meter is relatively adequate in predicting the moisture content of paddy grains.

Analysis of residual plot shown in **Figure 6**, indicated that the residual values are randomly distributed with a mean square value of 0.68.

Moreover, comparison of moisture content measurements between oven method and prototype unit grain probe moisture meter using *t*-Test, showed no significant difference at 5% level of significance with *P* value of 0.32.

Table 1. Physical dimensions of existing probes used for paddy and corn grains.

Parameter	Mean	Range	
		Min	Max
Probe Dimension			
Length, mm	623.5	422.0	825.0
Depth, mm	415.0	310.0	520.0
Diameter, mm	27.9	20.4	35.4
Weight, g	450	300.0	750.0

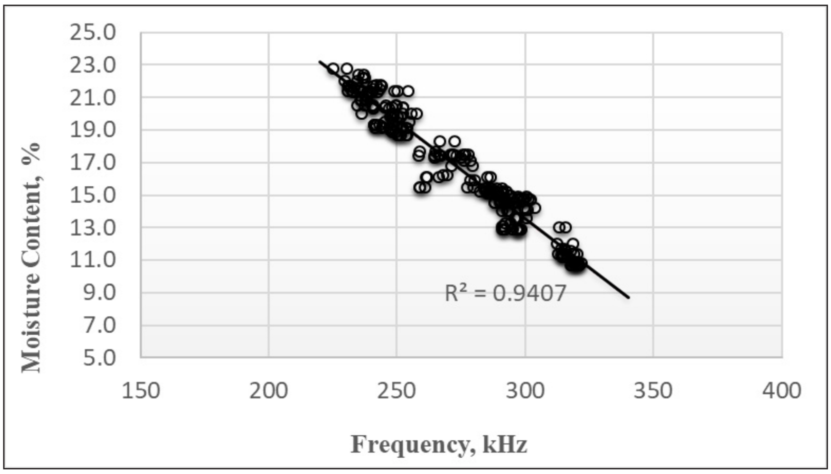

Figure 4. Calibration data generated from the laboratory experiments of paddy grains

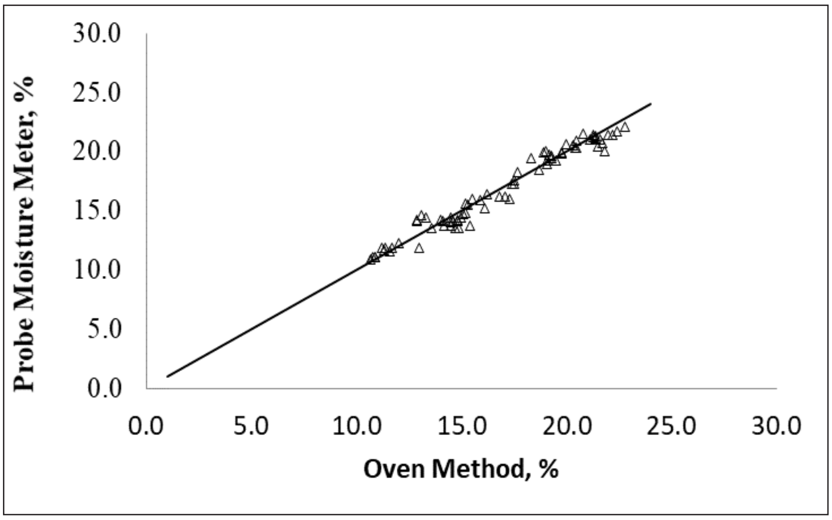

Figure 5. Validation data generated from the laboratory experiments of paddy grains

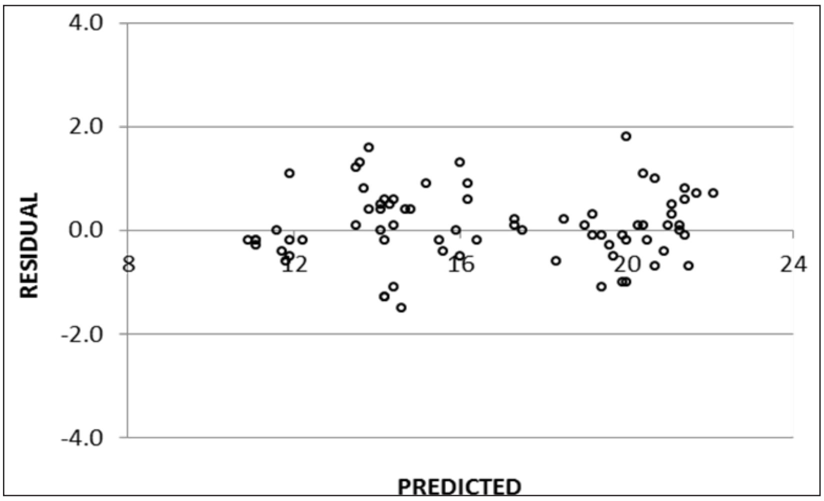

Figure 6. Residual predicted mositure content values for paddy grains

Effect of temperature and purity on the performance of the prototype unit grain probe moisture meter

A test was conducted to evaluate the effect of temperature to the performance of the grain probe moisture meter. With ambient temperature readings ranging from 21.8°C to 32.7°C, performance of the grain probe moisture meter was not significantly affected as indicated in the regression analysis conducted between temperature readings and mean error of measurements.

Results showed a very low R^2 of 0.20 indicating very low relationship between temperature and mean error. Likewise, a *P* value of 0.28 was computed indicating no significant relationship between temperature readings and mean error of measurement of moisture contents at 5% level of confidence. These findings were consistent to the observation of Stubsgaard (1997) that no temperature correction might be needed within the temperature range of 10°C to 30°C.

Performance of the grain probe moisture meter was also tested with different levels of purity of paddy grains. Actual samples measured for moisture content readings were the samples used for the test. Spread of data generated for 35 measurement points as shown in **Figure 7** indicated an acceptable level of performance for purity level ranging from 94 % to 100%. The spread of mean error of measurement against temperature readings were all within the acceptable mean error of 0.8% based on standards and tolerances set by the National Institute for Standards and Technology (NIST, 2015). A more consistent finding, however was observed at purity levels of 99% and higher. The observed mean error that tended to be negative values at lower purity range and positive values at higher purity range seemed to indicate significant effect but results of regression analysis has proven otherwise with an R^2 of 0.03 and *P* value of 0.32.

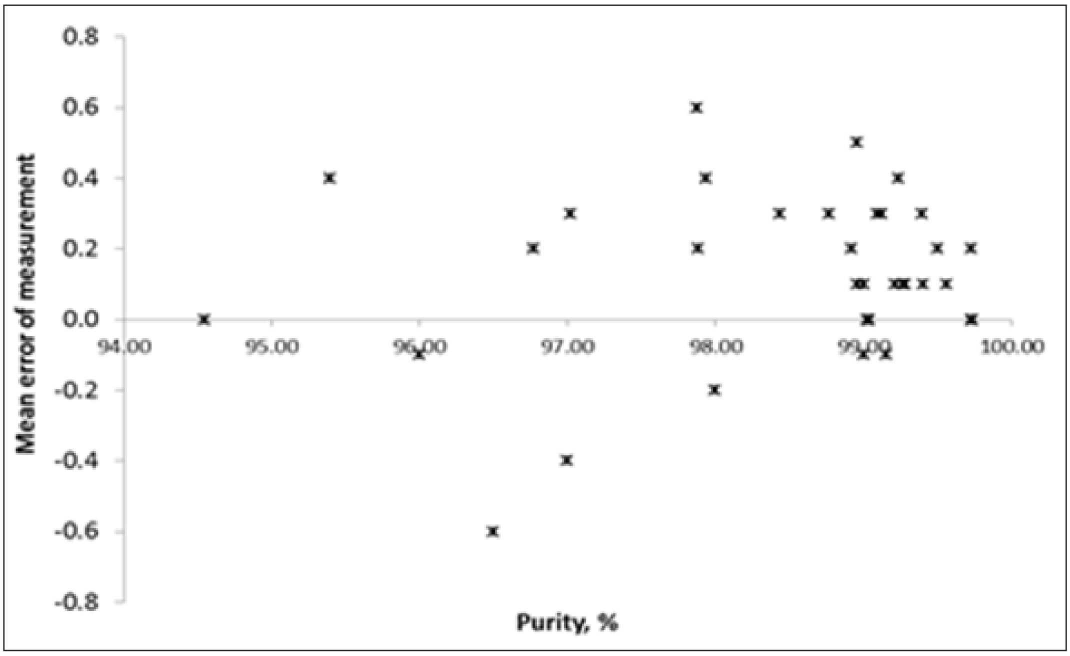

Figure 7. Effect of paddy purity level against mean error of measurement

CONCLUSION AND RECOMMENDATIONS

A frequency-based grain probe moisture meter was developed using capacitive sensor oscillator circuit. The prototype unit grain probe moisture meter can measure moisture content of grains, specifically paddy. Calibration experiments showed very good linear relationship between frequency and moisture content with relatively high coefficient of determination (R^2) of 0.94 and a relatively low standard error of estimate (SEE) of 0.80 were established. Model validation tests showed excellent results with residuals mean square value of 0.68.

The developed prototype unit was provided with a detachable grain probe base, a 100-gram capacity test chamber which serves as capacitive sensor, toggle switches for power and grain type selector and a handle for ease of sampling. The prototype unit grain probe moisture meter was micro-controller based, with 7-segment LED display where moisture content readings are displayed. The supply voltage for the circuit was a 3.7V Lithium-ion rechargeable battery. The prototype unit grain probe moisture meter has the advantage of simultaneously performing grain sampling and moisture content determination.

It is recommended that the prototype unit grain probe moisture meter be tested for other grains like corn, legumes and other seeds at various level of operations of the grain industry.

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SIMULATION MODEL FOR DRYING AND COOLING OF ROUGH RICE IN FIXED-BED

Romualdo C. Martinez[1]

ABSTRACT

A simulation model for drying and cooling of rough rice in fixed-bed was developed. It was based on Thompson model for high temperature drying of corn, but in this study, thermo-physical properties and thin-layer models for rough rice were employed. Simulation of drying process assumed thermal equilibrium between grain and air, while moisture transfer was governed by a thin-layer drying equation. On the other hand, simulation of cooling process assumed both thermal and moisture equilibrium. The simulation model was developed into user-interactive software that would run under Microsoft Windows desktop environment. The software allowed user to input simulation conditions, i.e., initial grain moisture content and temperature, initial weight, bed dimensions, airflow rate, and air temperature and relative humidity. Non-uniform grain and air conditions could be imported from Microsoft Excel. Stopping criterion for simulation could be set in terms of target moisture content or drying time. The software provided option to perform grain mixing and reversal of airflow. Simulation results were presented in terms of drying or cooling curves and summary tables and could be exported to Microsoft Excel, Word, PowerPoint and other Microsoft Windows desktop applications. It is recommended that the accuracy of the model be validated by actual grain drying and cooling experiments.

Keywords: Cooling, Drying, Grain, Rough rice, Simulation

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INTRODUCTION

Drying and cooling are the most often used processes to preserve grain quality. Freshly harvested grains deteriorate rapidly if not immediately dried or cooled. In the Philippines, use of heated air grain dryers as alternative to sun drying is rapidly increasing. Also, grain processors are beginning to appreciate the benefits of storing grain in silos with refrigerated cooling systems.

There are many factors that need to be considered when analyzing and de-signing grain drying or cooling systems. These factors include drying or cooling air temperature and relative humidity, airflow rate, initial grain moisture content and temperature, grain depth, bin dimensions, target moisture content and drying or cooling time. Conducting full-scale experiments considering all these interacting factors would be difficult, time consuming and costly, if not impractical.

Mathematical modeling and simulation offers helpful support to analyze drying or cooling system. Through simulation, alternative grain drying or cooling scenarios can be analyzed rapidly, eliminating infeasible solutions and identifying potential ones that can be subjected to further investigation by performing actual drying experiments. Thus, process of analyzing drying or cooling systems could be accelerated and number of drying and cooling experiments reduced (Brooker, 1992; Bala, 2016).

Modeling and simulation of grain drying and cooling processes is mathematically complex. Drying and cooling involve simultaneous heat and mass transfer processes described by equations. Solutions to these equations can-not be derived completely by explicit or analytic methods, but will require iterative numerical solutions. This study developed a simulation model for drying and cooling of rough rice in fixed-bed and its user-interactive software implementation as Microsoft Windows desktop application.

METHODOLOGY

Modeling and Simulation of Drying and Cooling Processes

The drying and cooling processes of rough rice in fixed-bed were modeled and simulated as follows:

1. Assume that drying or cooling are processes that occur in series of short time steps;

2. Divide grain bed into a number of thin layers;

3. During each time step, starting from first layer at air inlet, air passes from layer to layer until exhausted from grain bed;

4. Heat and mass balance equations determines the grain moisture content and temperature changes that occurred in a given layer as well as changes in air temperature and humidity

5. Exhaust air condition from one layer is used as inlet air condition to next layer

6. Layer by layer calculations are made over entire bed over series of time steps until stopping criterion of drying or cooling process is reached.

In Step 4 the Thompson (1968) and Thompson (1972) models were adapted to simulate heat and moisture transfer processes. These models were originally developed for corn. In this study, thermo-physical properties and thin-layer models for rough rice were employed.

Shown in Figure 1 are basic input and output parameters of the thin layer model of Thompson (1968) and Thompson (1972). Inlet air with temperature, T_o, absolute humidity, H_o, and superficial air velocity, v, passes through the thin layer for a time interval, Δt. The thin layer had an initial moisture content, M_o, and temperature, G_o. Moisture was transferred between grain layer and air resulting to change in final moisture content, M_f, and absolute humidity, H_f, of exhaust air.

Temperature of exhaust air, T_f, was changed in proportion to change in grain temperature, G_f.

Thompson (1968) model assumed thermal equilibrium between air and grain during each time step, while moisture transfer rate was governed by a characteristic thin-layer drying equation. It is the model used to simulate the drying process. Thompson (1972) model on the other hand assumed both thermal and moisture equilibrium. It is the model used to simulate the cooling process.

Thompson (1968) Model

In Thompson (1968) heat and mass balance processes in a thin layer drying were modeled as follows:

1. Sensible heat balance was performed to determine equilibrium drying air temperature, T_e. Heat and mass balances were presented in kg^{-1} dry air basis,

$$c_a T_o + H_o (h_{vo} + c_v T_o) + C_g G_o = c_a T_e + H_o (h_{vo} + c_v T_e) + C_g G_e \qquad (1)$$

where:
T_o - inlet air temperature, °C
T_e - equilibrium drying air temperature, °C
G_o - initial grain temperature, °C
G_e - equilibrium grain temperature, °C, equal to T_e
H_o - inlet air absolute humidity, kg kg_{-1}
c_a - specific heat of dry air, 1.005 KJ kg^{-1} $°C^{-1}$
c_v - specific heat of water vapor, 1.850 KJ kg^{-1} $°C^{-1}$
h_{vo} - latent heat of vaporization of free water at reference temperature, 2500.8 KJ kg^{-1} $°C^{-1}$
C_g - specific heat of grain, converted to KJ kg^{-1} air $°C^{-1}$

The value of C_g was calculated from following equations,

$$C_g = c_g R \qquad (2)$$

$$R = \frac{\rho_g \, \Delta x \, (1 - M_{owb}/100)}{60 v \, \Delta t \, \rho_a} \qquad (3)$$

where:
c_g - specific heat of grain, KJ kg^{-1} $°C^{-1}$ (Table I)
R - dry matter to dry air ratio for each layer and time step, kg kg^{-1}
M_{owb} - initial moisture content of grain bed, % w.b.
ρ_g - bulk density of grain, kg m-3 (Table I)
ρ_a - density of air, kg m-3 (Table II)
Δx - depth of thin layer, m
Δt - time step, min
v - superficial air velocity, m s^{-1}

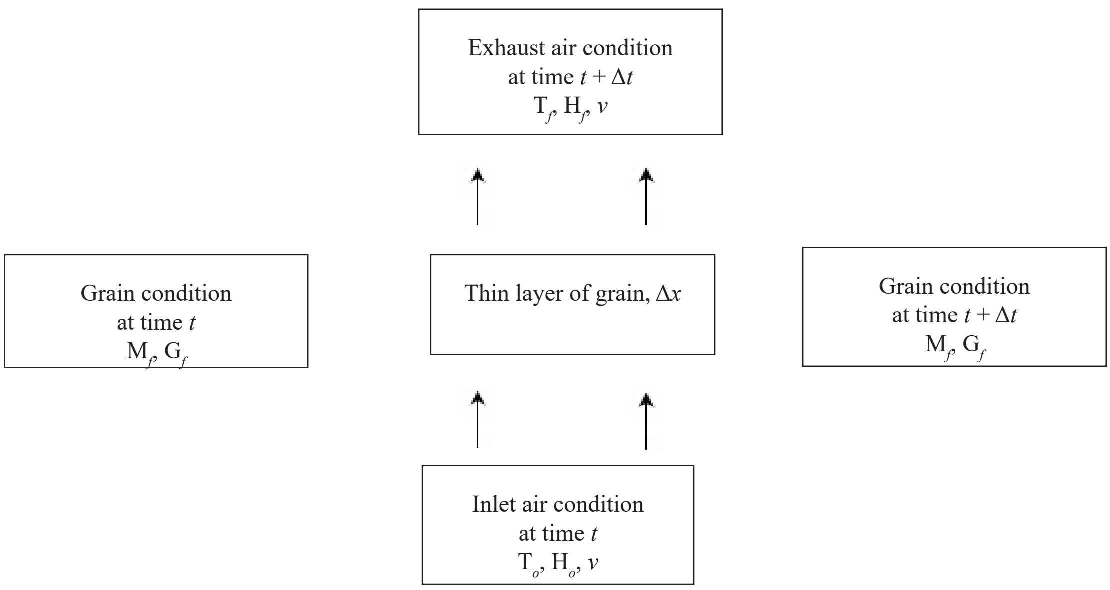

Figure 1. Input and output parameters of Thompson (1968) model.

Equations for grain and moist air properties are given in Table 1 and Table 2.

2. Solving equation (1) for T_e,

$$T_e = \frac{(c_a + c_v H_o)\, T_o + C_g G_o}{c_a + c_v H_o + C_g} \tag{4}$$

3. Equilibrium moisture content, M_e, of thin-layer is determined by first calculating relative humidity, RH_e, that corresponds to equilibrium temperature, T_e, and absolute humidity, H_o, (see Table 2 for moist air properties),

Table 1. Grain properties

Property	Equation
Thin-layer drying (Martinez, 2002)	$MR = \frac{M_f - M_e}{M_o - M_e} = exp(-kt^n)$ (5) where: $k = exp(-13.882+2.3712ln(T_o) - 0.5020ln(H_o))$ (6) $n = \exp(1.7203-0.30364\ln(T_o) + 0.26821\ln(H_o))$ (7)
Equilibrium RH (ASABE, 2016)	$RH_e = 100\,[1 - \exp(-0.000035502(T_e + 27.396)\, M_e^{2.31})]$ (8)
Bulk density (Wratten , 1969)	$\rho_g = 519.4 + 5.29\, M_{owb}$ (9)
Specific heat (Wratten , 1969)	$c_g = 0.921 + 0.0545\, M_{owb}$ (10)
Latent heat of vapori-zation (Hunter, 1989)	$\Delta L = R_y (T_e + 273.16)^2 \frac{[1 - RH_e / 100]}{[RH_e / 100]} 0.0000355 M_e^{2.31}$ (11)
Resistance to airflow (ASABE, 2016)	$\Delta P' = \frac{6290\, v^2}{\ln(1+5.58v)}$ (12)

where:

HRYR - head rice yield reduction ratio, dimensionless
R_v - gas constant for water vapor, 461.5 J kg^{-1} °C^{-1}
$\Delta P'$ - specific resistance to airflow, Pa m^{-1}

Table 2. Moist air properties.

Property	Equation
Saturation vapor pressure	For $273.16 \le T_k \le 533.16$ $\frac{P_s}{R} = \frac{\exp[a+bT_k + cT_k^2 + dT_k^3 + eT_k^4]}{[fT_k - gT_k^2]}$ (13) where: $R = 22105649.25$ $d = 1.2558e^{-4}$ $a = -27405.526$ $e = -4.8502e^{-8}$ $b = 97.5413$ $f = 4.34903$ $c = -0.146244$ $g = 0.0039381$

Property	Equation
Latent heat of vaporization	For $273.16 \leq T_k \leq 338.72$
	$h_{fg} = 2502535.259 - 2385.76424\,(T_k - 273.16)$ (14)
	and for $338.72 \leq T_k \leq 533.16$
	$h_{fg} = (7329155978000 - 15995964.08 T_k^{\,2})^{0.5}$ (15)
Wet-bulb temperature	For $273.16 \leq T_k \leq 533.16$
	$P_{swb} - P_v = B'\,(T_{kwb} - T_k)$ (16)
	where:
	$B' = \dfrac{1006.9254\,(P_{swb} - P_{atm})\,[\,1+0.15577\,\dfrac{P_v}{P_{atm}}]}{0.62194 h'_{fg}}$ (17)
Hunimdity Ratio	For $273.16 \leq T_k \leq 533.16$
	$H = \dfrac{0.6219 P_v}{P_{atm} - P_v}$ (18)
Density	For $273.16 \leq T_k \leq 533.16$
	$\rho \, \dfrac{P_{atm} - P_v}{287 T_k}$ (19)
Relative humidity	$c_g = 0.921 + 0.0545\,M_{owb}$ (20)
Latent heat of vaporization (Hunter, 1989)	$\Delta L = R_v\,(T_e + 2723.16)^2\,[\dfrac{1 - RH_e/100}{RH_e/100}]\,0.0000355\,M_e^{2.31}$ (21)
Resistance to airflow (ASABE, 2016)	$RH = \dfrac{P_V}{P_s}\,100$ (22)

where:

T_k - temperature, °K
T_{kwb} - wet bulb temperature, °K
P_s - saturation vapor pressure, Pa
P_v - vapor pressure, Pa
P_{atm} - atmospheric pressure, Pa
RH_e - equilibrium relative humidity, %

$$M_e = \frac{1}{100}\left[\frac{\ln(1-RH_e / 100)}{-0.0000355\,(T_e + 27.4)}\right]^{1/2.31} \quad (23)$$

where:

M_e *equilibrium moisture content, % d.b.*

4. A new drying curve is specified when equilibrium drying temperature changes and amount of drying in previous curve is transformed to the current curve. This transformation is made by calculating equivalent drying time, t_e. Based from thin-layer equation,

$$MR = \frac{M_o - M_e}{M'_o - M_e} = \exp(-kt_e^{\,n}) \quad (24)$$

and equivalent drying time is calculated as,

$$t_e = \left[-\frac{1}{k}\ln\left(\frac{M_o' - M_e}{M_o - M_e}\right)\right]^{1/n} \quad (25)$$

where:

M_o - current moisture content of thin-layer, % d.b.
M_o' - initial moisture content of grain bed, % d.b.
MR - moisture ratio, dimensionless
t_e - equivalent drying time, min
k, n - drying constants (see Table I) evaluated at T_e, H_e, M'_o

5. t_e is equivalent drying time needed for drying curve to reach current moisture content. Final moisture content, M_f, at end of current time step, Δt, is then calculated from thin-layer equation using time, $t_e + \Delta t$

$$MR = \frac{M_f - M_e}{M_o - M_e} = \exp[-k(t_e + \Delta t)^n] \quad (26)$$

and solving for M_f,

$$M_f = M_e + (M_o - M_e)\exp[-k(t_e + \Delta t)^n] \quad (27)$$

where:

M_f final moisture content, % d.b.

6. The amount of moisture transferred from the grain, equal to M_o - M_f percentage points, is transferred to the air, and changes the absolute humidity by amount, ΔH,

$$\Delta H = \frac{(M_o - M_f)}{100} R \quad (28)$$

and final absolute humidity was calculated as,

$$H_f = H_o + \Delta H \quad (29)$$

where:

H_f - *final absolute humidity, kg kg^{-1}*
ΔH - *change in absolute humidity, kg kg^{-1}*

7. Final temperature was determined from final heat balance,

$$c_a T_e + H_o(h_{vo} + c_v T_e) + C_g G_e + c_w(H_f - H_o) \quad (30)$$
$$G_e = c_a T_f + H_f(h_{vo} + c_v T_f) + C_g G_f + \Delta L\,(H_f - H_o)$$

where:

T_f - final air temperature, °C
G_e - equilibrium grain temperature equal to T_e, °C
G_f - final grain temperature equal to T_f, °C
c_w - specific heat of water, 4.186 KJ kg^{-1} °C^{-1}
ΔL - difference between latent heat of vaporization of water in grain and that of free water, KJ kg^{-1}

Solving for T_f,

$$T_f = \frac{(c_a + c_v H_o)\,T_e - (H_f - H_o)(h_{vo} + \Delta L - c_w G_e) + C_g G_e}{c_a + c_v H_f + C_g} \quad (31)$$

Thompson (1972) Model

Thompson (1972) model assumed both thermal and moisture equilibrium between air and thin-layer of grain during each time step. There was no need for characteristic thin-layer cooling equation. The following heat and mass balances were solved to simulate the cooling process:

1. Heat balance between air and grain,

$$c_a T_o + H_o (h_{vo} + c_v T_o) + C_g G_o + c_w (H_f - H_o) G_o = c_a T_f + H_f (h_{vo} + c_v T_f) + C_g G_f \quad (32)$$

2. Mass balance between air and grain,

$$H_f - H_o = \frac{(M_o - M_f)}{100} R \quad (33)$$

3. Equivalence between relative humidity of air and equilibrium relative humidity (ERH) of grain as described by equation,

$$ERH_f = 100 \; \frac{1-exp(-0.0000355)}{[(T_f + 27.4) \; M_f^{2.31})]} \quad (34)$$

The air relative humidity, *RH*, which corresponded to given air temperature, *T*, and absolute humidity, *H*, is given in Table II.

The three equations would have three unknowns; $T_f(G_f)$, H_f and M_f. Analytical solution of these equations could not be obtained explicitly, but could be solved by numerical procedures. The secant method (Press, 2007) was found to converge rapidly to the solution. The following calculation steps were developed:

1. Make first estimate,

$$H_f = 0.99 \; H_o \quad (35)$$

2. Calculate final moisture content, M_f, from mass balance equation,

$$M_f = M_o - \frac{100 \; (H_f - H_o)}{R} \quad (36)$$

3. Calculate final air temperature, T_f, from heat balance equation,

$$Tf = \frac{(c_a + c_v H_o)T_o - (H_f - H_o)(h_{vo} - c_w G_o) + C_g G_o)}{c_a + c_v H_f + C_g} \quad (37)$$

4. Calculate ERH_f from T_f and M_f, using equations given in Table II

5. Calculate RH_f from T_f and M_f using equation (34)

6. Calculate the difference between ERH_f and RH_f,

$$\Delta RH_f = ERH_f - RH_f \quad (38)$$

7. Make second estimate,

$$\Delta H_f = 1.01 \; H_o \quad (39)$$

8. Repeat steps 2 to 6 to calculate the second estimates of M_f, T_f, ERH_f, RH_f and ΔRH_f

9 Calculate the third estimate of H_f using secant method,

$$Hf_3 = Hf_2 - \Delta RH_2 \; \frac{Hf_1 - Hf_2}{\Delta RH_1 - \Delta RH_2} \quad (40)$$

where subscripts *1, 2* and *3* corresponded to the first, second and third estimates

10. Repeat steps 8 and 9 until the relative difference between Hf_2 and Hf_3 is less than 0.0001 %, replacing Hf_1 with Hf_2, ΔRH_{f1} with ΔRH_{f2}, and Hf_2 with Hf_3 before proceeding with the next iteration.

Software Development

Mathematical and numerical solutions for simulation of drying of rough rice in fixed-bed developed by Martinez (2001) were adopted in this study. Solutions to model and simulate the cooling process were added. The simulation model was developed into user-interactive software. The software, including rewriting of program codes and development of user was programmed using Microsoft Visual Basic Community 2017 (Zak, 2017).

The software would run as desk-top application under Microsoft Windows environment. Visual Basic Community 2017 (Zak, 2017). The software would run as desktop application under Microsoft Windows environment.

RESULTS AND DISCUSSION

User-Interactive Simulation Software

The developed simulation software for drying and cooling of rough rice fixed-bed is shown in Figure 2. The software interface would allow users to input the initial grain moisture content and temperature, grain weight or grain bed depth (height), ambient air tempera-ture and relative humidity or wet-bulb temperature, dryer length, dryer width, and airflow rate or air velocity.

The simulation software would allow input of non-uniform grain moisture content and temperature, and variable (non-uniform) air temperature and relative humidity (or wet-bulb temperature) conditions by copying weather data from Microsoft Excel file (Figure 3). Users could choose the simulation stopping criterion in terms of final moisture content or drying/cooling time (Figure 4). Users also have option to simulate grain mixing and air reversal (Figure 5).

Rough Rice Drying in Flatbed Dryer

To illustrate the capability of soft-ware to simulate grain drying, shown in Figure 5 are typical conditions of drying rough rice in flatbed dryer with reversi-ble airflow commonly used in Philippines. After 10 hours of drying (with air reversal after 5 hours), rough rice with initial moisture content of 24 % was dried to an average moisture content of 13.2 %. The bottom grain layer had a moisture content of 12.9 % while upper layer had 13.4 % - a moisture gradient of 0.5 % moisture content (Figure 6).

In Simulation Results window shown in Figure 6, users could also view temperature curves, relative humidity curves and summary results table. Moreover, users would have option to copy graphs to Windows Clipboard and paste them to Word, Excel, PowerPoint and other Microsoft Windows desktop applications. Users would also have option to copy simulation results data to Windows Clipboard and paste them to Excel for further analysis.

If rough rice was dried with neither air reversal nor grain mixing, simulation results would show that average final moisture content would be slightly lower at 12.8 % (Figure 7).

However, bottom grain layer would be over-dried at 11.3 % moisture con-tent and top grain layer under-dried at 14.5 %. The moisture gradient would be relatively high at 3.2 % moisture content. Thus, simulation would show the benefit of flatbed dryer with reversible airflow in terms of more uniform drying of grains.

Cooling Rough Rice in Grain Silo

To demonstrate the capability of software in simulating grain cooling, shown in Figure 8 are the simulation conditions of cooling 600 tons of dry rough rice in grain silo. The silo had a floor area of 100 m^2 and grain bed reached a height of 10 m. Cooling air had a temperature of 18 °C and relative humidity of 60 %. Airflow rate was 3,600 m^3/h. These relatively dry cooling air conditions could be achieve by grain coolers increasingly used in the Philippines.

Results of simulation showed that after 5 days of continuous cooling, grains reached a uniform temperature of 17.8 °C from an initial temperature of 28 °C (Figure 9). Slight drying of grains (from 14 % initial moisture content to 13.6 % final moisture content also occurred during cooling process (Figure 10).

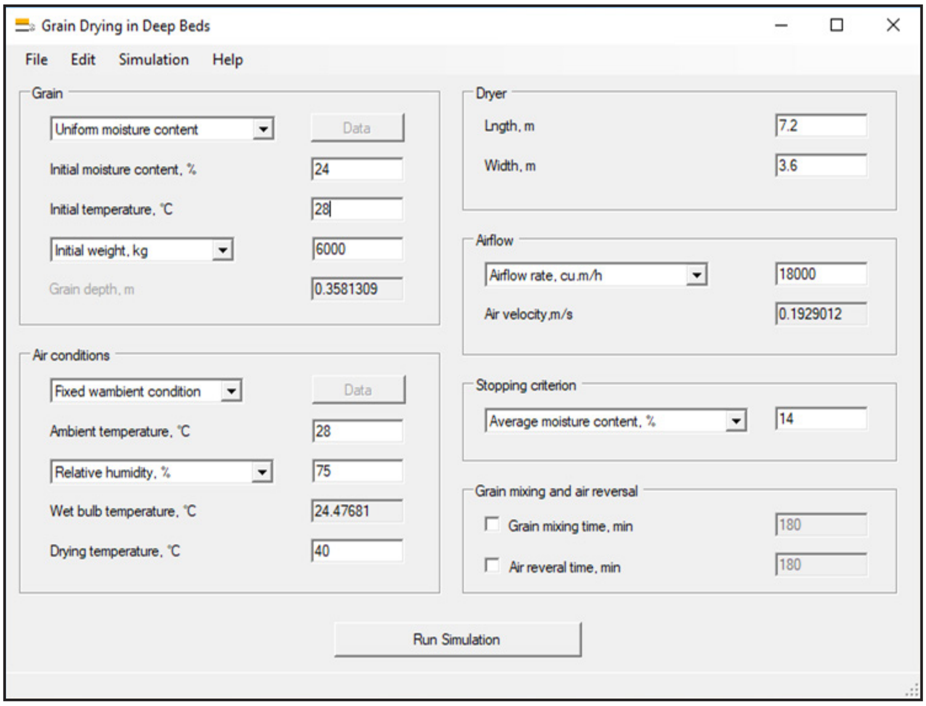

Figure 2. Simulation software for drying and cooling of rough rice in fixed-bed.

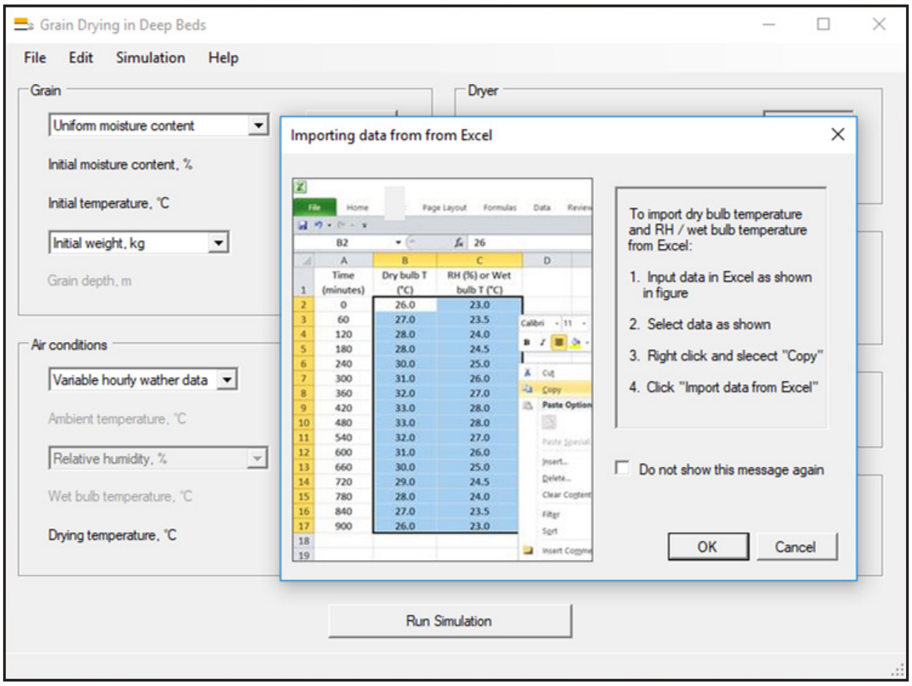

Figure 3. Variable air condition.

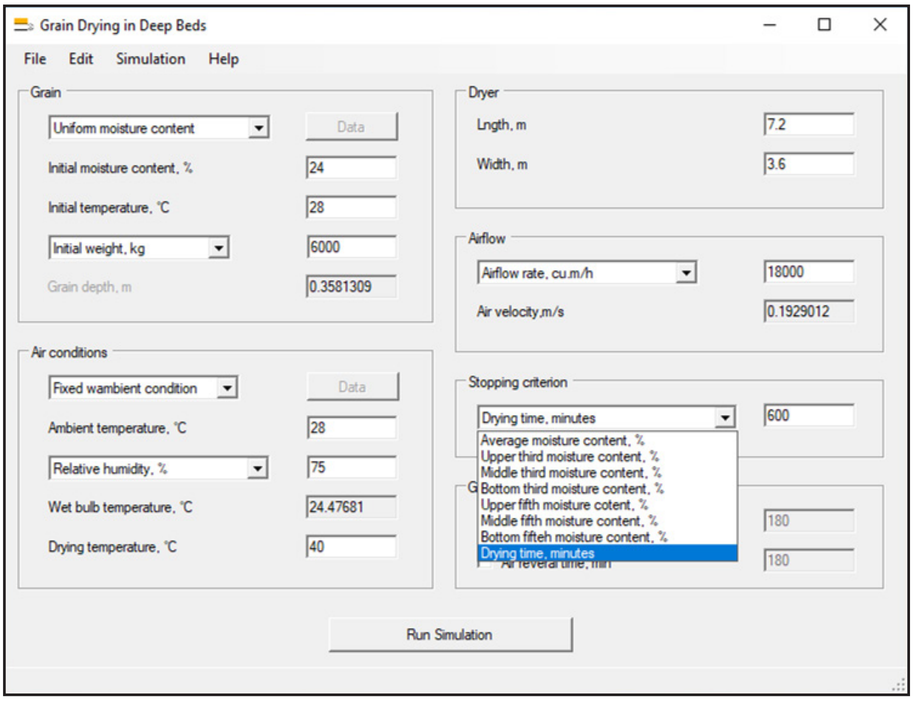

Figure 4. Simulation stopping criteria.

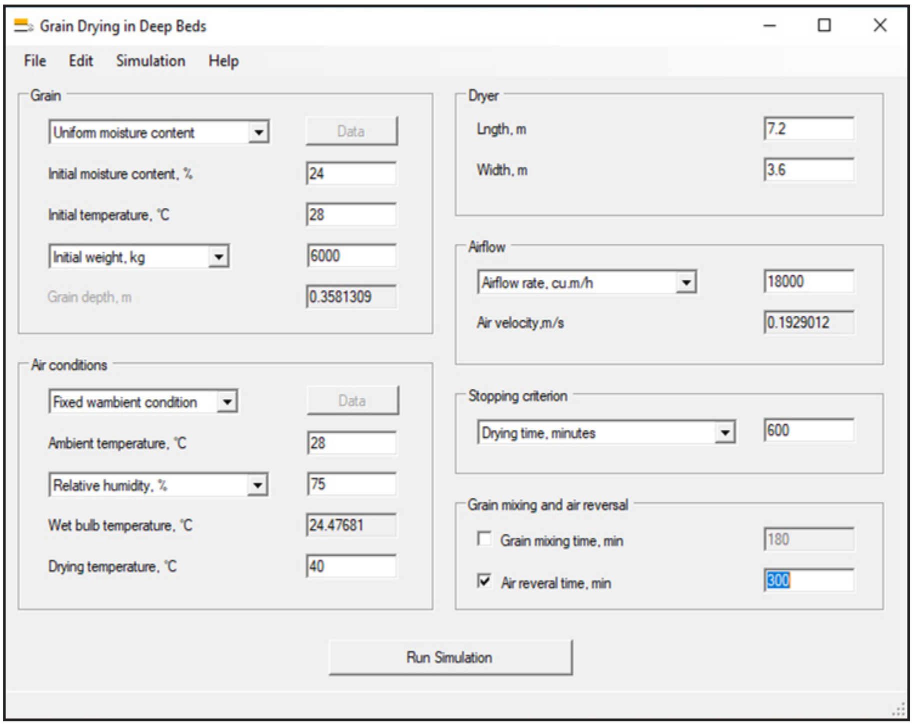

Figure 5. Flatbed dryer with reversible airflow.

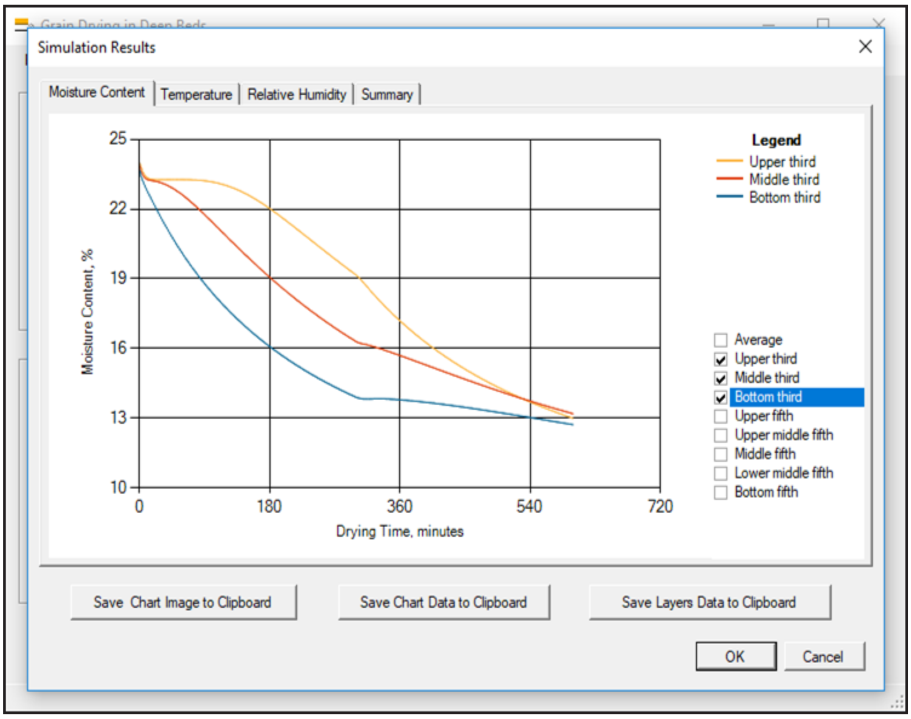

Figure 6. Simulation of drying with reversible airflow.

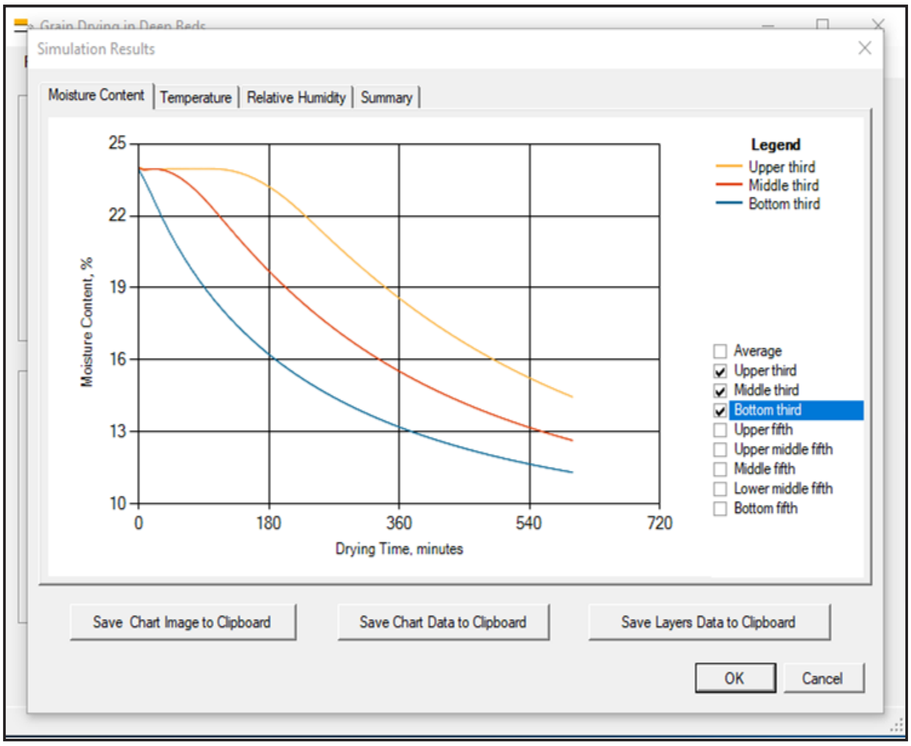

Figure 7. Results of drying without grain mixing

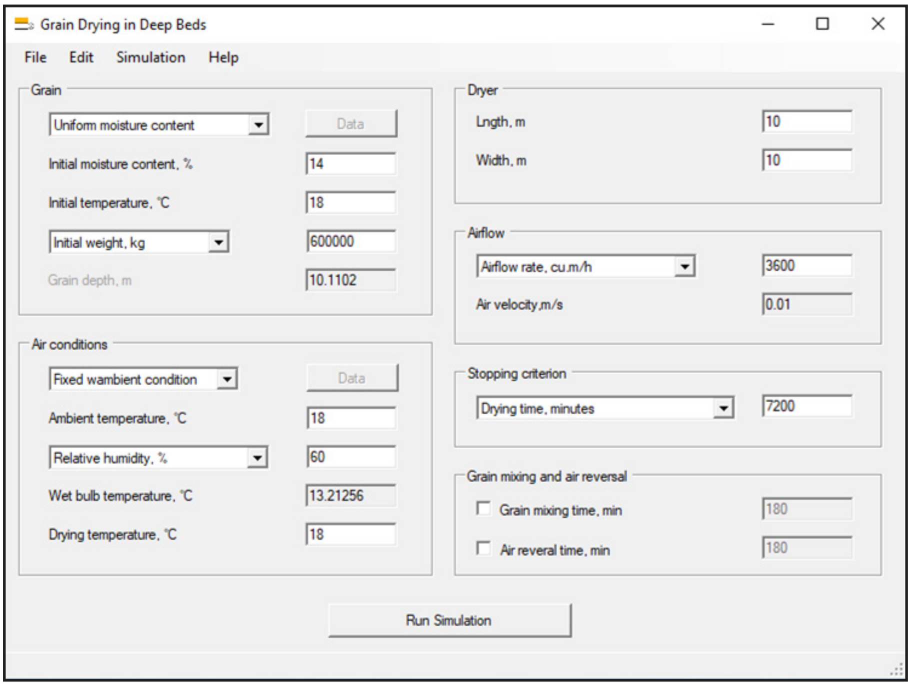

Figure 8. Cooling 600 tons of rough rice in silo.

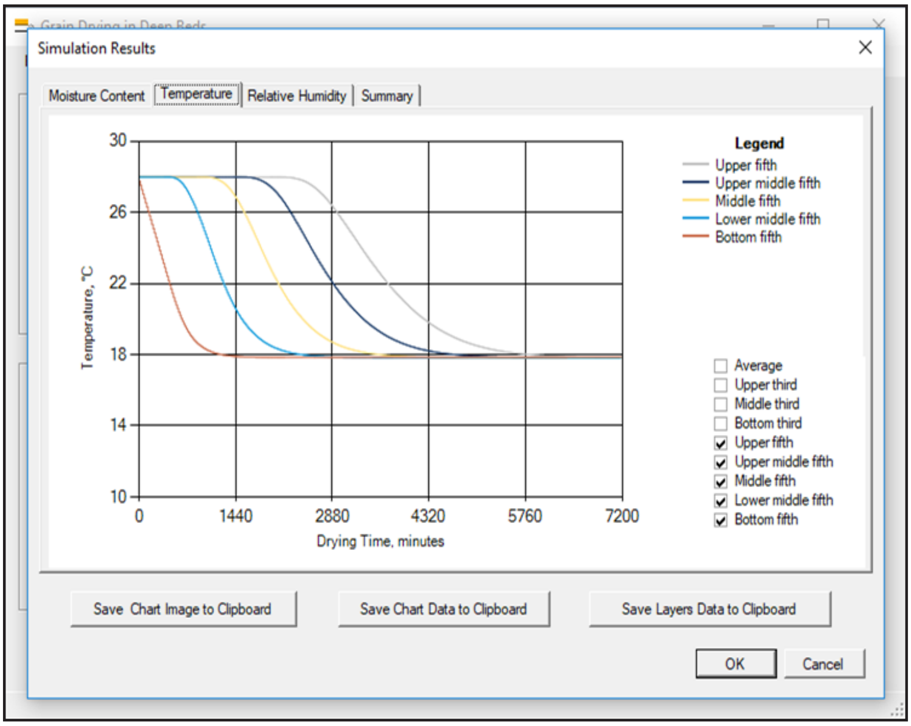

Figure 9. Results of cooling 600 tons of rough rice in silo.

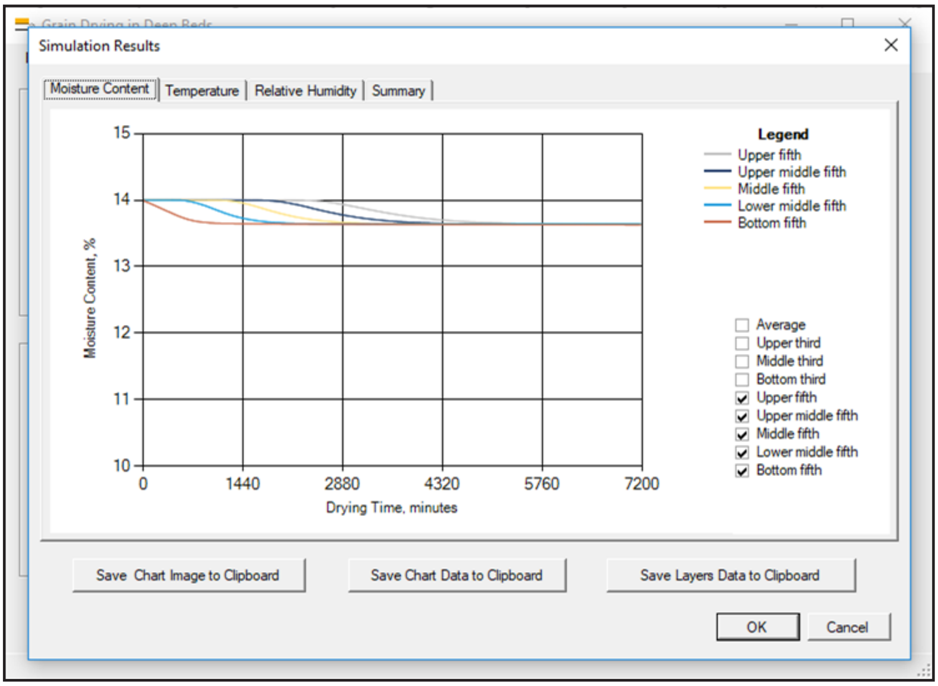

Figure 10. Slight drying during cooling in grain silo.

CONCLUSION

A simulation model for drying and cooling of rough rice in fixed-bed was successfully developed and implanted as user-interactive software that ran under Microsoft Windows desktop environment.

Future enhancement of simulation software will include addition of more grains and calculation of other parameters like drying and cooling efficiencies, specific energy consumption, drying and cooling costs and others. In this study, validation of the simulation model was not conducted. It is recommended that the accuracy of the model be validated by actual grain drying and cooling experiments.

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DESIGN AND DEVELOPMENT OF PRE-CLEANER FOR CORN

Michael A. Gragasin[1], Christ Russell D. Suan[2], Jayvee P. Illustrisimo[3], and Romualdo C. Martinez[4]

ABSTRACT

The inevitable accumulation of stones, corn cobs and other impurities in the corn grains could cause damage to corn mill components. This eventually affects the efficiency and operation of corn mill. To address this problem, this research developed an air-screen cleaner and destoner to separate stones, corn cobs and other foreign materials from the corn grains. The design of the pre-cleaner features an oscillating-type air-screen cleaner with large-hole screen and controlled air current and a pressure-type destoner using one blower only. The pre-cleaner was subjected to series of test trials wherein corn grains were intentionally mixed with different sizes of stones, corn cobs, and other impurities to determine the destoner and cleaner efficiencies and establish the optimum settings for the blower speed and angle of inclination of destoner screen. Test results revealed that the pre-cleaner has an input capacity of 500 kg/hr with an overall destoner efficiency of 85.94% and cleaning efficiency of 98.66% at blower speed of 2,600 rpm and 120 angle of inclination of the destoner screen.

Keywords: Corn Mill, Pre-cleaner, Agricultural Machinery, Postharvest Facilities

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INTRODUCTION

The challenge facing agricultural engineers working on the improvement of existing corn mills in the Philippines is how to produce good quality corn grits at low production cost without sacrificing milling recovery. Corn mill is being used in the processing of corn grains for the production of corn grits, the staple food of 15 % of the population in the Philippines (DA Corn Program, 2014).

Cleaning corn grains is essential in producing high-quality corn grits. The high presence of impurities in the corn grains could significantly affect the performance of corn mill, thus, fail to satisfy the Philippine Agricultural Engineering Standard (PAES) for corn mill (PAES 211:2000) as presented in Table 1. A corn mill with degerminator efficiency of lower than 80% indicates the production of poor-quality corn grits given the high presence of pericarp, tip cap, and germ in the product. On the other hand, a corn mill with main product recovery of less than 64% indicates the incidence of postharvest losses during milling operation

Majority of the corn shellers in Visayas and Mindanao are not capable of efficiently removing corn cobs from the corn grains. Likewise, majority of the corn farmers are drying their produce in the highway that resulted in the accumulation of stones in the corn grains. The high presence of corn cobs, stones, and other impurities in the corn grains could cause clogging in the degerminator of the corn mill and could damage sensible parts of the corn mill particularly the screens of the degermer and the rotary mill. As such, it is imperative that shelled corn grains should undergo cleaning process before milling. The removal of foreign materials from the corn grains not only cleans corn grains but also increases milling efficiency, protects the corn mill parts from abrupt damages and lessen the power load requirement of the corn mill (Wrigley et al., 2016; Bhattacharya and Ali, 2015).

New designs of grain or seed cleaners to separate grain/seed from contaminants are available (Tieben, 1987; Misra et al., 1991; Bayshugulova et al., 2015; Bilde, 2015). Among the rice seed cleaner developed in the Philippines is a compact triple-airstream, triple-screen (Pasikatan et al., 1996).

However, the importance of pre-cleaner as one major components of a corn mill system has been neglected in the Philippines as highly evident in the absence of operational pre-cleaner for corn mill and the associated agricultural engineering standard for such in the country. Moreover, there are very limited published scientific literatures concerning specific design, test performance and standards on pre-cleaner for corn.

The purpose of this research was to develop an appropriate pre-cleaner for village-type corn mills. Specifically, it aimed to: (1) Establish the technical parameters that will lead to the design and development of appropriate pre-cleaner; (2) Come-up with operational model of pre-cleaner; (3) Establish the technical performance of the developed pre-cleaner; and, (4) Determine the financial viability of a village-type corn mill with the developed pre-cleaner as integral part of the corn mill system.

Table 1. Performance Criteria for Corn Mill Prescribed by PAES

Criteria	Performance Data
Main Product Recovery, percent, minimum	64
Degerminator Efficiency, percent, minimum	80

METHODOLOGY

Project Framework

The conceptual framework of this research has followed the traditional input-process-output model approach. The technical requirements of village-type corn mill for clean corn grains have served as basis (input) in the design and development (process) to come up with pre-cleaner that can be integrated to existing corn mill system (output) to further improve the performance of the corn mill in terms of quality and quantity of corn grits produced (impact).

Design of the Pre-cleaner

A stand-alone pre-cleaner (Figure 1) was considered to maintain the original configuration of existing village-type corn mill. The pre-cleaner is designed to have two major functions: (1) Oscilating air-screen cleaner; and, (2) Pressure destoner. The design features of an oscillating-type air-screen cleaner with large-hole screen and controlled air current and a pressure-type destoner using one blower only.

The design of the air-screen cleaner and the destoner were drawn through CAD software. The details of each part were fully configured showing label and measurement of every part of the design. The CAD drawings have served as reference in the fabrication of prototype unit.

Fabrication of Prototype Unit

The fabrication of the air-screen cleaner and the destoner were awarded to ACT Machineries and Metalcraft Corp. with PHilMech shouldering all the fabrication cost. It was strictly preferred that the partner local manufacturer was limited to those who were already fabricating and marketing village-type corn mill to ensure that they are already familiar of the corn mill design, thus, fast tract the fabrication of the prototype unit. A non-disclosure agreement was forged with ACT Machineries and Metalcraft Corporation to protect the Intellectual Property Right of PHilMech on the design of the pre-cleaner technology.

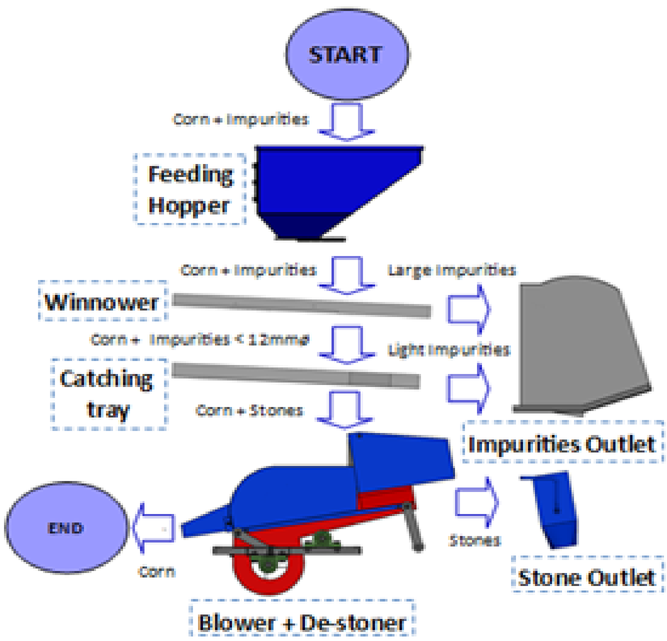

Figure 1. Schematic diagram of the corn pre-cleaner showing its parts and operation and flow of materials

Laboratory Testing

Laboratory set-up and test trials were conducted to determine the workability and viability of the design. Laboratory testing was conducted to determine the technical performance of the air-screen cleaner and destoner.

Test Materials

Corn samples used during testing were prepared in sufficient quantity and identical characteristics in terms of moisture content, purity, and variety. For all test trials conducted, the same variety was used and originated from the same lot. Total samples used for each test trial were 50 kg. The corn samples were then mixed with 500 stones of different sizes (small, medium, large) with distinct color for easy identification and 2.5 kilograms of corn cobs for the testing of destoner and air-screen cleaner, respectively. The utilization of 2.5 kg of corn cobs conforms the Philippine Agricultural Engineering Standards - Method of Test for corn mill (PAES 211:2000) as stated in its Annex B that test materials to be used shall have a minimum purity of 95% (with 5% impurities).

The conditions of the corn samples used in each test trials were determined using three representative samples, each weighing one kg. The gathered samples were taken for laboratory analysis to determine its moisture content and purity. During each test trial, three samples each were again collected from the discharge outlet of the pre-cleaner for laboratory analysis to determine the purity and moisture content of the corn samples after testing.

Test Trials

The performance of the developed pressure destoner was evaluated based on its effectiveness to remove stones at different sizes. The effectiveness of the pre-cleaner in removing stones from the corn grains was established by determining the destoner efficiency with respect to varying angles of the destoner screen (8o, 10o, 12o, 14o, and 16o). Note that the angles of the destoner screen could be easily set using a Clinometer. The angle setting with most efficient result was then served as the optimum angle setting of the destoner screen.

During test trials, the corn samples weighing 50 kg each were intentionally mixed with 500 stones of different sizes (i.e., small, medium and large). Each size group of stones was painted with different color to easily identify their respective category during collection and to determine the effectiveness of the design to remove stones at varying sizes. The total number of stones collected per size category at the destoner screen was counted. The efficiency of the destoner per category was determined using the formula:

$$\textit{Destoner Efficiency} \quad \frac{\textit{No. of stones collected by the destoner}}{\textit{No. of stones used in the experiment}}$$

Likewise, the performance of the developed air-screen cleaner was evaluated based on its effectiveness to remove corn cobs and other impurities. The effectiveness of the air-screen cleaner in removing impurities was established by determining the corresponding cleaner efficiency of the air-screen cleaner with respect to varying blower speed (i.e. 2400 rpm, 2600 rpm, 2800 rpm, 3000 rpm and 3200 rpm). With this, the right speed of the blower could also be established considering the cleaner efficiency and corn grain losses.

In the laboratory trials, a total of 2.5 kg of corn cobs and other impurities were mixed with corn samples weighing 50 kg. The total weight of corn cobs and other foreign materials removed by the air-screen cleaner were collected. Varying blower speeds (rpm) were attained using a variable frequency drive (VFD) whereas the accuracy of blower speed readings was verified using a tachometer. The efficiency of the cleaner was determined using the formula:

$$\textit{Cleaner efficiency} \quad \frac{\textit{Weight of impurities collected}}{\textit{Total weight of impurities}}$$

Experimental Design and Statistical Analysis

The performance of the developed air-screen cleaner and destoner with respect to different settings, (i.e., angle of inclination and blower speed) was gathered and analyzed using Analysis of Variance (ANOVA). Statistical analysis was performed using Statgraphics Plus, a statistic package that performs and explains basic and advanced statistical functions.

Financial Analysis

Test trials were also conducted for a village-type corn mill with the developed air-screen cleaner and destoner as one integrated corn milling system following the Philippine Agricultural Engineering Standard - Method of Test for Corn Mill (PAES 211:2000).

The financial viability of a village-type corn mill with the developed pre-cleaner as one integrated corn mill system was determined using the Net Present Value and the Internal Rate of Return (IRR). The net present value (NPV) is a measurement of profit calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of time (Kurt, 2003), as follows:

$$NPV = \frac{Rt}{(1+i)^t}$$

where: t is the time of the cash flow; i is the discount rate, i.e. the return that could be earned per unit of time on an investment with similar risk time of the cash flow; and R = the net cash flow i.e. cash inflow – cash outflow, at time t.

On the other hand, the IRR is an indicator to measure the financial return on investment of an income generation project and is used to make the investment decision (Hartman et al., 2004). The IRR is obtained by equating the present value of investment costs, i.e., cash outflows, and the present value of net incomes, i.e., cash inflows. This can be shown by the following equality:

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

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

where: I_0 is the initial investment costs in the year 0 (the first year during which the project is constructed) and $I_1 \sim I_m$ are the additional investment costs for maintenance and operating costs during the entire project life period from year 1 (the second year) to year m. $B_1 \sim B_m$ are the annual net incomes for the entire operation period (the entire project life period) from year 1 (the second year) to year m. By solving the above equality, the value of r or commonly known as the Internal Rate of Return (IRR) was obtained.

The break-even point, payback period, and benefit-cost ratio were also included in the financial analysis to determine the financial feasibility of a village-type corn mill with integrated pre-cleaner.

RESULT AND DISCUSSIONS

Concept of the Design

A stand-alone pre-cleaner was fully considered in the design to maintain the original configuration of the village-type corn mill. The design features an oscillating-type air-screen cleaner and pressure-type destoner. The air-screen cleaner was placed on top of the destoner so that the air coming from the destoner can be reused for the winnowing requirement of the air-screen cleaner.

In the design of the pre-cleaner as shown in Figure 2, the following basic technical parameters were considered: (1) capacity should be 350-700 kg/h; (2) removal of corn cob, stones and other impurities in single machine operation; (3) cleaning and destoning mechanisms can be done simultaneously using single-electric motor; (4) air current coming from the destoner blower can be utilized for winnowing operation; (5) reciprocating movement of destoner caused by the eccentric shaft can be utilized for oscillating movement of the air-screen cleaner; and, (6) hopper can be loaded of up to 25 kg where grain intake into the cleaner can be easily regulated.

Air-screen Cleaner Assembly. Inasmuch that the purpose of air-screen cleaner is to remove corn cobs and other light impurities from the corn grains, the screen was made of ½ inch diameter perforated sheet so that even large kernels of hybrid corn varieties can freely pass through the screen hole. In the design, the top screen separates larger impurities (weeds, husks, etc.) from smaller impurities (stones, corn cobs, weeds, etc.). Since the air-screen cleaner assembly is connected to the destoner assembly, the reciprocating movement of destoner provides oscillating movement of the air-screen cleaner. Given such design, corn cobs that passed through the perforated sheet are blown away by recycled air coming from the destoner. Air velocity, uniformity of feed, and perforation size and shape are extremely important to the performance of grain cleaners (Chakraverty et al., 2003). The slope of the air-screen cleaner was made adjustable to easily establish the optimum angle of inclination of the air-screen cleaner.

Destoner Assembly. The destoner assembly was designed with a screen mounted at an angle that moves in a reciprocating manner caused by an eccentric shaft. This is based on the technical design principle that stones that were mixed with grains can be separated accordingly by their differences on specific gravity (Tangpinijkul, 2010; Klein et al., 1961). In designing the destoner, therefore, air coming through the destoner screen can stratify stones and corn grains by their differences on specific gravity. The reciprocating movement of destoner assembly causes the heavy stones to move upward towards the discharge outlet at the high end of the destoner screen, while light products (corn grains) are discharged from the low end of the destoner screen.

Performance Evaluation

During test trials of the pre-cleaner, the performance of each part was fully observed and several modifications were undertaken until the target performance of the pre-cleaner was achieved.

Air-screen cleaner efficiency. Table 2 shows the effect of blower speed on the air-screen cleaner efficiency of the developed pre-cleaner. As evident, the innovative design of the air-screen cleaner is effective in separating corn cobs and other light foreign materials given the significant improvement of the purity level of the corn samples from 95.2-98.0%, even at minimum blower speed of 2,400 rpm. The concept of the design, thus, successful in reusing air coming from the destoner for the air current requirement of the air-screen cleaner. The air-screen cleaner efficiency of the machine was recorded at 78% for blower speed of 2,400 and 97.73% for blower speed of 3,200 rpm. In fact, high purity of corn grains of as high as 99.8% was achieved at blower speed of 3,200 rpm but this already entails high percentage losses since 9.07% of corn grains are already thrown out with the impurities.

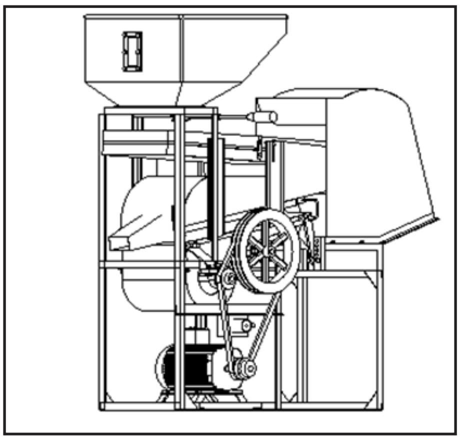

Figure 2. CAD drawing of pre-cleaner

Table 2. Air-screen cleaner efficiency and percentage of corn grains at different blower speed

Blower Speed (rpm)	Corn Grain Purity[1/] (%)	Corn Grain Losses (%)	Cleaner Eff. (%)
2,400	98.0	0.60^{d}	78.00^{e}
2,600	98.5	0.83^{d}	83.60^{d}
2,800	98.8	2.66^{c}	89.67^{c}
3,000	99.4	4.47^{b}	93.87^{b}
3,200	99.8	9.07^{a}	97.73^{a}

1/ Initial purity of corn samples was determined at 95.2%.
Note: Means across column having the same superscript are not significantly different at 5% level

Table 3: Destoner efficiency with respect to different angle of inclination of destoner screen

Angle of Inclination of Destoner Screen	Destoner Efficiency (%)
8^{o}	83.64^{a}
10^{o}	82.83^{a}
12^{o}	82.04^{a}
14^{o}	67.96^{b}
16^{o}	30.24^{c}

What is the right speed of the blower to establish the optimum level of air-screen cleaner efficiency and corn grain losses? The instantaneous difference of the rate of change of the air-screen cleaner efficiency and corn grain losses with respect to the change of blower speed was estimated. The highest rate of net increase of the air-screen cleaner efficiency with respect to corn grain losses was estimated at blower speed of 2,600 rpm as highly visible in Figure 3.

Destoner Efficiency. In the determination of destoner efficiency, the destoner screen was adjusted to different angles after the pre-cleaner was leveled on the ground surface using a Clinometer. As evident in Table 2, the destoner efficiency increased with the decrease of angle of inclination of the destoner screen. At 8 degrees inclination, the destoner efficiency was estimated at 83.64%. The destoner efficiency of the pre-cleaner becomes 30.24% when the angle of inclination of the destoner screen was adjusted to 16 degrees.

To establish the right angle of inclination of the destoner screen, the instantaneous rate of change of the destoner efficiency with respect to the change of angle of inclination was also estimated. The angle of inclination with the lowest rate of decrease of destoner efficiency was considered as the right setting of the destoner screen. As clearly depicted in Figure 3, the lowest rate of decrease is at 12 degrees angle of inclination with -0.79%. As such, this point was adopted as the correct angle of inclination of the destoner screen with optimum level of destoner efficiency.

Modification of the Air Duct. The air-duct that is placed on top of the destoner screen was modified to improve the passage of air coming from the destoner so that this can be efficiently used for the air-screen cleaner. The results of test trials revealed that the air-screen cleaner efficiency has significantly improved to 98.6% from 87.67%, while the destoner efficiency has significantly improved to 85.93% (Table 4).

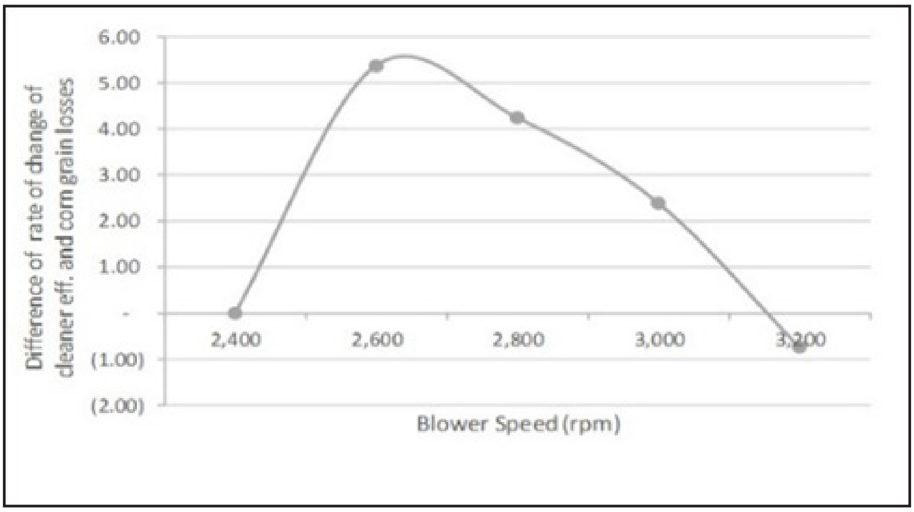

Figure 3. Rate of increase of air-screen cleaner efficiency with respect to blower speed

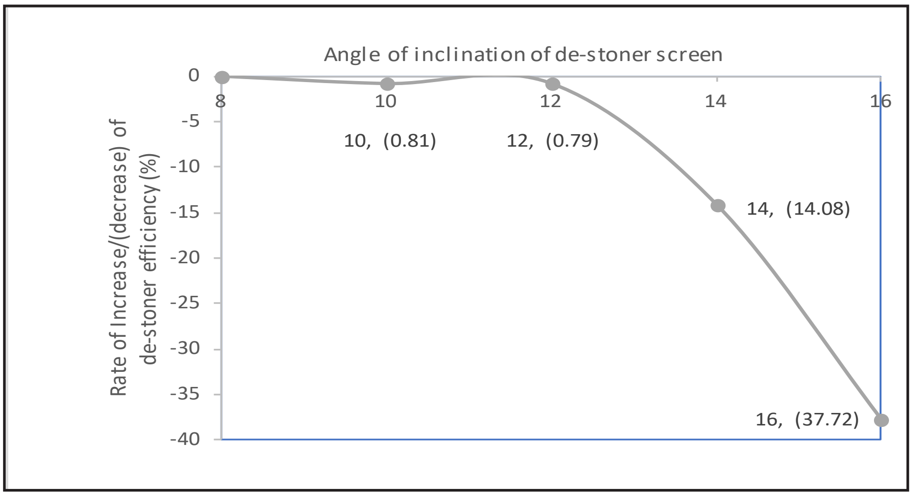

Figure 4. Rate of increase of destoner efficiency with respect to angle of inclination

Table 4. Performance of the pre-cleaner based on the initial and improved design, In Percent

Performance Parameter	Initial Design	Improved Design
Air-screen cleaner Efficiency	87.67[a]	98.66[b]
Destoner Efficiency	82.04[a]	85.93

Technical Specifications of the Pre-cleaner

Based on the result of laboratory and field trials, the developed pre-cleaner has an input capacity of 320-500 kg/h with air-screen cleaner efficiency and destoner efficiency of 98.66% and 85.93%, respectively. The pre-cleaner is powered by a 2 hp (1.49 kW) electric motor. The elevator assembly has an input capacity of 300-800 kg/h. It is connected to a speed reducer, power-driven by an electric motor.

The elevator assembly has an input capacity of 300-800 kg/h. It is connected to a speed reducer, power-driven by an electric motor.

Performance of a Corn Mill with the Developed Pre-Cleaner

Performance tests on the effectiveness of the developed pre-cleaner with a village-type corn mill were conducted following the Philippine Agricultural Engineering Standard - Method of Test for Corn Mill (PAES 211:2000). The developed pre-cleaner was connected to the compact corn mill developed by PHilMech as shown in Figure 5. As highly evident in Table 5, the input and milling capacities of the corn mill with 5% corn cobs were only 118.77 kg/h and 113.67 kg/h, respectively.

On the other hand, the input and milling capacities of the corn mill when the corn samples have passed through the pre-cleaner becomes 374.01 kg/h and 275.27 kg/h, respectively. Likewise, with cleaned corn samples, the main product recovery and degerminator efficiency of the corn mill becomes 64.17% and 87.14%, respectively. This is in real contrast to the performance of the corn mill when the corn samples have not passed through the pre-cleaner given a low main product recovery of only 57.36%.

It is important to note that the corn samples used in the test trials contain 5% corn cobs with 500 pieces of stones at varying sizes. Without pre-cleaning, the coefficient of friction and the density of corn samples have changed given the high presence of impurities in the corn samples that contribute to a slower movement of corn samples during corn milling. Based on the result of laboratory analysis (Table 6), corn grains with 5% corn cobs have a higher coefficient of friction of 0.532 and lower density of 756.6 g/cm3 as compared to 820 g/cm3 density of corn sample with only 0.033% corn cobs. Laboratory analysis confirms that once the corn samples with 5% corn cobs have passed through the developed pre-cleaner, a 99.07% purity (or with 0.03% corn cobs) can be achieved.

The result of laboratory analysis as manifested in Table 5, thus, confirmed previous observations during field trials that the high presence of corn cobs in the corn grains have greatly affected the performance of the developed village level compact corn mill. But most importantly, the result of laboratory analysis, thus, validated the importance of the developed pre-cleaner on the efficient operation of the existing corn mill.

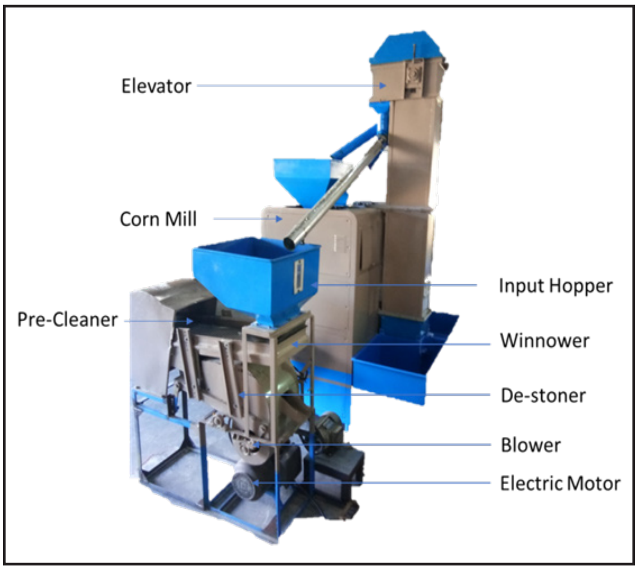

Figure 5. Integrated corn milling system system

Table 5. Performance of compact corn mill with and without pre-cleaner

Parameters	Without Pre-cleaner	With Pre-cleaner
Condition of samples		
% corn cob	5.00	0.033
No. of stones	500	70
Input Cap. (kg/h)	118.77	374.01
Milling Cap. (kg/h)	113.67	275.27
Main Product Rec. (%)	57.36	64.17
Degerminator Eff. (%)	85.67	87.14

Table 6. Coefficient of friction and density of laboratory corn samples

	With 5% Corn Cob	With 0.03% Corn Cob
Coeff. of friction	0.532	0.364
Density	756.6	820.0

Table 7. Total annual operating cost, cost of milling, and financial indicators

Particular	Without Pre-cleaner	With Pre-cleaner
Annual Fixed Cost (Php)	48,500	65,167
Depreciation	30,000	40,167
Repairs and maintenance	18,500	25,000
Annual Variable Cost (Php)	79,244	96,153
Electricity	51,744	68,653
Labor	27,500	27,500
Annual Total Cost (Php)	127,744	161,320
Cost of milling (Php)		
Per kilogram Output	0.95	1.19
Per kilogram Input	0.60	0.76
Net income (Php/kg)	1.12	0.99
Net Present Value (PhP)	1,440,366	1,104,076
Internal Rate of Return	68.63%	35.16%
Net Present Value (Php)	1,440,366	1,104,076

Financial Analysis

The effect on the financial viability of a village-type corn mill with the developed pre-cleaner as integrated to a corn mill system was analyzed. In the financial analysis, the total annual operating time used in the estimation was 660 hours (i.e., 5 months, 22 days per month, and 6 hours of operation per day).

As shown in Table 7, the estimated cost of milling per kilogram output for corn mill with pre-cleaner was Php 1.19 as against Php 0.95 for corn mill without pre-cleaner given a higher investment cost and electricity cost. However, the cost of milling of Php 1.19 is still far below the prevailing milling fee of Php 3.10-4.70 per kg of corn grits output or Php 2-3 per kg of corn grain input. Even if the integrated corn mill system will be used for custom milling business and will charge a milling fee of Php 2 per kg input and an indirect cost amounting to 20% of the milling cost will be added to the milling cost, a net income of Php 0.99 per kg can still be realized.

The financial analysis revealed that the custom-milling business is financially feasible given a net present value Php 0.65 million for a total initial investment cost of Php 500,000 for 12 years of operation and internal rate of return of 35.2%. The payback period of a corn mill with pre-cleaner is 3.74 years with benefit-cost ratio of 1.3. The break-even volume of a corn mill with pre-cleaner was 34,418 kg per year.

CONCLUSION AND RECOMMENDATIONS

The inevitable accumulation of stones, corn cobs and other impurities in the corn grains could cause damage to corn mill components and could eventually affect the efficiency and operation of corn mill. To address such scenarios, this research developed a pre-cleaner and elevator for the electric-driven PHilMech compact corn mill.

The study was conducted to come up with a technically feasible and financially viable pre-cleaner and elevator. The fabrication of the prototype unit was collaborated with a partner

The results of test trials revealed that the developed pre-cleaner is efficient in removing impurities and stones from the corn grains. The developed pre-cleaner has air-screen cleaner efficiency and destoner efficiency of 98.66% and 85.93%, respectively. The integration of the developed pre-cleaner to a village-level corn mill has significantly improved its input capacity, main product recovery and degerminator efficiency or product quality.

While the integration of a pre-cleaner to a village-type corn mill has affected its financial feasibility given the additional increase in investment and electricity costs, the result of financial analysis revealed that the total cost of milling per kilogram output was still cheaper at Php 1.19 as compared to current milling fee of Php 3.10-4.70 per kg output. This still leads to estimated net income of Php 0.99 per kg output of the integrated corn mill system. Financial indicators of an integrated corn mill with pre-cleaner, if this will be used for custom-milling business, revealed that the estimated net present value is Php 0.65 million for an initial investment of Php 0.50 million for 12 years of business operation with internal rate of return of 35.2%. The pay-back period is 3.74 years with benefit-cost ratio of 1.3.

It is recommended that the developed pre-cleaner technology shall be adopted by the local manufacturers who are currently fabricating and marketing village-type corn mills to ensure that the corn grains are free from impurities known for affecting the quantity and quality of milled corn products. The adoption of the developed pre-cleaner technology can further improve the life span of replaceable parts of the corn mill prone to wear and tear particularly the degermer screen which can substantially reduce maintenance cost and prevent unnecessary delays during corn milling operation.

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CHEMICAL PROPERTIES, SENSORY ANALYSIS AND ETHYLENE PRODUCTION OF 'LAKATAN' (*Musa acuminata*) BANANA FRUIT TREATED WITH 1-METHYLCYCLOPROPENE (1-MCP)

Bryl I. Manigo[1] and Cesar A. Limbaga Jr.[2]

ABSTRACT

Preventing the accumulation of ethylene around harvested bananas is one way to delay their ripening. 1-Methylcyclopropene (1-MCP) is a novel compound that can prolong shelf life of fresh produce by inhibiting the action of ethylene at the receptor level. Effectiveness of 1-MCP is governed by various factors such as cultivar, fruit maturity, concentration, time of exposure and method of application. In this study, methods of application (1-MCP gas exposure for 20 hours, 1-MCP spraying through 1-MCP aqueous spray solution, and no 1-MCP application) on 'Lakatan' banana fruits were evaluated to determine the total soluble solids (TSS), total titratable acidity (TTA) and pH, organoleptic attributes such as aroma, taste, pulp color and over-all acceptability, and ethylene production of the fruit. Fruits treated with 1-MCP through gas exposure and spraying methods reduced TSS and TTA while pH was higher than in fruits with no 1-MCP application. On the other hand, fruits with no 1-MCP treatment had better aroma, taste, pulp color, and over-all acceptability after ripening at 25 – 30 ˚C compared to 1-MCP treated bananas through gas exposure and spraying methods when they reached full ripeness under similar condition. Ethylene production of 'Lakatan' banana fruit was significantly reduced through 1-MCP application with gas exposure being more effective than spraying.

Keywords: Postharvest, Tropical fruit, Ethylene action blocker, Chemical reactions, Gas chromatography

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INTRODUCTION

Banana is the fourth largest agricultural commodity produced in the Philippines. In 2012, more than 80% of the bananas (and 99% of the Cavendish cultivars) were produced on the island of Mindanao, with Davao, Northern Mindanao and Soccskargen as the top regions and Davao del Norte, Compostela Valley and Bukidnon as the top three provinces (PSA, 2012).

'Cavendish' variety is traded internationally. In fact the country is the second largest exporter of bananas next to Ecuador with some 2.6 metric tons exported in 2012 (Prowse, 2013). On the other hand, 'Lakatan' variety is traded locally and has the potential in the export market.

By nature, these commodities have limited shelf life, thus, postharvest handling is crucial. Major losses during shipment often occur especially on the transport of fresh bananas to markets. These conditions negatively impact the market value of bananas which contributes banana quality depreciation and limits export trade (Lassois et. al., 2010).

Nutritionally, fresh bananas are a good source of carbohydrates, protein, fibers with ultimately a good amount of calories, and a low fat content. It contains approximately 35% carbohydrates, 6-7% fibers, 1-2% proteins, and also contains essential elements such as potassium, magnesium, phosphorus, calcium, iron, and vitamins A, B6, and C (Banana facts, in IITA Research to nourish Africa, 2008).

Chemical properties of fruits is an important indicator of fruit quality. Postharvest handling to maintain these qualities is an important consideration in crop management to avoid considerable losses. In many places, there is significant loss of the food value of banana due to improper post harvest management practices that causes huge economic loss (Ahmad and Siddiqui, 2015).

Fruit growth and development affects its chemical properties which involve many changes in its morphology, anatomy, physiology and biochemistry (El-Otmani et al., 1987). These chemical properties which indicate fruit quality needs to be considered during postharvest handling to avoid nutritional losses. When a fruit matures, the changes occur in rind texture, juice composition and taste (Chahidi et al., 2008). pH and mineral composition may also influence the catalytic activity of cell wall enzymes and can have a profound effect on anthocyanin stability and color expression (Huber and O'Donoghue, 1993; Almeida and Huber, 1999; Holcroft and Kader, 1999). A total soluable solid (TSS) is an important quality attribute for many fresh fruits during ripening (Lu, 2004). It was reported that fruit pH changes was 3.0 in orange juices (Kelebek et al., 2008), 4.2 to 4.4 during storage in peaches (Zhang et al., 2008) and 3.0 to 3.5 in citrus fruits (Chahidi et al., 2008) during storage. During fruit ripening and softening process, starch is broken down to the simple soluble sugars and also the amount of soluble pectin will increase, leading to fruit softening (Afshar and Rahimi, 2010).

Preventing the accumulation of ethylene around produce is among the approaches used to delay ripening of bananas. In recent years, researchers discovered effective compounds that control ethylene biosynthesis by Aminoethoxyvinylglycine (AVG) or block production, action, and synthesis or compete for ethylene binding sites by 1-Methylcyclopropene (1-MCP). 1-MCP is a novel compound that can prolong the shelf life of fresh produce by inhibiting the action of ethylene at receptor level (Blankenship and Dole, 2003; Watkins, 2006, Nanthachai et al., 2007). This gaseous plant growth and ripening regulator blocks the action and binding sites of ethylene by means of blocking the ethylene receptors in the tissues of plants, flowers, fruit and vegetables, thus preventing the ripening process (Mir, et al., 2004; Watkins, 2006).

1-Methylcyclopropene (1-MCP) is a highly volatile gas, thus commercially it is available in an encapsulated form in α-cyclodextrin (CD). The appropriate amount of water or KOH buffer is required as a trigger to release this encapsulated 1-MCP gas molecules (Watkins, 2006; Mir, et al., 2004). These gaseous molecule blocks the sites of ethylene binding and action in fruit. When 1-MCP molecules sit on ethylene receptor sites, it binds the receptor sites and does not allow the receptor to "unlock" like the ethylene molecule does. Therefore, no signal can be sent for a chemical reaction, which delays the further ripening. But as mentioned earlier, ethylene and receptor site formation is a continuous process, and 1-MCP does not bind the receptor site permanently. So, eventually new receptor sites can be formed and ethylene can regain its sensitivity for them, once the entire available 1-MCP molecule has been used up to block available receptor sites (Blankenship, 2001).

The ability of 1-Methylcyclopropene (1-MCP) to delay ripening of mature-green 'Cavendish' bananas has been evaluated extensively over the years (Joyce et al., 1999), yet, no study has been conducted for 'Lakatan'. Diverse results influence the effectiveness of 1-MCP which governed by various factors. These factors include variety of the crop, fruit maturity, levels of concentration, time of exposure, preharvest treatments, postharvest handling, storage conditions (temperature and humidity), and length of storage. The interactions of these factors affect the occurrence of physiological disorders of crops (Watkins, 2006).

The main objective of this experiment was to determine the effect of 1-MCP on 'Lakatan' Bananas in terms of its chemical properties (total soluble solids or TSS, total titratable acidity or TTA, and pH); organoleptic attributes (aroma, taste, off-flavor, off-odor, pulp color and over-all acceptability) and ethylene production. In addition, the best method of application was also determined.

METHODOLOGY

Site and Duration of the Study

The study was conducted at NEH Learning and Exchange Farm, Pantaron, Sto. Tomas, Davao del Norte last March – April 2018. The experiment was conducted and performed under an ordinary storage room.

Experimental Design and Treatments

The experiment was carried out following a Completely Randomized Design (CRD). There were three treatments which were replicated three times. The treatments were as follows: T1 - 1-MCP Gas Exposure (exposed for 20 hours; dosage: 400 nL/L-1 1-MCP); T2 – 1-MCP Spraying (dosage: 400 nL/L-1 1-MCP) and T3 – No 1-MCP application.

Fruit Selection and Postharvest Treatment

'Lakatan' fruits were harvested at the banana farm of USEP-Tagum Campus, Apokon, Tagum City. Two (2) weeks before the schedule of harvest, tagging in the field was done to ensure conformance to the quality attributes such as fruit age of 10 hanging weeks at harvest, hand positioned on the 2nd – 4th from the distal hand (only 3 hands were used in each bunch), has 3 functional leaves at harvest, has uniform hand class of 7 and classified under class A quality standard based on export market requirements. After harvesting of selected fruits, bunches were dehanded, weighed, installed with tags and transported to the research site. The fruit hands were then clustered carefully and crown of the clusters were trimmed off smoothly. Fruit clusters and fingers were submerged in the water for 15 minutes allowing the latex to coagulate. Fruits were then removed from the water and allowed to set aside for 5 minutes in the plastic crates in preparation for fruit treatment.

1-MCP Fruit Treatment

1-MCP Gas Exposure Method. A computed amount of 1-MCP powder (dosage: 400 nL/L-1 1-MCP) was placed in a 150 ml glass container positioned inside the airtight chamber where the fruits were arranged. A tube was installed connecting to the glass container to the outside. After closing and sealing the chamber, a 10 ml distilled water was added through the tube. The water triggered the release of 1-MCP and eventually initialized instantaneously occupying the whole space of the chamber. The small fan inside the chamber was turned on and the chamber was kept closed for 20 hours. 1-MCP produced under Rohm and Haas (active ingredient: 1-Methylcyclopropene – 3.8%) was obtained from the University of the Philippines Mindanao Campus, Mintal, Davao City.

1-MCP Solution Spray Method

An aqueous spray solution was made where an amount of 1-MCP powder was added with one liter distilled water. The prepared 1-MCP spray solution was applied to the fruits using atomizer within 10 minutes right after its preparation. After spraying, the fruits were enclosed in plastic bags for 2 hours to allow time for binding of 1-MCP. After 2 hours, treated fruits were removed from the plastic bags, packed in a carton with treatment codes and placed in its respective storage areas. Treated fruits were stored in an ordinary room condition (25-30 °C) throughout the duration of the study.

Data Gathered

Treated fruits were evaluated based on the parameters for chemical properties such as total soluble solids (TSS), total titratable acidity (TTA) and pH, organoleptic attributes such as aroma, taste, pulp color and over-all acceptability, and ethylene production of the fruit. Chemical properties was measured in the laboratory using a hand-held refractometer for TSS, titrimetric method with standard 0.1 NaOH using 0.1% phenolphthalein as indicator in measuring TTA and digital pH meter for pH. The sensory evaluation was based on its organoleptic attributes at peel color indicator 6 (CI 6) and was measured using a scale of 1-10 following an affective method. A trained panelists of 10 who were also consumers of bananas answered questions stipulated in a questionnaire.

Ethylene production was measured using Gas Chromatography with flame ionization detector (GC-FID 2014; 6890N GC with 5973 Mass Spec). One cluster of banana served as representative per treatment. Clusters were weighed and then enclosed in a small respiration chambers for 1 hour. After which, 1 mL gas sample was collected through syringe and placed in a vacutainer. The vacutainers were positioned upside down in a styrofoam box containing water to water-lock the gas samples to prevent from dissipation. The samples were transported to the PHTRC of UP-Los Baños, Laguna for analysis. The gas samples were injected in a gas chromatography with flame ionization detector where peak heights for ethylene and the standard were measured. Gas collection was done from day 1 up to the termination of the research in a periodic (every 3 days) basis.

Statistical Analysis

The data were analysed using the Analysis of Variance (ANOVA). Square root transformation was necessarily used on some parameters that signifies departure from normality making ANOVA invalid. Difference among the treatment means was compared using Tukey's Honest Significant Difference (HSD) test.

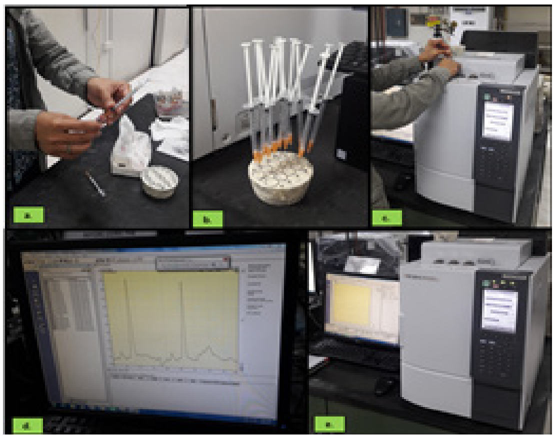

Figure 1. Ethylene Gas Reading. (a) Extraction of ethylene gas from the vacutainer, (b) Syringes containing ethylene gas for analyses, (c) Insertion of the syringe to the GC column, (d) sample of chromatograph, (e) GC-FID 2014.

RESULTS AND DISCUSSION

Total Soluble Solids (TSS), Total Titratable Acidity (TTA) and pH

The TSS, TTA and pH of fruits are important indicators of fruit quality. The balance of sweetness and acidity determines quality of taste and affects consumer acceptability. TSS, TTA and pH of pulp were measured when fruits had reached full yellow stage (CI 6). An initial measurements of TSS, TTA and pH of the fruit gathered before fruit treatment were recorded at 8.00 °Brix, 1.37 meq/100g sample and 5.60 respectively.

The effects of TSS, TTA and pH as influenced by method of 1-MCP application is presented in Table 1. Based on the statistical analysis of the data, TSS and TTA of 'Lakatan' fruits were significantly affected by methods of 1-MCP application while pH showed no significant difference among treatments. Fruits under ambient condition with no application of 1-MCP registered the highest Total Soluble Solids (TSS) than fruits with 1-MCP treatment either gas exposure or through spraying.

Total Titrable Acidity (TTA), on the other hand, was determined in the basis of % malic acid present, being the most dominant acid in bananas (AOAC, 1996). Among all methods of 1-MCP application, untreated fruits have the highest mallic acid content, being the most dominant acid in Bananas, than fruits with 1-MCP treatment either Gas exposure or through Spraying. pH values of ripe bananas ranges from 4.5 – 5.5. In this study, methods of 1-MCP application failed to show any significant effects in terms of pH of pulp.

When bananas ripen, TSS of the fruit increases due to the sugar formation as a result of starch hydrolysis. In this study, fruits without ripening inhibitor followed normal chemical changes during ripening process associated with changes in firmness and formation of acids and sugars which was similar to the results observed on the study of Salvador et. al. (2007). Normally, 'Cavendish' bananas in the lowland ranges from 18 – 21 ˚Brix while Red Banana has 23.41 ˚Brix when reached its full yellow stage as reported by Mohapatra et. al., (2016).

On the other hand, the total amount of acid increases during ripening. The malic acid concentration has been reported to vary between 0.8 and 7.5 meq/100 g fresh weight (von Loesecke, 1950) and to increase three to sevenfold during ripening (Barker and Solomos, 1962; Harris and Poland, 1937).

Table 1. TSS, TTA and pH of ambient stored 'Lakatan' fruit pulps at full yellow stage as influenced by method of 1-MCP application.

TREATMENTS	TITRATABLE ACIDITY, SOLUBLE SOLID AND pH 1		
	TSS (˚Brix)	**TTA (meq/100g)**	**pH ns**
Initial (Day 0)	8.00	1.37	5.60
Method of 1-MCP Application			
T1 - 1-MCP Gas Exposure	19.08 [b]	3.25 [b]	5.18
T2 - 1-MCP Solution Spraying	19.28 [b]	3.27 [b]	5.00
T3 - Control / No 1-MCP Application	21.25 [a]	3.70 [a]	4.72
CV (%)	7.77%	7.67%	5.12%

1 = means with the same letter do not differ significantly using Least Significant Difference Test;
* = significant at 5% level; ** highly significant at 1% level; ns denotes not significant

Bananas like any other fruits contain many compounds which are soluble in water (e.g. sugars, acids, Vitamin C, amino acids and some pectins.) These soluble compounds form the soluble solid content of the fruits. In most ripe fruits, sugar forms the main component of soluble solids. Sugar develops during fruit ripening and softening process, as starch is broken down to the simple soluble sugars and also the amount of soluble pectin will increase, leading to fruit softening (Afshar & Rahimi., 2010).The amount of TSS or sugar in bananas usually increases as they mature and ripen. Thus, the soluble solid contents of the fruit can be a useful index of maturity or stage of ripeness (Dadzie & Orchard, 1997).

The pH values give a measure of the acidity and alkalinity of a product, while titratable acidity gives a measure of the amount of acid present. Evaluating the pH and titratable acidity if bananas could be considered as indicators of fruit maturity or ripeness. They are primarily used to estimate consumption quality and hidden attributes. Acids make an important contribution to the postharvest quality of the fruit as taste is mainly a balance between the sugar and acid contents, thus, postharvest evaluation of acidity is important in the assessment of taste (Dadzie & Orchard, 1997).

Based on the results of this experiment, as ripening was considerably delayed for 1-MCP treated fruits (Figure 2), normal chemical and biochemical changes of bananas were either disrupted or retarded. The delay on the ripening as evident on the softening and peel color change on 1-MCP treated fruits significantly affects the formation of sugar and acid content of 'Lakatan' fruits. The peel appeared as full yellow but the chemical processes was delayed or inhibited.

Organoleptic Attributes

The sensory attributes were evaluated using a scale of 1-10 to assess the pulp color, taste, aroma, off-odor, off-flavor and overall acceptability of 'Lakatan' fruits at peel color indicator 6 (Figure 3). For pulp color, taste, aroma and overall acceptability parameters, 10 was the highest sensory score while off-odor and off-flavor has an inverse rating scale description.

Shown in Table 2 are the results of organoleptic evaluation of fruit samples as affected by method of 1-MCP application under ambient storage. Sensory attributes of fruits were significantly affected by1-MCP.

Figure 2. 'Lakatan' banana fruits at 10 days of storage in an ambient condition room showing delayed ripening of 1-MCP treated fruits (T1- 1-MCP Gas Exposure Method and T2 - 1-MCP Solution Spraying) compared to T3 (No application of 1-MCP).

Table 2. Organoleptic attributes of ambient stored 'Lakatan' fruits at full yellow stage (CI 6) as influenced by method of 1-MCP application.

TREATMENTS	ORGANOLEPTIC ATTRIBUTES 1					
	Aroma *	Taste *	Pulp Color *	Off-Flavor **	Off-Odor **	Overall Acceptability*
T1 - 1-MCP Gas Exposure	7.60^{b}	7.85^{b}	7.92^{b}	2.07^{a}	2.15^{a}	8.03^{b}
T2 - 1-MCP Solution Spraying	7.80^{b}	7.85^{b}	7.90^{b}	1.90^{b}	1.90^{b}	7.82^{b}
T3 - Control / No 1-MCP Application	9.05^{a}	9.02^{a}	8.87^{a}	1.32^{b}	1.32^{c}	8.95^{a}
CV (%)	11.56%	34.15%	32.36%	9.79%	9.16%	9.72%

1 = means with the same letter do not differ significantly using Least Significant Difference Test;
** = significant at 5% level; ** highly significant at 1% level; ns denotes not significant*

Figure 3. 'Lakatan' banana fruits at CI 6 ready for sensory analysis.

In terms of method of 1-MCP Application, fruits of no 1-MCP treatment had the highest sensory scores in terms of pulp color, taste, aroma and overall acceptability and the lowest sensory scores for off-odor and off-flavor (Table 2). In contrast, 1-MCP treated fruits either through gas exposure or spraying yielded lower sensory scores in terms of Aroma, Taste, Pulp Color and Overall acceptability but with more intense off-flavor and off-odor than untreated fruits.

As the chlorophyll in the peel breaks down, the starch within the fruit is converted into simple sugars. As a result, the peel turns yellow and the fruit softens up and becomes sweet. This change leaves the peel much softer and thinner than it was initially, making it much easier to "peel" back from the pulp (Müller & Kräutler, 2010). When the fruit delays the ripening process such in the case of 1-MCP treated fruits, the conversion of sugar will slow down or will be delayed. The decrease in pH and increase in titratable acidity will also slow down significantly. In effect, flavor will be affected (Kulkarni & Aradhya, 2005).

The 1-MCP treated fruits have lower sensory attributes due to the delay in the conversion of starch to sugar as well as attaining an acceptable sugar and acid balance. However, these fruits will eventually be equated with fruits without 1-MCP treatment but requires more time.

Ethylene Production Measurement (nL/gram/hour)

Ethylene production of 'Lakatan' fruits was measured to evaluate the effect of 1-MCP on the ethylene production of 'Lakatan' fruits as influenced by method of 1-MCP application. Analysis of variance (ANOVA) showed that ethylene production of 'Lakatan' fruits was not significantly affected by method of 1-MCP Application one but showed significant effects on the succeeding days of storage *(Table 3).*

Ethylene production of 1-MCP gas exposure significantly reduced the ethylene levels of the fruits compared to other treatments. However, higher ethylene levels showed on day 16 for treatments 1 and 2 compared to treatment 1 with no application of 1-MCP. This is probably because 1-MCP of the methods of 1-MCP application reacts with the ethylene receptor and inhibits the action of ethylene. When 1-MCP molecules sit on ethylene receptor sites, it binds the receptors sites and does not allow the receptor to "unlock" like the ethylene molecule does (Blankenship, 2001).Therefore, no signal can be sent for a chemical reaction, which delays the further ripening. In this case, the ethylene level of 1-MCP treated fruits rose up because they are not used compared to fruits without 1-MCP treatment where receptors were not blocked.

In some commodities, 1-MCP lowered ethylene production in strawberry (Jiang et al., 2001), slowed ethylene production in apricots and plums (Dong et al., 2002), and inhibited ethylene production in apples (Fan et al., 1999). When fruits were treated with 1-MCP, the ethylene climacteric was delayed by 6 days and reduced in level over 50% in avocado (Jeong et al., 2002) and it was also reduced in plums (Abdi et al., 1998) and apricots (Dong et al., 2002) treated with 1-MCP.

In contrast, in pineapple (*Ananas comosus*) the decline in ethylene production was slowed in 1-MCP-treated fruit compared with a control, resulting in 1-MCP fruit producing more ethylene than the control (Selvarajah et al., 2001). Ethylene production was increased by 1-MCP in *Penicillium digitatum* infected grapefruit (Mullins et al., 2000) through uninhibited expression of the stress-associated ACC synthase genes; however these fruit remained green.

Table 3. Ethylene emission of ambient stored 'Lakatan' fruits as influenced by method of 1-MCP application.

TREATMENTS	**ETHYLYNE EMISSION (nL/gram/hour) 1**					
	Days of Storage					
	Day 1 ns	**Day 4 ****	**Day 7 ****	**Day 10 ****	**Day 13 ****	**Day 16 ****
T1 - 1-MCP Gas Exposure	0.41	0.51^{b}	0.42^{c}	0.88^{b}	1.39^{b}	2.23^{ab}
T2 - 1-MCP Solution Spraying	0.38	1.01^{a}	0.85^{b}	1.55^{a}	1.50^{b}	2.33^{a}
T3 - Control / No 1-MCP Application	1.91	1.13^{a}	1.16^{a}	1.52^{a}	1.89^{a}	1.99^{b}
CV (%)	16.06%	7.75%	6.48%	5.11%	8.40%	5.94%

1 = means with the same letter do not differ significantly using Least Significant Difference Test;
** = significant at 5% level; ** highly significant at 1% level; ns denotes not significant*

CONCLUSION AND RECOMMENDATIONS

The 1-Methylclopropene (1-MCP) and Ethylene have obvious effects on a wide range of climacteric fruits especially in bananas. The 1-MCP significantly delays the physiological and chemical processes of the fruit while ethylene enhances the ripening process associated with yellowing, softening, and chemical changes. These two factors significantly affect the quality of the produce. 1-Methylcyclopropene (1-MCP) has significant effects in delaying the ripening of 'Lakatan' fruits in terms of prolonging shelf life and maintaining postharvest quality.

In this study, methods of application (1-MCP gas exposure for 20 hours, 1-MCP spraying through 1-MCP aqueous spray solution, and No 1-MCP application) on 'Lakatan' banana fruits were evaluated to determine the total soluble solids (TSS), total titratable acidity (TTA) and pH, organoleptic attributes such as aroma, taste, pulp color and over-all acceptability, and ethylene production of the fruit. Both gas exposure and spraying methods reduced TSS and TTA of 1-MCP treated fruit, while pH was numerically higher than in fruits with no 1-MCP application. On the other hand, fruits with no 1-MCP treatment had better aroma, taste, pulp color, and over-all acceptability after ripening at 25 – 30 ˚C compared to 1-MCP treated bananas when they reached full ripeness (peel color indicator 6) under similar condition. Ethylene production of 'Lakatan' banana fruit was significantly reduced by 1-MCP application with gas exposure being more effective than spraying.

Based on the results of this experiment, as ripening was considerably delayed, normal chemical and biochemical changes of bananas were either disrupted or retarded. The delay on the ripening as evident on the softening and peel color change on 1-MCP treated fruits significantly affects the formation of sugar and acid content of 'Lakatan'. The peel appeared as full yellow but the chemical processes was delayed or inhibited.

Having these effects and evidences, it is suggested to conduct research involving the application of exogenous source of ethylene to measure the interaction effects of Ethylene and 1-MCP. These are very helpful in unferstanding the role of ethylene in tropical fruits and how 1-MCP can control their production or inhibits its action.

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ASSESSMENT OF THE POSTHARVEST HANDLING OF TOMATO (THE CASE OF BUKIDNON, PHILIPPINES)

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ABSTRACT

The study aimed to establish baseline information on postharvest handling systems of tomato and at the same time determine the postharvest losses incurred in the system. Bukidnon is the top producer of tomato among the provinces in the Philippines which accounts for about 19% of the average total volume of production.

Tomatoes are harvested about 75 to 85 days after transplanting. Most of the variety planted in Bukidnon is "Dwarf Green". Harvesting of tomato is done early morning and sorting is done by classifying tomato according to size and degree of ripeness. All of the farmers in Bukidnon use wooden crates in transporting tomato to the trading post. Majority of tomatoes in Bukidnon are brought to Divisoria which is the major trading center of fruits and vegetables in the Philippines.

The total loss from the farm to the final market in Divisoria was about 24.14% after nine days of harvest. High losses incurred at pre-harvest which totalled 12.26% were due to infestation, immature and over matured fruit. The 11% losses at wholesaler-retailer level were caused by pathogen damages, spillages and transpiration.

It is recommended that farmers and other stakeholders will be provided with training on production technologies which include pest management, postharvest handling management and good agricultural practices.

Keywords: Tomato, Postharvest handling system, Quantitative and Qualitative losses

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INTRODUCTION

Tomato (*Lycopersicum esculentum*) which is locally known as "kamatis" is the fourth important vegetable in the country in terms of volume of production. It plays an important role in the economy because it is a short duration crop that can provide high returns to farmers. A hectare of tomato with a yield of 12,753 metric tons sold at PhP13.00 per kilogram can give profit of PhP73,140.00 per hectare (PSA.gov.ph). Average per capita consumption from 2010 to 2017 was 1.63 kilogram (PSA.gov.ph). Various processed forms include pastes, sauces, purées, jams, candies, juices and ketchup but most of the production is consumed directly.

The country produced about a yearly average of 213,305 metric tons of tomato with an area of 16,815 hectares from 2010 to 2017 with an average yield of 13MT per hectare. About 77% of the average volume of production was produced by 10 major tomato producing provinces in the country. The top tomato producing provinces are: Bukidnon, Ilocos Norte, Ilocos Sur, Pangasinan, Sur, Nueva Ecija, Quezon, Iloilo, Nueva Vizcaya and Misamis Oriental. Bukidnon is the top producer of tomato among the provinces which accounts for about 19% of the average total volume of production. The province of Ilocos Norte and Ilocos Sur respectively dominated the second and third places at 14 and 11% share in the total production.

Bukidnon is the largest vegetable producing province in Northern Mindanao. It is also a major producer of rice, corn, sugar, coffee, rubber, pineapple, tomato, flowers, cassava, and other fruits and vegetables. Vegetable products of Northern Mindanao are mostly shipped or transported to Manila and other provinces such as Cebu, Iloilo, Bacolod, Zamboanga, Davao, Butuan and Palawan. Estimated volume of vegetables shipped by sea and air bound for Manila and other major cities accounted for 79% and four percent, respectively. Only 17% was distributed locally (DTI report, 2007).

The effort of providing the food needs of the growing population is more often focused on increasing production. Duman (2010) emphasized that there is significant need to reduce the supply chain losses in the developing countries. On the contrary, postharvest handling management should be applied immediately to get better quality of vegetable harvest.

Tomatoes like other crops also have postharvest problems. These are: 1) short shelf-life; 2) inadequate cold storage facilities which lead to high rate of rejects; 3) high rates of transport damage; 4) inadequate farm to market roads; and 5) lack of postharvest facilities like packing house.

The losses in tomato are about 18 to 38% due to rotting and weight loss (Apaga and Nuevo, 2010). With high postharvest losses incurred in tomato and the concern to save on losses for food, there is a need to assess the postharvest handling system of tomato especially the losses incurred in every chain.

The results will serve as basis for providing appropriate interventions to tomato sub-sector to minimize or reduce postharvest losses.

The general objective study was to assess the postharvest losses of tomato. Specifically the study aimed to: (1) identify and characterize the postharvest handling systems of tomato from farm to the market; (2) determine the quantitative and qualitative losses at major points in the postharvest handling systems; and (3) identify the problems and constraints in the postharvest handling systems.

REVIEW OF LITERATURE

According to the report of Department of Trade and Industry in Bukidnon (2007), the development of the tomato industry is hampered by some of the following problems: 1) lack of vegetable processing activities that can extend the shelf-life of tomato and which can also help increase the income of the farmers; 2) lack of complementation across the production areas which result to oversupply of tomato; and 3) high postharvest losses which emanate from inadequate postharvest technology, poor farm to market roads and absence of cold storage facilities.

Concepcion and Digal (2008) noted that the vegetable supply chain in the Philippines follows a traditional chain where farmers sell their produce in the spot market to traders, consolidators, vegetable processors and wholesalers in the wet markets.

Llanto G.M. et. al (2012) said that the lack of an efficient transport and distribution system increases the cost of transporting agricultural produce, reduces the quality and quantity of those goods, and diminishes the profitability of actors involved in the supply chain.

METHODOLOGY

Literature search, use of secondary data, survey, loss assessment, and consultation workshops were conducted to gather necessary data. Tracing method was adapted to determine the major postharvest handling systems and stakeholders in the supply chain of tomato from Bukidnon.

Focus group discussions and key informant interviews

Key informant interviews and focus group discussions were used to gather data needed in the analysis of the supply chain. FGDs were conducted in top tomato producing barangay/ municipalities to elicit information on the production and postharvest practices. A minimum of 10 tomato farmers or 10% of total number of tomato farmers per top producing barangay attended the focus group discussion. The information gathered specially on postharvest and marketing practices served as basis in the conduct of loss assessment studies. Initial information was also gathered from the farmers on postharvest losses.

Postharvest Loss Measurement

Postharvest losses emanate from poor production, postharvest and marketing management. Qualitative losses affect the market value of the crops. Vegetables that are affected with blemishes and misshaped have lower market price compared to vegetables that are free of blemishes and good in form Quantitative loss is defined as the physical loss caused by reduction in product weight and volume. The method and formulas used in the loss assessment was partly adopted from Ramos et.al (2009).

The actual operations from production in Sumilao, Bukidnon, postharvest handling of the product to retail market in Manila were observed and noted. The following data were gathered during the conduct of the study: 1) the initial condition and weight of the produce from farm to market; 2) distance travelled; 3) temperature and relative humidity; and 4) quantitative and qualitative losses. Data on cost of production, farm management practices and postharvest handling of the farmer-cooperators were also obtained.

Qualitative Losses

Visual quality rating and quality profile were used in determining the quality loss. Visual quality rating (VQR) refers to the physical attributes of the commodity as affected by handling or mechanical damage during harvest and handling operations. The evaluations of the losses in quality were performed at the determined points of the commodity flow. For every sample, 5 to 10% of the total weight of fruits per container was subjected to the rating. Quality evaluation of the samples was performed by two to four trained researchers then average rating of samples was computed. The VQR scale used for actual handling trials was set based on the pre-identified defect types of tomatoes and quality standards of buyers, and consumers (Table 1).

Quality Profiling

Quality profile (QP) is a method of evaluation where the general quality of the produce is described by its frequency or percentage of defects or damage present. The degree, extent or description of the quality defects or damage (e.g. bruises, compressions, rotting) were defined and agreed by the trained evaluator. Table 2 shows the quality traits used in quality profiling.

Table 1. Rating scale used in visual quality rating (VQR) of tomato samples

Scale	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 and physiological damaged)
2	Minimum level of edibility (11 to 20% physical damaged and/or visible pathogen damaged)
1	Non-edible (>20% physical and physiological damaged)

Table 2. Quality traits used in describing quality profile (QP) of tomato

Pre-harvest	Postharvest		
	Mechanical damage	Pathological defects	Physiological defects
Sunscald	Deep dents	Soft rot	Overripe
Cat-faced	Compression damage	Wilting	Blotchy ripening
Cracking	Bruise	Signs of disease	
Irregular/blotchy	Puncture	Due to mechanical damage	
Ripening	Cut		
Puffiness	Cracked		
Zippering			
Small dots			
Insect damaged			

Quantitative Losses

Quantitative loss referred to as physical loss caused by a reduction in product weight. The following formula were used in the calculation of the different types of losses in the supply chain.

Pre-harvest losses (%PHL) refer to losses that are due to natural causes such as genetic, nutrient, cultural management and other environmental factors. This also includes pest and diseases at farm level of infestation.

$$\%\ PHL = \frac{wt.\ PHL}{Total.yield + wt.\ of\ PHL} \qquad (1)$$

Harvesting and sorting loss are good marketable fruits that are left in the field ground during harvesting or fruits that are accidentally thrown off as rejects but are marketable during sorting.

$$\%\ harv.loss = \frac{wt.of\ harvesting\ loss}{wt.\ of\ marketable\ fruits} \qquad (2)$$

$$\%\ sort.loss = \frac{wt.\ of\ sorting\ loss}{wt.\ of\ marketable\ fruits} \qquad (3)$$

Weight loss refers to losses that are due to transpiration and spillage.

$$\%\ wt.loss = \frac{weight_{Initial} - weight_{Final}}{weight_{Initial}} \qquad (4)$$

Non-Marketable Rejects are fruits with physical and physiological defects that are removed during sorting and are not saleable.

$$\%\ non\text{-}mktble. = \frac{Wt.\ rejects}{weight_{Initial}} \quad (5)$$

Marketable rejects fruits that have market value and sold at a lower price due to minor defects.

$$\%\ Mktbl.\ rejects = \frac{Wt.\ of\ mktble.rejects}{weight_{Initial}} \quad (6)$$

Physiological defects are due to unfavorable change in color or ripeness.

$$\%\ Phys.defects = \frac{Wt.phys.defects}{Weight_{Initial}} \quad (7)$$

System/handling Loss is the total loss incurred from harvesting down to retailers area.

$$\%\ System\ loss = \frac{\sum Losses_{(start\ to\ end)}}{Volume_{(start)}} x\ 10 \quad (8)$$

Valuation of losses

Losses at each point of in the postharvest marketing system were computed based on the actual data collected from each handling point, from the farm until it reaches the retail market. Market and storage conditions were simulated in the laboratory to determine effects of longer storage. Losses at each handling point of the major marketing systems from farm to retail market were computed using the following formulas;

Percent point weight loss are the losses that are computed per transaction or points

$$\%\ pt.wt.loss = \frac{wt._{(pt.1)} - wt_{(pt.2)}}{wt._{(pt.2)}} \quad (9)$$

Percent point rejects fruits that are removed due to physical or physiological defects

$$\%\ Rejects_{(retail)} = \frac{wt.\ of\ rejects_{retail}}{initial\ wt._{wholesale}} \quad (10)$$

RESULTS AND DISCUSSION

Description of Study Area

Bukidnon is situated in the province of Northern Mindanao. The climate is relatively cool and moist throughout the year primarily because of its elevation and mountainous topography. Mean temperatures are around 24 degrees Celsius, reaching a maximum of 30 and a minimum of 18 degrees. The top tomato producing municipalities and which were covered by the study are Malaybalay City, Dalwangan, Impasug-ong and Sumilao.

Varieties planted

In Bukidnon, the most common varieties planted by majority of farmers are Dwarf White and Dwarf Green. Dwarf White and Dwarf Green are preferred by farmers because it is adaptable in their soil type, resistant to pest and diseases, has thick skin which makes this varieties good for long duration transport. Other tomato varieties planted are Hybrid 17, Harabas 746, White Apollo, Pink Apollo, Macapuno, Improved Pope Diamante Max, and Agatona.

Planting and Harvesting Seasons

Planting season is dependent on the type of climate prevalent in the area. Bukidnon has two types of climate which are Type III and Type IV. Type III has no pronounced rain but relatively dry during the months of November to May and the southern part of the province, the climate is classified as Type IV with no dry season.

In Bukidnon, regular season starts in March and ends in October. Peak season planting is from May to July. The months of November to May are relatively dry and farmers who plant tomato from August to December should have available water supply. The off season planting is from August to December and majority of farmers plant tomato from September to November. This is the time where farmers from Luzon are at risk of planting tomato because of occurrence of typhoon in the area. Harvesting of tomatoes is whole year round since farmers were able to plant tomatoes during off- season.

Postproduction practices

All of the farmers in the major producing areas used maturity period and color of the fruits as indicators when tomatoes are ready for harvest. Tomatoes are harvested about 75 to 85 days after transplanting.

Harvesting of tomato is usually done early morning and placed either in pail, wooden or plastic crates. Sorting is done by classifying tomato according to size and degree of ripeness. Tomatoes that are also damaged (i.e. decayed fruit, pest damaged) are taken out to prevent contaminations. Some farmers mix kerosene, cooking oil and water then use the mixture in swiping tomatoes to remove surface moisture and dusts.

Wooden crates are used because it is cheaper than plastic crates. A wooden crate costs only PhP25.00 – PhP30.00 per piece while the plastic crate cost PhP300.00 to PhP400.00 per unit. In addition, plastic crates need to be transported back to be reused by the owners. Each wooden crate can contain 25-32 kilogram of tomatoes. Tomatoes in crates are transported from farm to Bulua Trading Post using small trucks.

During off season harvest, tomatoes are classified as: 1) small; 2) medium and large. During the months of October to January, farm gate prices can reach as high PhP45-60.00 per kilogram for big, PhP30-45.00 per kilogram for medium and PhP15-30.00/kg for small. Reject tomatoes are even sold for a farm gate price of PhP 8-12.00 per kilogram. In contrast, during peak season production (June to July), the price of tomato per kilogram is PhP3.00 for small, PhP8.00 for medium and PhP11.00 for big.

All of the farmers interviewed in Bukidnon use wooden crates which allow buyers to see the condition of tomato through the openings. Buyers from Metro Manila and other distant provinces prefer matured green tomatoes to avoid high losses and over ripping during transport to Manila.

Figure 1 shows the postharvest handling of tomato from Bukindon to Manila.

Postharvest-handling system of tomato

This section presents the following: 1) market flow; 2) loss assessment; and 3) postharvest handling cost of tomato from farm to market. Market flow traces the movement of tomato from the farm to the final market. Loss assessment includes the qualitative and quantitative measurement of losses from farm to market. Postharvest handling costs involve assessment of expenses from production, postharvest and marketing expenses. Losses incurred in every chain were also considered in the analysis.

Postharvest handling of tomato

Table 3 shows the details on postharvest handling system of tomato. Harvesting of tomatoes is done early morning at 6:00 A.M. It takes around 8-12 persons to harvest 1,500 kilograms tomato. Two persons are assigned to haul the tomatoes that are placed either in crates or in pail to the sorting areas. The average travel time from the farm to sorting areas is four to five hours.

Upon reaching the sorting areas, tomatoes are poured in the sorting table and sorted based on size (e.g. small, medium and large) and degree of ripeness. It takes six persons in two hours to sort 1,500 kilograms of tomato. Only tomatoes that are green are placed in crates for Manila market. Tomatoes in crates reached Bulua Trading Center at around 3:00 P.M. and buyers examine it to make sure that it's all green to prevent losses due to over ripe.

During lean months tomatoes are paid immediately by the traders but during peak season harvest, farmers have to wait for the payment until their tomatoes are sold to Manila traders. Tomatoes are shipped to Manila for 48 hours placed in the container van with ambient temperature and have to wait for about six to eight hours before it will be unloaded. Most of the tomatoes are brought to Divisoria storage room where air conditioned units are installed. Tomatoes are resorted every after two days based on degree of ripeness.

Figure 1. Postharvest handling system of tomato. 2014

Market flow.

Bukidnon produces around 19% of the total national production of tomatoes. From the major producing municipalities, tomatoes in wooden crates are transported by open truck to Bulua Trading Center. Figure 2 shows that about 97% of tomatoes produced in the top producing municipalities of Bukidnon are delivered to Bulua Trading Center, Cagayan de Oro and 91.18% of which are transported to Luzon, Visayas and Mindanao. These losses incurred during transit totalled to 5.82% are caused by spoilage, bruises, and spillage. The remaining four percent are retained in their respective local markets, but only 2.82% were sold and 0.82% was rotten and damage.

From Bulua Trading Center, 64.4% of tomatoes delivered are transported to Luzon and 45.2% of which are brought to Divisoria, The remaining tomatoes are transported in Visayas (33.6%) and Mindano (10%). Some farmers opt not to harvest when price of tomato is very low (PhP2.00-PhP5.00 per kilo).

Tomatoes that are marketed to Manila are transferred to container yard. From Cagayan de Oro, the ship passes Cebu City before going to Manila. Travel time from Cagayan de Oro port to Cebu City is about eight to nine hours and another 20 hours going to Manila.

Tomatoes are then unloaded from the container vans in Manila and taken to Divisoria. Tomatoes are placed in air-conditioned bodegas for two to six days before they are sold for wholesale and retail.

Table 3. System of handling tomatoes from Bukidnon to Manila, June-July 2014

Process Flow	Player	Labor/Vehicle/ Facility	Duration	Activity Details
Harvesting	**FARMER LEVEL (Sumilao, Bukidnon)**	8-12 persons	4-5 hours (depending on distance of farm to market)	- Usually done at 6AM - Tomatoes from green mature to red are hand picked then placed in pails then transfered to wooden crates.
Cleaning/Sorting		4-6 persons	4-5 hours	- Sorting is simultaneously done with sorting and packing. - Tomatoes are sorted according to size and degree of ripeness. Only tomatoes from green mature to pink color are marketed.
Packing		1-2 persons	Min/box	- Tomatoes are closed-packed in wooden crates (24-25kg) then loaded to the truck. If the truck is not available, crates are covered with plastic canvass and stayed near the farmers' house until the truck arrived
Transport		2-3 persons Elf/ jeepney (50-200 crates)	3-4 hours	- Loading to truck then transported to Bulwa Market. - Arrival is usually at 3:00 PM
Marketing	**TRADER LEVEL (Bulua, CDO, Misamis Or.)**	2-3 persons 1 stall (200-300 crates capacity)	3-4 hours	- binding of crates - Dispoal of tomatoes to agent/wholesalers. - Payment to farmer is made after most of the tomatoes are sold.
Transport	**WHOLESALER/ RETAILER (Manila & nearby Provinces)**	Truck- 6-7 tons capacity, 10 ft. container van 256 crates	48 hours (6-10 hours waiting period in Mla Pier)	- From Bulwa to Divisoria •Loading time 200 crates/hr •Bulwa – Pier: 30 min •Pier to Pier: 48 hours •Pier to Stall in Divisoria.
Storage (Air-conditioned)		Bodega: 700-1000 crates capacity	1-5 days	- Storing and ripening of tomatoes in airconditioned bodegas. - Two 1.5hp Air conditioned is installed and alternately used in a bodega.
Sorting		Sorting baskets , hammer and nails	2-3	- Upon arrival tomatoes are sorted according to size, marketability and peel color. - Sorting is done every 2 days.
Marketing		Stalls with various vegtables	1-2	- Tomatoes are then sold ripe to retailers or directly to consumers. - 60% of tomatoes are sold in orange ripe stage while the remaining is sold to other viajeros at green mature to breaker stage - Rate of disposal is 50 to 70 crates / day.
Transportation	**RETAILER**	Tricycle:20 crates capacity; Jeepney: 50-60 Truck:100-200	1-2	- From the stall of the wholesaler, the tomatoes are sometimes transported by tricycles then transferred to a jeeney or trucks to transport it to major markets in Manila and nearby provinces.
Sorting and Marketing		Stalls with multiple vegtables	2-3 days	- Tomatoes are usually sorted according to degree of ripeness, quality and size. - All stocks (2-5 crates) are sold within two to three days after purchase, the the retailers will purchase again.

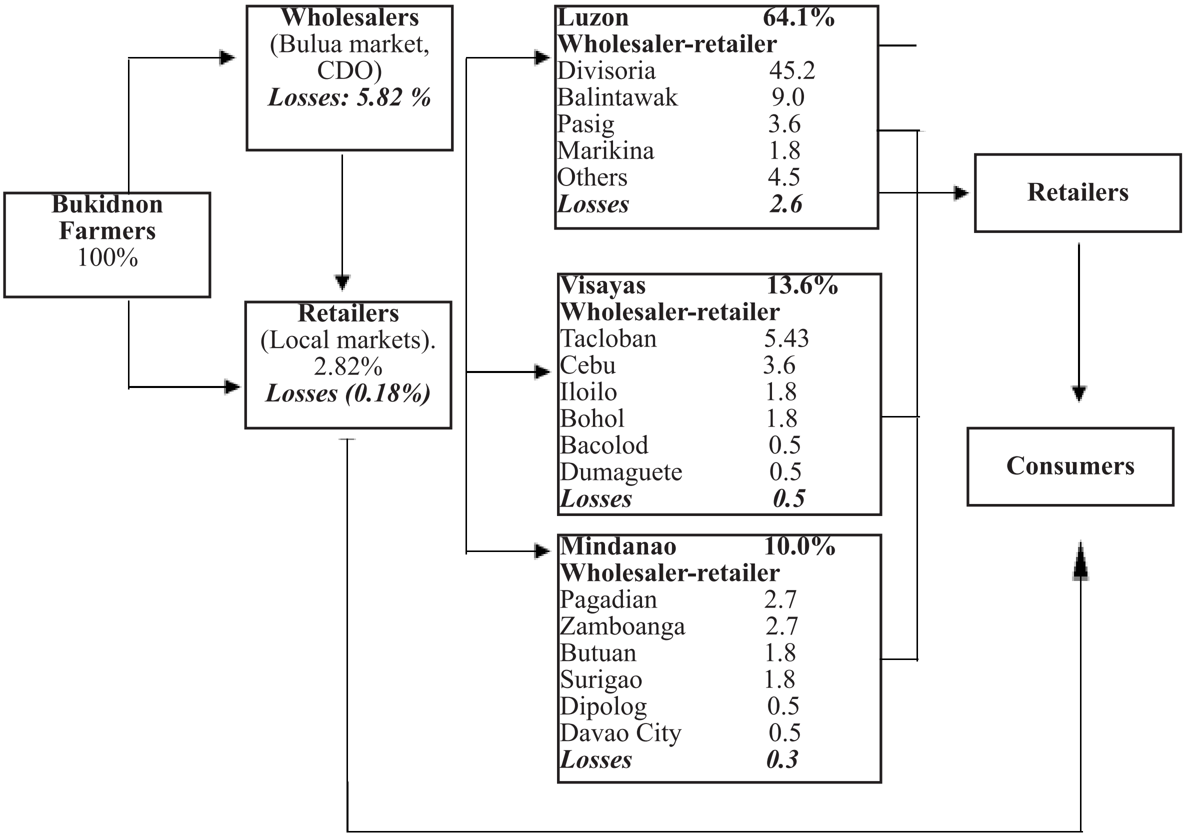

Figure 2. Commodity and volume flow of tomato from farm to Bulua Trading Post, CDO (Sources: FGD among tomato farmers and KII among wholesaler, retailers and traders, 2014)

Major stakeholders in the industry

The roles of the different stakeholders are vital in the development of tomato industry. Hereunder are their respective functions and activities:

Farmers. They are engaged in tomato production. They source-out funds for the purchase of seed, fertilizer and pesticides, care and maintenace of the crop. They facilitate and pay for harvesting, sorting, hauling and delivery. They do the postharvest management and marketing of crops.

Farmers are supported by: 1) informal lenders; 2) local government units that provides seeds, training and extension support; 3) Department of Agriculture that provides irrigation facilities and training; 4) State and College Universities that provide extension support; and 5) input suppliers.

Input Suppliers. They supply seeds, fertllizers, pesticides, bamboo materials (trellising), plastic mulch. Input suppliers are seed companies, agri-input suppliers, traders and bamboo producers. They are supported by the Bureau of Plant Industry who provides varietal testing. Fertlizer and Pest Management inspect and provide certification of safe usage of products.

Local retailers.They purchase tomatoes; rent stalls; sort tomatoes; sell tomatoes to local buyers.

Financers. They provide inputs or financial support to farmers and buy the produce

Agents/Middlemen. They purchase and/or procure tomatoes from trader/consolidators. They also arrange hauling and transportation of tomatoes; receive payment and incentive from wholesalers and pay for communication expenses.

Traders/Consolidators. They provide financial support to farmers; engage in buying and selling of tomato; rent bodega/stalls; purchase tomatoes from farmers; pay for hauling of crates from stall to truck.; binding (strapping) of crates (CDO only), electricity and water and one to two stay-in laborers.

Wholesaler-retailers. They send payment for tomatoes and transportation cost and give share agents, if any. They pick up tomatoes at delivery points; rent or maintain bodega/s for storing and ripening of tomatoes; pay for electricity and other storage costs. They hire laborers to sort tomatoes every two to three days when necessary. They sell tomatoes and other vegetables to retailers and to provincial traders.

Provincial Traders. They purchase tomatoes from wholesalers or directly from farmers; process tomatoes for local market; and sell tomatoes to retailers and/or end users.

Retailers. They purchase tomatoes from wholesaler or "bodegeros". They rent stalls in local markets**.**

Consumers. They purchase raw tomatoes from wholesalers or retailers.

Service Providers. Provide loans, trucking and shipping services.

Loss Assessment

Loss assessment for tomato was conducted last June 28 to July 9, 2014 in Barangay Poblacion, Sumilao, Bukidnon. The variety of the tomato harvested by the farmer-cooperator was Dwarf White and at its fourth harvest when the assessment was conducted. The postharvest operations from the farm to market were observed and documented.

Eight crates of tomato containing 23-25 kilograms were randomly collected, weighed and tagged as samples. One kilogram of samples per crate were marked for quality analysis and rated for visual quality rating (VQR) and quality profiling (QP). The tomatoes were transported to Bulua Trading Center, Cagayan de Oro City on July 30, 2014.

A total of 161 crates (23-25kg/crate) were loaded to the truck for transport to Bulua market. The total travel time from farm to market was two hours and 10 minutes. Farmers shoulder transportation cost amounting to PhP40.00/crate. The farmer has predetermined market outlet before the delivery. Consolidators inspect tomatoes and have to wait for the price offer of prospected buyers before giving his/her price to the farmers. The landed price in Bulua Trading Center was PhP150-PhP180.00/crate or PhP6.00-PhP7.00 per kilogram during the conduct of the loss assessment. This is low due because it was peak season. Tomatoes are sold to Manila and the cost of shipment is PhP16,000 per 10-footer container van with a capacity of 260 crates or PhP70.00/crate. The cargo ship departed at 11:15PM of June 30, 2014 and arrived at Manila on July 2, 2014. The shipment/container vans was brought out two hours after the ship's arrival then transferred to Pier 18 where most vans containing fruits and vegetables are picked-up by trucks hired by wholesalers-retailers.

The cost of hauling tomatoes from port to Divisoria is PhP15.00 per crate. The stocks are re-sorted every two days by degree of ripeness at P10.00/crate. Rotten tomatoes and rejects are removed. Tomatoes that were bought by the wholesaler-retailer at PhP250.00/ crate were sold at PhP300 to PhP 350 per crate to retailers and other traders. The wholesaler reported that 60 percent of the stocks were sold at orange/yellow orange stage for retailers in Metro Manila and the remaining 40 percent were sold to other provinces (Bicol, Ilocos, Batangas and other provinces in Luzon) at Green Mature/breaker stage. They purchase and sold about 700 to 1000 crates per week.

Tomatoes are stored in air-conditioned bodegas/air-conditioned warehouses with the capacity of 700 to 1000 crates, with 2 2Hp air-conditioner alternately switched on to maintain the temperature (20°C to 23°C). They do this to attain even ripening of tomatoes and prevent high weight loss.

Quantitative Losses

Losses from the farm to market were measured. Pre-harvest losses totalled 12.26% which emanated from infested, deformed, over matured or immature fruit. Six percent (6%) handling loss was recorded that is due to spillage in harvesting, sorting at farm and transport, and transpiration from farm to Bulwa, Market. The transpiration and spillage loss from the consolidators' level in Bulua Market to Divisoria Market is 3.40% losses due to. From CDO port, the wholesaler-retailer will receive the cargo after two to three days then the wholesaler-retailer will sort the tomatoes based on degree of ripeness. Losses incurred due to pathogen damage, physiological and some pre-harvest defects totalled 3.45%. Some factors that may contributed to high losses are: farmers lack of knowledge on proper postharvest handling, delay transport due unavailability of truck to immediately transport the crop from farm to Bulua Trading Post, Cagayan de Oro City and the long duration of travel in ship container vans for 48 hours plus 8 hours before it is released from the port. Extending the storage period by three days will result to additional 6.37% and 4.92% losses due to pathogen damage and physiological defects, and transpiration, respectively.

Qualitative losses

To determine the specific causes of losses, VQR and QP were done. Majority of the defects observed emanated from mechanical factors. Pathogen damages were also noted. The average rating score at the first day was 4.96 and at the fourth day, the score was 3.7 which means that most of the tomatoes are still in marketable condition.

Table 4. Summary of postharvest losses at different stages in the supply chain, Bukidnon- Manila, 2014

Stages and activities	Type of loss	Days after harvest	% loss
1. *Farmer level losses due to*		4th harvest	
Pre harvest Losses	Infested, immature,		12.26
Postharvest Losses	over-mature, etc.		
a. Harvesting	Transpiration/spillages/ uncollected fruits		3.01
b. Sorting & Packing	Transpiration/spillages/		0.23
c. Transportation	Transpiration/spillages mechanical-damages	0.5 day	2.76
Postharvest losses at farmer level to consolidator			**6.00**
2. *Consolidator/trader level lossess due to*		0.75 day	
a. Marketing & Transportation: Consolidator to Wholesaler	Transpiration/spillages		3.40
Postharvest losses from consolidator to wholesaler			**3.40**
3. *Wholesale-retailer level lossess due to*		5-6 days	
a. Re-sorting - Wholesaler/Retailer	Physiological defects		0.09
	Pathogen damages		2.72
	Pre-harvest defects		0.26
	Mechanical damage		0.38
b. Storage (for ripening)			
c. Marketing & Transportation - Wholesaler/Retailer			
Postharvets losses at wholesaler level			**3.45**
Total quality defects (rejects)			**3.45**
Total losses due to transpiration and spillage			**9.40**
Total postharvest losses to wholesaler-retailers level		**6-7 days**	**12.85**

Stages and activities	Type of loss	Days after harvest	% loss
a. Re-sorting	Pathogen damages	2-3 days in in the storage/retail	6.37
b. Marketing & Transportation - Wholesaler (reatiler to retailer)	Transpiration/spillages		4.92
Total losses after 1-3 days at wholesaler/retailer level		**9 days**	**24.14**

Figure 3. Unsold ripe tomatoes from Bulua that were sent back to farmers area

Marketing Losses

Consolidators in Bulua reported that during peak season, they sometimes experience marketing losses in form of unsold stocks due to over supply. Buyers, especially those from Manila and Visayas do not buy ripe tomatoes as it will just rot during transit and hasten the ripening of the stocks in the container van. The tomatoes that are unsold after two to three days are just returned back to the farmers.

Postaharvest Handling Cost Analysis

All the expenses in producing tomato from farm to market were recorded and analysed to come-up with cost analysis. As shown in Table 4, the total cost of producing, harvesting, and transporting tomato to wholesale market is around Php4.50 per kilogram. At farm gate price of about Php5.88 per kilogram, the farmer earns Php1.19 per kilogram. Price of tomato varies per day depending on the volume of tomatoes brought to the market. In instances where the farm gate price is Php2.00 to Php3.00 per kilogram, farmers usually choose not to harvest because there will be no profit for them at that price.

Among the stakeholders, wholesalers earn the highest profit of Php2.10-PhP3.10 per kilogram. They bear the highest operational expenses, cost of rejects and weight loss. Transportation cost from Bukidnon through land and sea to Manila Port at Php2.41 per kilo and Php0.59 per kilo from port to Divisoria is the highest among the costs incurred by the wholesaler-retailers. The agent Bulua trading post earns around Php0.80 for every per kilogram purchased for the wholesaler- retailers in Metro Manila. Retailers in Divisoria, earn Php2.00 to Php3.00 per kilogram of tomato purchased from the wholesalers.

The share of the farmer's cost and income in the consumer's price is 24.69% and 6.26%, respectively (Table 5). For every peso that spent by the farmer, he receives Php0.26 given that the farmgate price was Php5.88 per kilo. On the other hand, the consolidators, wholesalers-retailers, and retailers gets Php2.10, Php0.39, and Php1.94 for every peso that they spend in trading tomatoes.

Transportation costs including manual loading and hauling accounts for 26.73% of the consumers' price followed by the production cost of 8.21% and postharvest operations at 7.21% (Table 6).

While retailers have the highest share in the consumer's price in terms of margin at 13.89% wholesaler-retailers profit more because of the larger volume of 700 to 1000 crates they sold per week.

Total losses from farm to retail market accounts for PhP0.68 to PhP0.80 pesos per kilo of tomato retailed at PhP19.00 per kilo in Manila. Losses constitutes 3.58% of the consumers' price.

Table 5. Cost and net income shares of the different chain actors in Sumilao, Bukidnon to Divisoria, Manila market, June-July, 2014

PARTICULARS TOTAL	FARMER	CONSOLIDATOR	WHOLESALER/ RETAILER	RETAILER	
Location	Sumilao, Bukidnon	Bulua, CDO	Divisioria, Manila	Hauling to retail market and retailing	
Costs, Php/kg	4.50	0.38	5.35	1.36	11.59
Value of losses	0.19				
Net Income, Php/kg	1.19	0.80	2.10	2.64	6.73
Price sold, Php/kg	5.88	7.06	15.00	19.00	
Cost share, %	24.69	2.00	30.74	7.16	64.58
Net income, %	6.26	4.21	11.05	13.89	35.42
TOTAL	30.95	6.21	41.79	21.05	100.00

Table 6. Value chain per kilogram of tomato, Bukidnon to Manila, June-July 2014

Player, inputs, costs and margins	Value per item	% of retail price	Price per phase of operation
1. FARMER		*Sumilao, Bukidnon*	
Production cost, P/kg	1.56	8.21	1.56
Harvesting, hauling fee& sorting Fee, P/kg	1.37	7.21	2.93
Transportation fee, P/kg	1.57	8.26	4.50
Harvesting loss, *3.01%*	0.18	0.95	4.68
Sorting loss, *0.23%*	0.01	0.05	4.69
Farmer's Profit, P/kg	1.19	6.26	5.88
2. AGENT/CONSOLIDATOR/MIDDLEMEN		*Bulwa, Cagayan de Oro, Misamis Oriental*	
Unloading	0.08	0.42	5.96
Packaging	-	-	5.96
Hauling of stocks to truck	0.01	0.05	5.97
Labor exp. (binding of crates & other act)	0.2	1.05	6.17
Stall fee, Electricity & water bill	0.05	0.26	6.22
Communication & other expenses	0.04	0.21	6.26
Agent/ Consolidator/Middlemen Profit, P/kg	0.80	4.21	7.06
3. WHOLESALER-RETAILER		*Divisoria Market, Manila*	
Fixed Labor	0.06	0.32	7.12
Agent's share	0.2	1.05	7.32
Packaging	0.98	5.16	8.30
Transportation cost (land & sea)	2.41	12.68	10.71
Loading & transport cost (port to market)	0.59	3.11	11.30
Unloading & hauling to storage	0.08	0.42	11.38

Player, inputs, costs and margins	Value per item	% of retail price	Price per phase of operation
Sorting cost	0.39	2.05	11.77
Storage rent	0.31	1.63	12.08
Laborer in stalls	0.17	0.89	12.25
Stall fee, Electricity & water bill	0.13	0.68	12.38
Communication & other expenses	0.03	0.16	12.41
Pt. weight loss: 3.49%	0.24	1.26	12.65
Pt. weight of rejects: 3.54 %	0.25	1.32	12.90
Wholesaler-Retailers' Profit, P/kg	2.10	11.05	15.00
4. RETAILER		***Manila and other markets in Luzon***	
Communication cost	0.07	0.37	15.07
Labor expense	0.35	1.84	15.42
Transportation cost (wholesale to retail)	0.43	2.26	15.85
Stall fee and other expenses	0.51	2.68	16.36
Retailers profit, Php/kg	2.64	13.89	19.00
Retail price of Tomato	19.00	100.00	

SUMMARY AND CONCLUSION

Tomato is an important cash crop in Bukidnon and it is faced with challenges of over supply during peak season and high losses. Results of the study revealed high incidence of losses emanating from pre-harvest and postharvest losses of 26.26 and 11.88% respectively. Pre-harvest losses were due to infestation, immature and over mature fruit. Postharvest losses stemmed from pathogens and mechanical damages.

The lack of farmer's knowledge on pre and postharvest handling management of tomato contributed to high losses. Harvested tomatoes have high pest infestation which can be prevented by good agricultural practice and proper application of pesticides. In the farm, farmers covered tomatoes in crates with canvass which caused rapid ripening and deterioration. Tomatoes are poured into sorting areas without care and placed in the wooden creates without lining. This practice leads to abrasion/bruises in the skin of the fruit which can be the entry of pathogens.

All of the farmers mentioned that fluctuating and low prices of tomato were their problem especially during peak season. According to the interview conducted, it is estimated that 25 to 30% of tomato produced during peak season were retained in the farm and trading post because of low price. Farmers do not harvest tomato when the price is PhP2.00 to PhP5.00 per kilogram. The high postharvest losses during the peak season emanates from fast ripening of fruits.

There is a need to educate the different stakeholders on proper production and postharvest handling of tomato. Technologies to extend the shelf-life of tomato would also be of great help to the industry.

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2. Name of authors must not contain professional or academic titles. The surname should be the last part of the authors' name. Affiliation of the authors should contain name of the agency or university he/she belongs, address, and the country of the authors. Include e-mail addresses of the corresponding authors.

3. Papers for submission must be recent and has not been published or submitted for publication in any other journal.

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21. Examples of different reference categories are shown below:

• *Book*

Fawcett, S. E., L.M. Elram, and J. A. Ogden. 2007. Supply Chain Management from Vision to Implementation. New Jersey: Pearson Education Inc. 530 pp.

• *Book portion*

Schuber, S. 1995. Proton release by roots. In: Singh BB, Mengel, K. Editors. Physiology and Biochemistry of Plants. New Delhi: Panama Publishing Corp. pp. 97-119

• *Journal*

Siemens, M.C and D.E. Wilkins. 2006. Effect of residue management methods on no-till drill performance. Applied Engineering in Agriculture. 22(1): 51-60.

• *Theses and Dissertation*

Rodeo, AJ. 2009. Low temperature conditioning to alleviate chilling injury in mango (*Mangifera indica* L. Cv. Carabao fruit (BS Thesis) College, Laguna, Philippines: University of the Philippines Los Banos.

• *Paper from a Proceedings*

M. Wegmuller, J. P. von der Weid, P. Oberson, and N. Gisin, "High resolution fiber distributed measurements with coherent OFDR," in Proc. ECOC'00, 2000, paper 11.3.4, p. 109.

• *Website*

Scofield, A. Undated. Vietnam: Silent Global Coffee Power. Retrieved on August 4, 2007 from http://www.ineedcoffee.com/02/04/vietnam/

• *Standard*

Agricultural Machinery Testing and Evaluation Center (AMTEC). 2003. Philippine Agricultural Engineering Standards. Volume 1. 2003. PAES 124:2002 Agricultural Machinery – Walking-type Agricultural Tractor – Specifications Part 3: Special Type (Float-Assist Tiller). College, Laguna, Philippines: University of the Philippines Los Banos (UPLB). p.8

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