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Goal and Scope

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

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

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CONTENTS

DESIGN AND DEVELOPMENT OF CACAO ROASTER USING RESPONSE SURFACE METHODOLOGY

Andres M. Tuates Jr.[1], Ian Joshua Santiago[2], Shiela Marie A. Villota[3] and Ofero A. Caparino[4]

ABSTRACT

Roasting is the process where heat treatment is applied to produce the fundamental chemical and physical changes in the structure and composition of cacao beans. It decreases the initial moisture content (MC) down to the ideal MC of two percent and below. It removes undesirable compounds such as acetic acids which are produced during bean fermentation. Chemical reactions such as the Maillard reaction and Strecker degradation which convert precursors into flavor characteristics of chocolate occur during roasting. Also, roasting separates the bean shell (outer husk) from the nib (inner bean) and makes cracking and winnowing much easier. The PHilMech developed drum-type cacao bean roaster is composed of three major components: roasting chamber, heat source and prime mover. It uses liquefied petroleum gas (LPG) as a source of heat. A 22OV, 2hp, 1740 rpm electric motor is attached to the machine to rotate the roasting drum during operation. The machine's roasting condition was optimized using three factors such as temperature, time and drum rotational speed. The results showed that the optimum temperature, exposure time and drum speed are 350^{o}C, 50 minutes and 15 rpm, respectively. The output capacity and specific energy consumption are 11.79 kg/ hr and 1861.50 kJ/ kg. The lowest moisture content of cacao beans obtained is 2%.Conduct of financial analysis on the use of cacao bean roaster, quality analysis, sensory evaluation of roasted cacao beans and determination of contaminants such as acrylamide are highly recommended.

Keywords: Cacao roaster, Optimization, Response surface methodology, Moisture content, Output capacity, Specific energy consumption

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INTRODUCTION

Raw cacao beans are bitter, astringent, and void of chocolate flavor. The development of chocolate flavor starts during the fermentation stage and lasts during drying, roasting and conching. Among these processes, roasting is the most crucial technological step in cocoa bean processing (Rocha et al., 2017). It is the process where heat treatment is applied to produce the fundamental chemical and physical changes in the structure and composition of cacao beans (PNS 2018). Specifically, it decreases the initial moisture content down to the ideal moisture content of 2% and below and removes undesirable compounds such as acetic acids which are produced during bean fermentation. Aside from that, chemical reactions such as Maillard reaction and Strecker degradation which convert precursors into flavor characteristics of chocolate occur during this process (Ishak 1997). Moreover, roasting separates the bean shells (outer husks) from the nibs (inner beans) which makes cracking and winnowing much easier (PNS 2012).

There are three types of roasting methods practiced by the cocoa processing industry viz. whole bean roasting, nib roasting and liquor roasting (Shafi 2018). In the Philippines, whole bean roasting is commonly practiced by cacao bean processors. However, most of the cacao processors especially in village operation use poor postharvest practices and in-appropriate postharvest facilities. Therefore, it is necessary to design cacao roaster that will ensure the quality of roasted cacao beans.

OBJECTIVE

General Objective

The general objective of the study is to design and develop cacao roaster to ensure the quality of roasted cacao beans.

Specific Objectives

1. To design and fabricate cacao roaster using locally available materials
2. To optimize the roasting process of cacao dried beans using the developed cacao roaster

METHODOLOGY

Preparation and Collection of Samples

The beans were also categorized as fairly good fermented in terms of fermentation index because it consists of 42% well-fermented beans (fully brown color) based on Malaysian standards for cacao beans.

Design and Fabrication of Cacao Roaster

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

Roasting Process Optimization

Ten kilograms of fermented cacao beans were prepared and subjected to each roasting experiment. Thermocouple wires were set up to measure the surface and inside temperature of the drum. Before the start of the roasting process, the roasting drum was pre-heated to obtain the desired temperature for each roasting condition. After pre-heating, the initial weight of the LPG tank was recorded. The heating time of two minutes was also performed to make sure that the desired temperature was met before loading the samples. Roasting time started after the samples were loaded inside the roasting chamber.

The roasting temperature and rotational speed of the drum were monitored and recorded every five minutes throughout the roasting process. Adjustment of roasting temperature was performed using the gas stove valve to make sure that the desired roasting temperature was achieved. After roasting, the cacao beans were unloaded by means of the inside paddles that push the beans through the output chute.

Representative samples for moisture content analysis were randomly collected and cooled down at the desiccator with active desiccant. The final weight of the LPG tank was also recorded eventually. Remaining roasted cacao beans were transferred to stainless trays to cool down at ambient room temperature for two hours. After cooling down, the final weight of remaining cacao beans was recorded.

Optimization of the Roasting Process

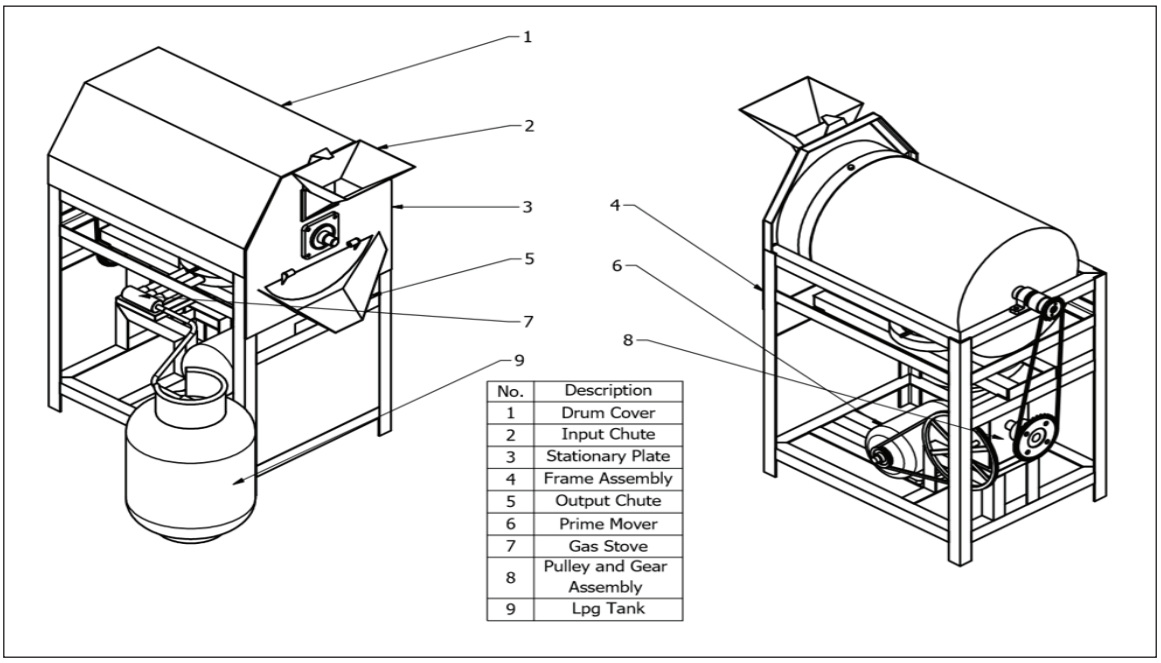
Moisture Content

Moisture content is one of the quality standards used to determine the flavor of roasted cacao beans (Zzaman, 2013). Manually dehulled roasted cacao bean samples were ground using mortar and pestle to avoid heating then eventually sieved using standard mesh size number (1 mm). Three 10g samples of ground cacao beans were placed in an air oven at 103°C for 16 hours. The moisture content of roasted cacao beans from different roasting conditions was calculated using the formula as follows (PAES, 2018).

$$MC_{wb} = \frac{W_i - W_f \times 100}{W_i}$$

where:

MC_{wb}= moisture content of cacao samples (%)
W_i= initial weight of cacao samples (g)
W_f= final weight of cacao samples(g)



No.	Description
1	Drum Cover
2	Input Chute
3	Stationary Plate
4	Frame Assembly
5	Output Chute
6	Prime Mover
7	Gas Stove
8	Pulley and Gear Assembly
9	Lpg Tank

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

Output Capacity

The output capacity of the cacao bean roaster was computed using the formula:

$$C_o = \frac{W_R}{T}$$

where:

C_o = output capacity (kg/hr)
W_r = weight of roasted beans (kg)
T = roasting time (hr)

Specific Energy Consumption

Specific energy consumption is the ratio of LPG consumption and the amount of roasted cacao beans, expressed in kilojoule per kilogram (PAES, 2018). The difference in weight of LPG tank each before and after roasting processes was computed. The formula used to compute the specific energy consumption of cacao bean roaster for each roasting condition was shown as follows (PAES, 2018):

$$SEC = \frac{F \times HV}{W_i}$$

where:

SEC = specific energy consumption (kJ/kg)
F = weight of LPG consumed
HV = heating value of LPG (46024 kJ/kg)
W_i = initial weight of samples

Experimental Design and Statistical Analysis

The machine's roasting condition was optimized using Response Surface Methodology following the Box Behnken Design. Three factors were used in the study viz. roasting temperature, roasting time and drum rotational speed. The optimized condition was selected based on the result of different responses viz. moisture, roasting capacity, and specific fuel consumption.

Analysis of variance (ANOVA) and regression analysis was used for fitting the models and also to examine the statistical significance of the model terms. The significance of all the fitted equation was determined using the F – values. Visualization of interactions between factors and responses was achieved using the response surface plots generated using the Design Expert Software version 11 (Balasubramanian, 2012).

Tables 1 and 2 show the actual values of the factors used in the experiments and the settings of 15 experimental runs.

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

Name	Units	Low	High
Temperature	Degree Celsius	150	350
Time	Minutes	30	90
Drum Rational Speed	Rev. per minute	15	35

Table 2. Experimental runs used in the optimization process

Run	Roasting Temperature (Celsius)	Roasting Time (minutes)	Drum Rotational Speed (rpm)
1	150	60	35
2	150	30	25
3	350	60	35
4	350	30	25
5	350	90	25
6	250	30	15
7	250	90	15
8	250	60	25
9	250	30	35
10	250	90	35
11	150	60	15
12	250	60	25
13	150	90	25
14	250	60	25
15	350	60	15

RESULTS AND DISCUSSIONS

Description of the machine

The PHilMech developed drum-type cacao bean roaster is composed of three major components: roasting chamber, heat source and a prime mover (Figure 2). The roasting chamber consisted of 40 cm diameter and 60 cm long cylindrical drum made with food-grade stainless steel with wisely designed steel paddles 3.8 cm in height responsible for mixing of cacao beans evenly. It was covered with a stationary plate where the input and output hoppers were attached.

Inside the roasting chamber the cacao beans were subjected to convectional heat from the inside air and conductional heat from the drum surface. The heat required to raise the temperature inside and outside the roasting chamber was supplied by an LPG tank by means of a cooking stove equipped with control valves. A 22OV, 2hp, 1740 rpm electric motor was attached to the machine to rotate the roasting drum during operation. The rotating roasting chamber was heated up by the heat source up to the desired temperature. When the roasting chamber heats up, the raw cacao beans were loaded using a conical-shaped input hopper. Inside the roasting chamber the cacao beans were subsequently mixed using the metal paddles attached inside the roasting drum.

During the process the cacao beans were subjected to the two sources of heat which are heat from the roasting drum surface (conduction) and heat from the inside air (convection). After a certain period, the raw cacao bean becomes roasted. Unloading of roasted beans was performed by means of the output section attached to the lower stationary plate.

Figure 2. PHilMech developed cacao roaster

Roasting process optimization

Moisture content

The maximum 2% moisture content is ideal for achieving the fundamental chemical and physical changes in the structure and composition of cacao beans such as darkening and development of chocolate flavor (PNS, 2018). The moisture content of cacao beans after roasting using the developed cacao roaster ranges from 0.651 to 6.527 %. Results showed that only time and temperature had significant effect on the moisture content of the beans. Using the values of significant coefficients, the model for moisture content of cacao beans was established:

*Moisture Content = 11.2901 + -0.0190575 * Temperature + -0.0526625 * Time*

The interaction of roasting temperature and time to the moisture content of roasted cacao beans with constant drum speed was interpreted using a surface plot in Figure 3. From the plot it can be seen that increasing roasting time and temperature decreases the moisture content of cacao beans. The same result was obtained by the study conducted by Zzaman (2013) about moisture changes in cacao beans using superheated roasting.

Effect on the output capacity of cacao bean roaster

An increase in the machine's output capacity is beneficial because it will result from increases in the production of roasted beans. The computed output capacity from different roasting conditions varies from 5.59573 to 19.7068 Kg/h. Time and temperature had a significant effect on the output capacity of cacao bean roaster. The equation for the output capacity of the said cacao bean roaster with significant equation coefficients is shown:

*Output Capacity = 38.691 + -0.008 * Temperture + -0.674 * Time + -0.087 * Drum Speed + 9.42917e-06 * Temperature2 + 0.003 * T ime2 + 0.001 * Drum Speed2*

The interaction of roasting temperature and time to a moisture content of roasted cacao beans with constant drum speed was interpreted using a surface plot in Figure 4. The increase in roasting time rapidly decreases the output capacity of cacao bean roaster while increasing the roasting temperature also decreases output capacity but in gradual effect due to moisture reduction in loaded cacao beans.

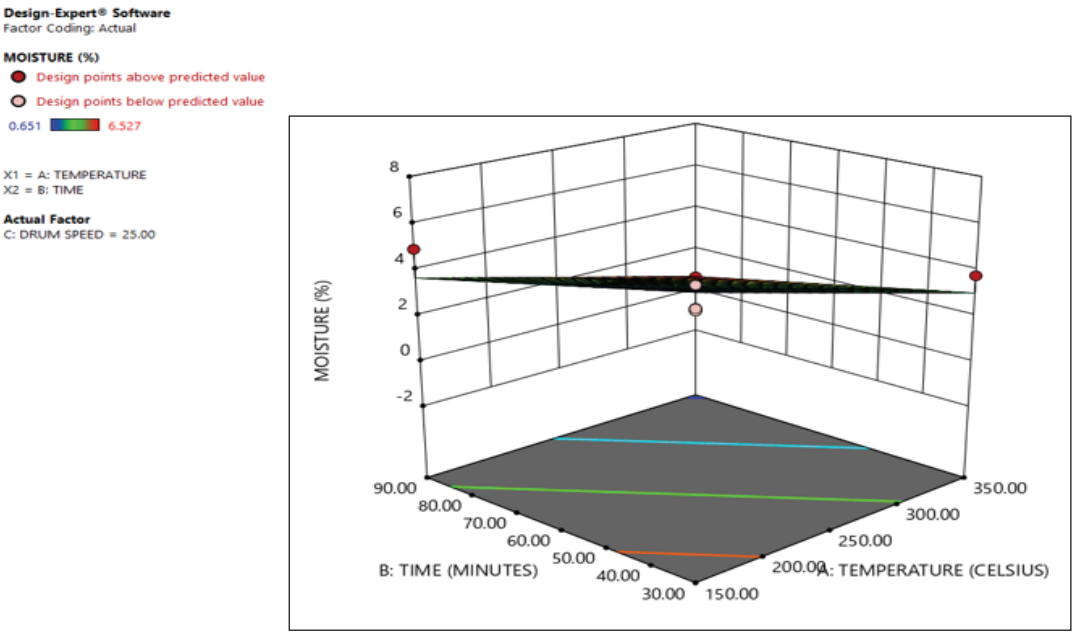


Figure 3. Response surface plot for moisture content

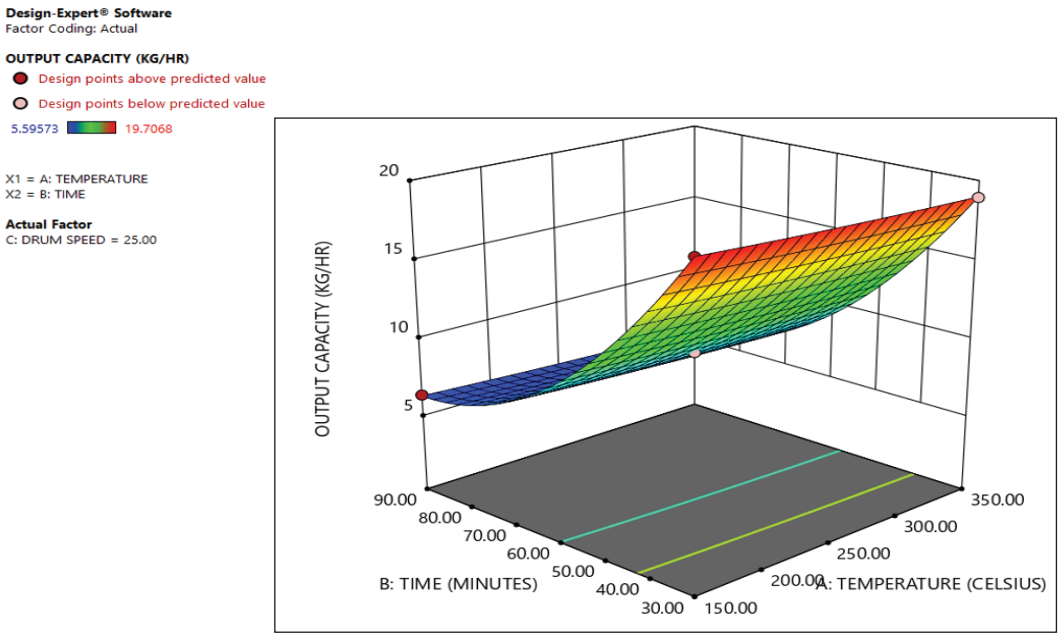


Figure 4. Surface plot showing the effect of varying roasting time and temperature in output capacity of cacao roaster

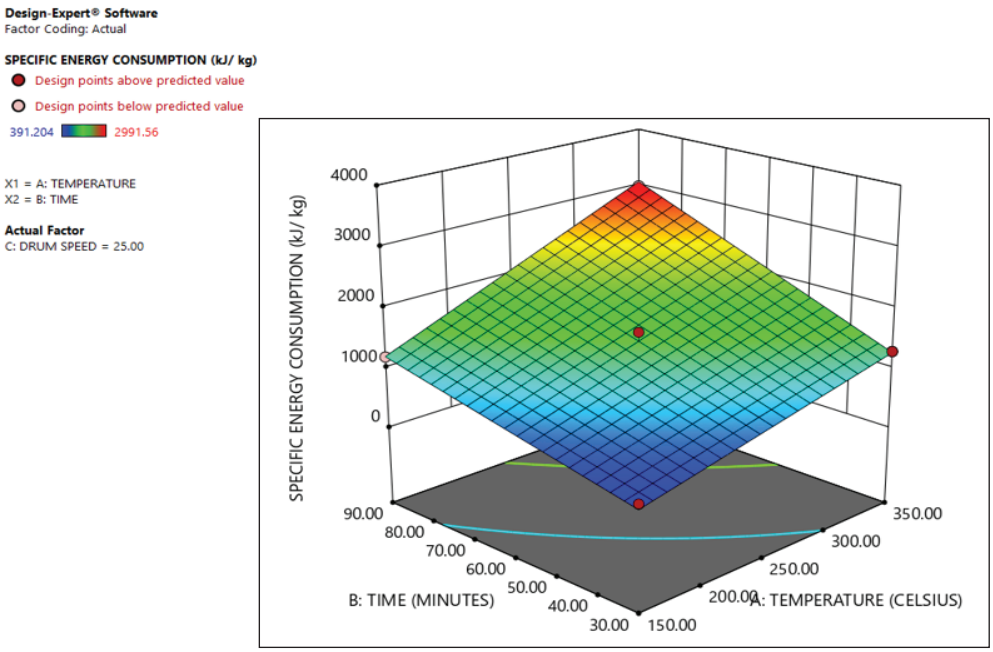


Figure 5. Surface plot showing the effect of varying roasting time and temperature in specific energy consumption of cacao bean roaster.

Specific energy consumption

Proper utilization of energy during roasting will reduce the cost of production of roasted cacao beans. The computed specific energy consumption varies from 391.204 to 2991.56 Kj/Kg.

Specific energy consumption

*= -532.92 + 2.58885 * Temp. + 3.73945 * Time + 0.074789 * Temp. * Time*

The response surface plots for specific energy consumption was shown in Figure 5. Based on the interaction of significant factors on specific energy consumption of cacao bean roaster, an increase in roasting time and temperature increased the specific energy consumption of cacao roaster.

Optimization and Validation Process

The optimization of parameters (moisture content, output capacity and specific energy consumption) was done using the developed models. The study aimed to develop a roasting condition that produces cacao beans with 2% moisture content and below, with increase output capacity and less specific energy consumption. The appropriate range of values for various parameters was selected, in the range of 0.64-2 % for moisture content, the maximum value for output capacity and minimum value for specific energy consumption. The condition with the highest desirability was chosen as an optimum condition.

After determining the optimum condition, validation was performed to check the efficiency of developed models. The actual values of moisture content, output capacity and specific energy consumption were found to be a little bit smaller than the predicted values. The difference was found to be not significant statistically. Table 3 shows that the optimum temperature, exposure time and drum speed are 350°C, 50 minutes and 15 rpm, respectively. The lowes moisture content of cacao beans obtained was 2%. The output capacity and specific energy consumption were 11.79 kg/ hr and 1861.50 kJ/ kg, respectively.

Table 3. Optimization and Validation of cacao bean roaster

Constraints	Goal	Lower Limit	Upper Limit	Importance	Predicted	Actual Values
Temperature	In range	150	350	3	350	-
Time	In range	30	90	3	50	-
Drum Rotational Speed	In range	15	35	3	15	-
Moisture Content	In range	0.64	2	3	2.00	1.94
Output Capacity	Maximize	5.59	19.70	3	11.79	11.21
Specific Energy Consumption	Minimize	391.20	2991.56	3	1861.50	1802.60

CONCLUSION

The PHilMech developed drum-type cacao bean roaster is composed of three major components: roasting chamber, heat source and prime mover. It used LPG as a source of heat. A 22OV, 2hp, 1740 rpm electric motor was attached to the machine to rotate the roasting drum during operation. The optimum temperature, exposure time and drum speed are 350°C, 50 minutes and 15 rpm, respectively. The lowes moisture content of cacao beans obtained is 2%. The output capacity and specific energy consumption are 11.79 kg/ hr and 1861.50 kJ/ kg, respectively.

RECOMMENDATION

Conduct of financial analysis on the use of cacao bean roaster, quality analysis ensory evaluation of roasted cacao beans and determination of contaminants such as acrylamide are highly recommended.

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UTILIZATION OF ADLAI HUSK AS COPPER IONS ADSORBENT MATERIAL

Edgar D. Flores[1] and Mark Daniel G. de Luna[2]

ABSTRACT

In this study, untreated husk of Adlai (*Coix lacryma-jobi L.*) was utilized as an adsorbent material for the removal of copper ions Cu (II) from aqueous solution. The investigation focused on evaluating the effect of various factors, including Adlai husk particle size, initial pH of the solution, initial Cu (II) concentration and temperature on the process of copper removal. The adsorption experiments were done in triplicate runs and analyzed using Minitab Software, employing factorial design. The study found that highest amount of Cu (II) was removed when the smallest range of particle size (75 -125 µm) and pH 6 were used. Moreover, the adsorption capacity increased with initial Cu(II) concentration and contact time. Increasing the temperature from 298K to 318K enhanced the adsorption capacity of Adlai husk for Cu (II) from 11.21 mg g^{-1} at to 13.60 mg g^{-1}, respectively. Column adsorption experiment can be done as it more closely simulates actual situations and the removal of adsorbate from a continuous stream of discharged wastewater.

Keywords: Adlai shell, Adsorption, Heavy metal, Wastewater

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INTRODUCTION

Adlai (*Coix lacryma-jobi L.*), more commonly known as Job's tears, is an agricultural crop native to several countries, including the Philippines, China, Japan and Taiwan. In addition to its cultivation for food, Adlai has also been traditionally used to treat warts, chapped skin, rheumatism and neuralgia (Lu et al, 2008, and has notable anticancer (Lee et al, 2008), anti-inflammatory (Chen et al., 2011) and anti-allergic properties (Chen et al, 2010). While Adlai is gaining recognition for its potential health benefits, its husk which accounts for about 50% of the grains by weight, is usually discarded and regarded as wastes during the milling process. Utilization of these waste and transform them into valuable resources would possibly gain economic value.

On the other hand, water effluent from industries such as electroplating, metal cleaning, plating baths, paper board mills, wood pulp and fertilizer productions contain various amounts of Cu(II) and other toxic heavy metals (Tong et al, 2011, Zhu et al., 2009, Li et al 2005). Small amounts of Cu (II) is essential to human beings but excess intake can be toxic to the human body. Some severe effects to humans include itching of the hands and feet, gastro-intestinal irritation, damages of liver and kidney (Huang et al, 2007) and lung cancer (Aydin et al, 2008). The discharge of wastewater containing high concentration of Cu (II) ions into streams poses a significant threat to the quality of water and soil including plants and animals.

Unlike some other substances, Cu (II) ions do not decompose over time and have a tendency to accumulate in living organisms which cause harmful effects on fish and other marine resources (Barros et al 2008; Sljivic et al, 2009). Thus, it is important to implement treatment measures for wastewater containing Cu (II) ions before it is discharged.

Several methods have been utilized to remove Cu (II) from wastewater, including chemical precipitation, coagulation and flocculation, reverse osmosis, membrane process, ion exchange, liquid extraction, electrodialysis and adsorption (Fu and Wang, 2010; Yadla et al, 2012). Among these methods, adsorption stands out as a cost-effective treatment process due to its simplicity in removing contaminants from water (Li et al, 2007). Among various adsorbents, activated carbon has proven to be highly effectively in removing pollutants both from water and gaseous environment (Chen et al, 2011). However, its application has been limited due to its high cost and difficulty to regenerate (Tan et al, 2008; Monvisade and Siriphanon, 2009). Said limitations have led many researchers to explore for novel, inexpensive, and locally available adsorbent materials from biomass resources.

Agricultural wastes are the most considered alternative materials to commercial activated carbon. Previous studies have investigated various adsorbents derived from agricultural wastes for removal of heavy metals from aqueous solutions. These include banana pith (Low et al 1995), peanut hulls (Brown et al, 2000), wheat shells (Basci et al, 2004), rubber leaf powder (Wan Ngah et al, 2008), saw dust (Rafatullah et al, 2009; Kalavathy et al, 2010), hazelnut (Demirbas et al 2009), sugarcane bagasse (Dos Santos et al, 2011), and palm kernel (Ho and Ofomaja, 2006) and others.

The exploration of these diverse and low-cost adsorbents for the removal of Cu(II) from wastewater may contribute to maintain a good environment and offer valuable prospects for commercial applications (Babel and Kurniawan, 2003). In line with this, the feasibility of Adlai husk as adsorbent material for the removal of Cu (II) from aqueous solution was evaluated. Additionally, the study investigated the effects of initial pH of the solution, Adlai husk particle size, initial Cu (II) concentration, contact time, and temperature on the removal of Cu (II) from aqueous solution.

METHODOLOGY

Chemicals and Analytical Method

All chemicals used in this study were analytical grade. The stock solution of Cu (II) (1000 mg L-1) was prepared by dissolving $Cu_2SO_4.5H_2O$ (100%, UNIVAR) in distilled water. The working solutions were prepared by diluting the stock solution with distilled water to the required concentrations.

The concentration of Cu (II) ions was determined using a spectrophotometer (D 890, Hach) set at wavelength λ=560 nm. The adsorption capacity (qe) was calculated using Eq. 1:

$$q_e = \frac{(C_0 - C_e) \times V}{M} \qquad (1)$$

Where C_o and C_e is the initial and final Cu (II) concentration, respectively, V is the volume of the Cu (II) ion solution (mL) and M is the mass of adsorbent (g).

Preparation of Adsorbent

Adlai husks obtained from PHilMech, Muñoz, Nueva Ecija, were initially washed with tap water followed by a thorough rinsing with distilled water. The cleaned samples were dried in an oven (OMS 100, Heratherm) at 100°C for 24 h. Subsequently, a laboratory grinder (GX-15A, Weitex) was employed to pulverize the husk and the resulting powder was subjected to sieving. Pulverized adlai shells with particle size ranging from 75 to >355 µm were used in all experiments.

Adsorption Studies

The adsorption of Cu (II) ions using Adlai husk was investigated through batch adsorption experiments in Erlenmeyer flasks with 100 mL Cu (II) solution to determine the effects of different variables on the adsorption process. The flasks were placed in a water bath shaker (LSB-0309, LABTECH) and agitated at 150 rpm set at a predetermined temperature.

Effect of pH. The solutions were prepared by adjusting the pH to specified initial pH values using 0.1M HCl (37%, ACI Labscan) or 0.1M NaOH (50%, Merck.) before mixing the adsorbent. The contact time was varied from 20 to 240 min while the adsorbent dose was maintained at 0.5 g non-treated Adlai husk powder and temperature at 25°C.

Effect of particle size. The effect of adsorbent particle size on the adsorption of copper using untreated adlai husk was studied at three different ranges of particle size (75 -125 µm, 125-355 µm and >355 µm). The contact time was varied from 20 to 240 min while the pH of the test solution, initial copper concentration and adsorbent dose were kept constant.

Effect of contact time and initial copper concentration. The effect of contact time and initial copper concentration on the adsorption of copper by adlai husk were determined by varying the contact time (20 to 240 min) and initial copper concentrations (10 to 100 mg L-1. The pH of the solution and adsorbent dose were kept constant.

Effect of temperature. The experiments were done in an Erlenmeyer flask containing 100 mL copper solution and agitated in laboratory shaker at 150 rpm and at varying temperatures (25°C, 35°C and 45°C). The contact time was varied from 20 to 240 min while the adsorbent dose, initial copper concentration, and pH were kept constant.

All adsorption experiments were done in 3 replications. The experimental data were analyzed using the analysis of variance (ANOVA). The mean values were compared with the aid of Minitab 16, employing factorial design.

RESULTS AND DISCUSSION

Batch adsorption trials were conducted to determine the effects of initial pH, adsorbent particle size, contact time, initial concentration and temperature on the removal of Cu (II) ions from aqueous solution. The adsorption experiment was done using untreated adlai husk powder.

Effect of initial pH

Figure 1 shows that the adsorption of Cu (II) ions by adlai husk increases with pH value. The highest Cu (II) adsorption was obtained at pH 6 while lowest at pH 4. Previous studies indicated that pH has significant effect on the removal of Cu (II) ions from aqueous solution. It was reported that highest removal of copper from aqueous solution was observed at pH 4 using rubber leaf powder (Wan Ngah et al, 2008), using palm kernel (Ho et al, 2006) and sugarcane bagasse (Dos Santos et al, 2011) at pH 5 and using hazelnut (Demirbas et al, 2009), saw dust (Rafatullah et al, 2009; Kalavathy et al, 2010) and wheat husk (Basci et al, 2004) at pH 6.

The amounts of Cu (II) ions adsorbed by adlai husk at 120 min contact time for pH 4, 5 and 6 were 4.52 mg g^{-1}, 5.25 mg g^{-1} and 6.98 mg g^{-1}, respectively. At low pH, H^+ exists in high concentrations and they compete with Cu (II) ions for active site on the surface of the adsorbent. Similar findings on the competition between H+ and Cu (II) ions for adsorption sites at lower pH were reported by Demirbas et al. (2009). On the other hand, at pH >6, copper starts to precipitate as Cu $(OH)_2$. This is verified by the copper speciation diagram reported by Wang et al. (2005) as shown in Figure 2. In addition, Cuppett et al., 2006 reported that copper precipitates as copper hydroxide usually in the range of pH 6.5 to 12. Thus, pH 6 was considered as the ideal pH in the adsorption of copper ions from aqueous solution using adlai husk.

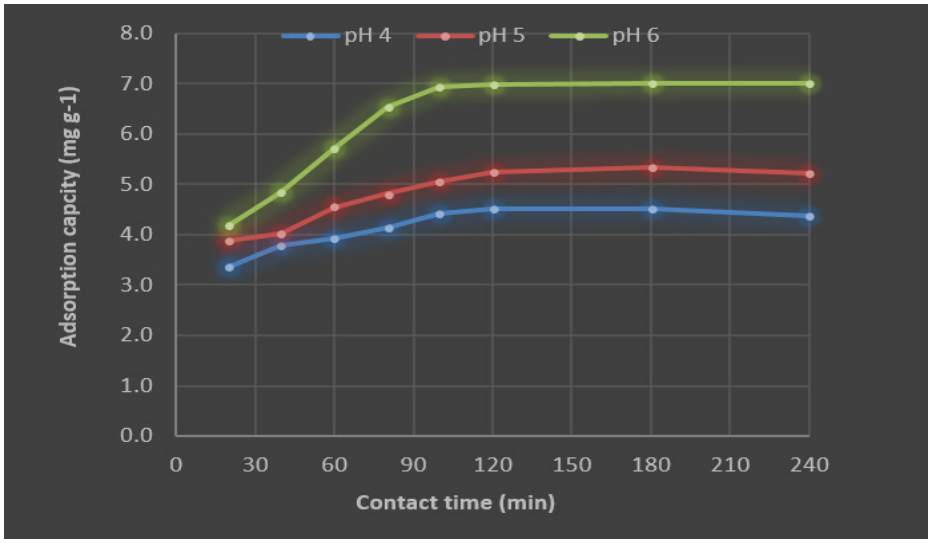

Figure 1. Effect of pH on the adsorption of Cu(II) ions

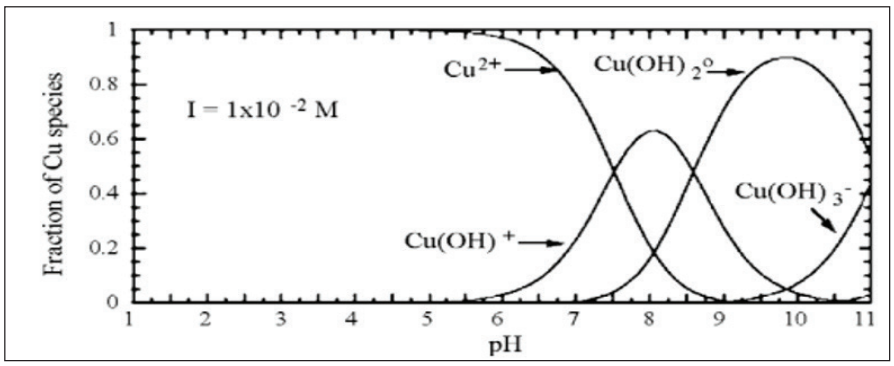

Figure 2. Distribution of copper species as a function of pH (Wang et al., 2005).

Effect of particle size

Adsorbent particle size is one of the limiting factors that may affect the diffusion and mass transfer of the adsorbate onto the adsorbent. In this study, the particle size of the adsorbent were altered in three different ranges and used in the adsorption experiment.

Figure 3 describes the effect of altering the particle size of the adlai husk on the adsorption of Cu (II) ions from aqueous solution. Reducing the size of the adsorbent increased the amount of Cu (II) ions adsorbed. The adsorption capacities at equilibrium time were 2.070 mg g^{-1}, 6.354 mg g^{-1} and 6.988 mg g^{-1} for adsorbent size of > 350 µm, 125 – 350 µm and 75 – 125 µm, respectively.

The smallest adsorbent size provided a more dominant removal of Cu (II) ions. This result could be attributed to an increase in total surface area as the particle size decreases and therefore more adsorption sites are available for the removal of copper ions (Wan Ngah et al, 2008).

The internal diffusion and mass transfer resistance of the adsorbate to penetrate the adsorbent decreases as the particle size decreases. Likewise, adsorbate may have a short path to transfer into the pores of the adsorbent with small particle size. As such, most of the adsorbent were utilized and increased adsorption capacity (Al-Anber, 2010). Thus, the range of particle size used in all succeeding adsorption batch experiments was 75-125 µm.

Effect of contact time and initial concentration

Contact time is an important parameter that provides information on the minimum time required to complete the adsorption process and the possible control diffusion mechanism between the adsorbate as it moves from the bulk solution towards the surface of the adsorbent.

The effect of contact time on the adsorption of Cu (II) ions using untreated adlai husk is shown in Figure 4. The adsorption capacity increased with time and observed to reach an equilibrium value at 120 minutes. Initially, the rate of Cu (II) ions removal was faster at the initial stage and then became slower until no more significant increase in adsorption at 120 min and beyond.

At first, large amount of Cu (II) ions were adsorbed onto the adsorbent because of more vacant active binding sites are available for adsorption. The binding site was shortly become saturated and difficult to be occupied by copper ions due to the formation of repulsive forces between the copper on the solid surface and the liquid phase (Srivastava et al, 2009; Achak et al, 2009).

Varying the initial concentration of Cu (II) from 10 to 100mg L^{-1} increased the adsorption capacity from 1.734 to 11.210mg g^{-1}. The increase of adsorption capacity may be explained by the reason that more adsorption sites were being covered as the metal ions concentration increases (Larous and Meniani, 2012).

Also, the rate of adsorption increase due to an increase in driving force of concentration gradient to overcome mass transfer resistance of copper ions to penetrate the adsorbent with the increase in initial concentration (Demirbas et al, 2009; Kalavathy et al 2010).

Effect of temperature

Figure 5 depicts the trend of copper adsorption using untreated Adlai husk at 100 mg L-1 initial Cu (II) concentration with three levels of temperatures (25°C, 35°C and 45°C).

Since highest adsorption capacity was observed at 100mg L^{-1} initial Cu (II) concentration, this was kept constant in all the temperatures used.

Varying the condition by increasing the temperature during the adsorption experiment increased the removal of Cu (II). At 120 min contact time when the adsorption is becoming constant, the adsorption capacity at 25°C was 11.210mg g^{-1}. At 35°C, the adsorption capacity increased to 12.520mg g^{-1} and then further improved to 13.60mg g^{-1} at 45°C. Results indicated that increasing the adsorption temperature enhanced the adsorption capacity of the adlai husk.

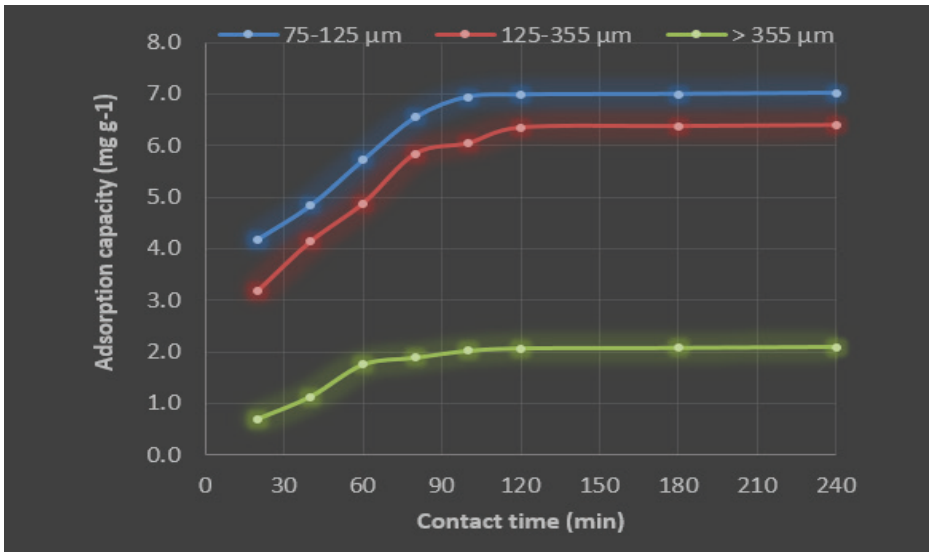

Figure 3. Effect of adsorbent particle size on the adsorption of Cu (II) ions

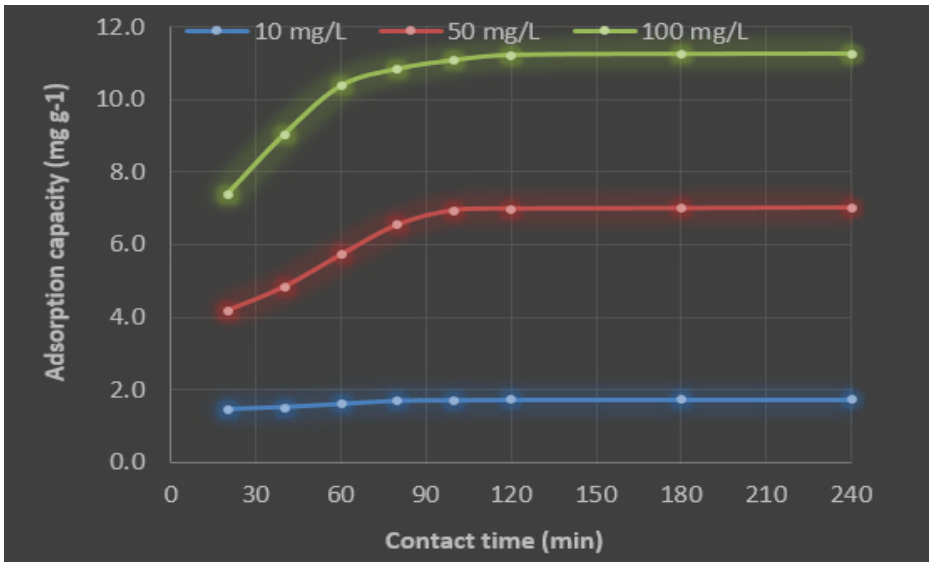

Figure 4. Effect of contact time and initial Cu (II) concentration on the adsorption of Cu (II) ions

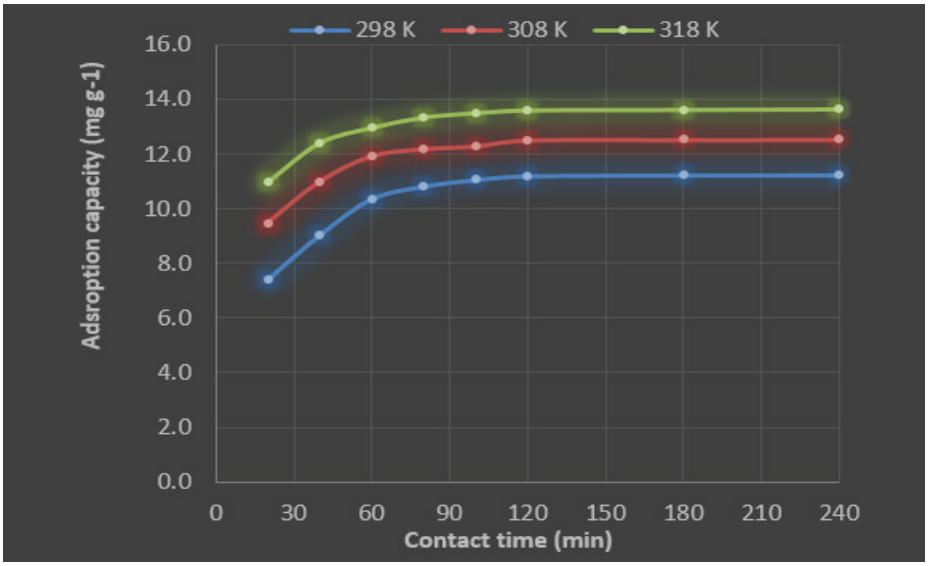

Figure 5. Effect of temperature on the adsorption of Cu (II) ions

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The adsorption of Cu (II) from aqueous solution using Adlai husk was investigated under various conditions. The effect of different factors such pH, particle size, initial Cu (II) concentration, contact time and adsorption temperature were undertaken. The copper removal was highest at lowest adsorbent particle size (75 to 120 µm) and at pH 6. The adsorption capacity increased with initial Cu (II) concentration and contact time until equilibrium value obtained at 120 minutes. The adsorptive performance of Adlai husk enhanced with increasing temperature.

The adsorption capacity of 11.21 mg g^{-1} for untreated Adlai husk powder at 298K further improved to 13.60 mg g^{-1} at 318K. The findings of the present study exhibited the potential of Adlai husks as an effective adsorbent for the removal of Cu (II) ions from aqueous solutions. To fully determine its actual adsorptive performance, column adsorption experiments can be done as this more closely mimic real-world situations in which the adsorbate must be removed from a continuous stream of discharged wastewater.

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DEVELOPMENT OF NON-DESTRUCTIVE MOISTURE METER FOR GREEN COFFEE BEANS AND PARCHMENT COFFEE

Arlene C. Joaquin[1] and Richard P. Avila[2]

ABSTRACT

The paper presents the development of a locally designed and fabricated non-destructive coffee moisture meter. The coffee moisture meter adopted a capacitive sensor oscillator circuit and can measure moisture contains of both green coffee beans (GCB) and parchment coffee of *Coffea arabica*, one of the most popular varieties grown in the country. The coffee moisture meter comprised of two-concentric cylinder test chamber, where whole coffee beans are placed; metal encasement containing the circuit and other peripherals; and a control and measurement menu panel. It is micro-controller based, with LCD read-out which displays MC reading and battery life. Validation and field testing results indicated that the prototype unit moisture meter is sufficiently accurate with R^2 value of 0.85 and 0.99 for GCB and parchment coffee, respectively. Moreover, accuracy tests conducted for the developed coffee moisture meter yielded a moisture content error, $\bar{y}$ of 0.15% and 0.20% for GCB and parchment coffee, respectively. Also, repeatability tests, expressed in Standard Deviation (SD) were computed at 0.09% for green coffee beans. Both results have indicated compliance to standard tolerances set by local and international standards, particularly the International Organization of Legal Metrology (OIML).

Keywords: Coffee, Moisture content, Non-destructive, Arabica, GCB, Parchment

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INTRODUCTION

Determination of moisture content (MC) at various stages of coffee production is one of the keys to quality and cost control. In the Philippines, this activity is primarily done in the traditional method of ocular inspection to estimate the level of MC in every postharvest operation.

Coffee is dried from approximately 60% to 12% moisture content, drying below this level may result monetary losses. Just like any other dried grains, coffee must be stored in dry and cool conditions with moisture content level from 11% to 15% for optimum storage and quality roasting (FAO, undated).

Temperature and length of roasting coffee are also based on moisture content of 12%-13%. Above these values, roasting requires more energy and might be incomplete. Below these values, beans might end up being over-roasted. Moisture content monitoring is also very critical in the hulling process. Too high MC (16% and above) slows down the motor of the hulling machine while too low MC makes the beans brittle resulting to broken beans.

In the Philippines, empirical method is the most common practice in determining moisture content of coffee beans. Problem in high moisture content of coffee produced by farmers is attributable to inaccuracy of measuring the MC of their product using empirical method. In an attempt to address this inaccuracy, Idago (2011) introduced and tested an imported prong-type electronic meter in the Cordillera region. Although the instrument showed promising result, further improvement is needed to come up with a more accurate, simple and low-cost moisture meter for coffee beans. Inherent to being imported, difficulty in after sales services of electronic meters was also expressed by the end-users. Similar type of moisture meters imported by a local importer-distributor was taken off the shelves because of reported inaccuracy in moisture reading. It is therefore, very critical that processes and instruments in MC determination is accurate and precise to avoid huge quantitative and qualitative losses in the entire coffee industry (Gautz, 2008).

The paper aims to present an alternative, inexpensive, simple yet accurate moisture meter to address the subjectivity and slow process of empirical MC determination commonly used by farmers and small traders in the Philippines.

OBJECTIVES

The general objective of the paper is to develop a non-destructive moisture meter for dried coffee beans from locally available materials. Specifically, the project aims to:

1. To design and fabricate a non-destructive moisture meter for green coffee beans and parchment coffee; and

2. To evaluate the performance of the developed moisture meter for coffee beans and parchment coffee in terms of technical efficiency.

METHODOLOGY

Design Considerations and Fabrication of Non-destructive Coffee Moisture Meter

A CAD-generated drawing as shown in Figure 1 was generated for the prototype unit coffee moisture meter. The design was conceptualized based on the assessment of existing moisture meters and specific preferences of the coffee processors established during the conduct of said needs assessment. Hardware components including printed circuit board (PCB) of the moisture meter was outsourced from a local electronic company and assembled at PHilMech instrumentation laboratory. Programming component and circuit design was provided by an in-house electronics engineer.

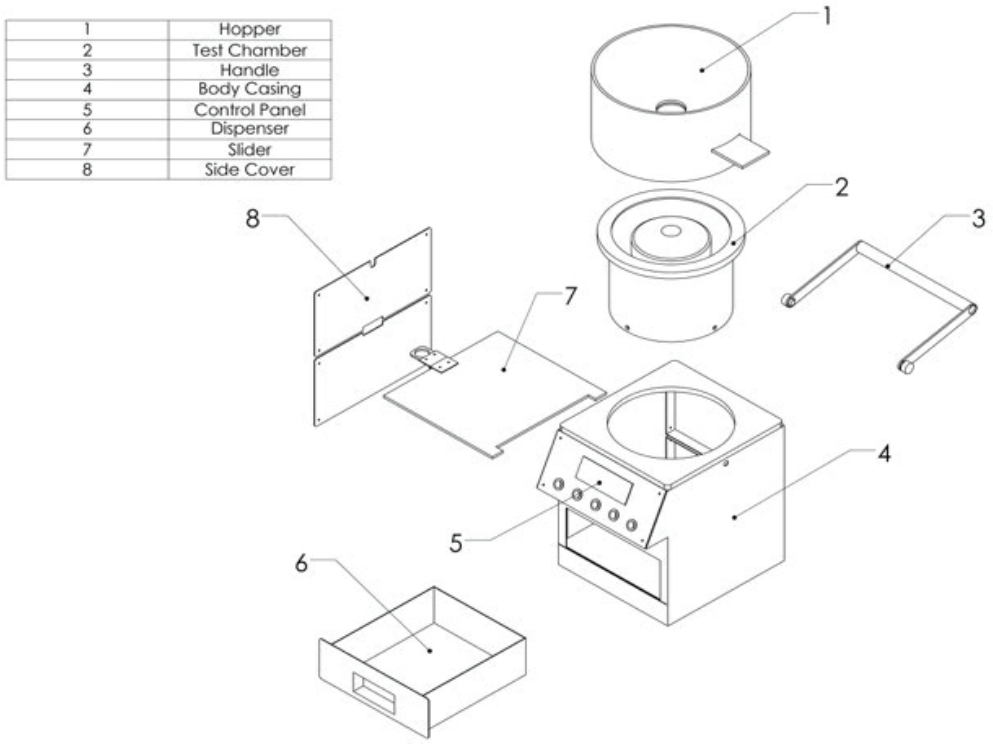

Figure 1. CAD-generated drawing of the coffee moisture meter

Model Calibration and Validation Process

Calibration models were derived from the relationship between frequencies produced by the circuit against varying MC of coffee beans. Coffee samples of *Coffea arabica*, with known MC of green coffee beans and parchment coffee were used for this purpose. Freshly harvested and de-pulped coffee cherries were cleaned and pre-conditioned, by air-drying the samples to its desired MC. Moisture content measurements were based on the ASAE S352.2 (2000) procedure on standard oven-drying method.

Pre-conditioned samples were then placed in plastic containers and kept in room condition and individually withdrawn during each calibration test. Shown in Figure 2 is the laboratory measurements done using the developed circuit with an oscilloscope where resulting frequency readings were initially displayed. A total of 229 and 245 data points were generated for GCB and parchment coffee, respectively. Based on the experimental results, a regression analysis was conducted relating moisture content to frequency values produced by the circuit to develop calibration models for both coffee type.

For the MC curve, validation tests were conducted using a total of 907 and 121 data points of varying MC for GCB and parchment coffee, respectively. The predicted MC were compared with oven MC values. A regression analysis was done to evaluate the coefficient of determination (R^2) as indicator for the fitness or how well the model predicts the outcome which is the actual MC readings of GCB and parchment coffee. The lowest possible value of R^2 is 0 and the highest possible value is 1. Put simply, the better a model is at making predictions, the closer its R^2 will be to 1 (Turney, 2022).

Figure 2. Calibration tests conducted for green coffee beans and coffee parchments for the prototype unit test chamber of the non-destructive coffee moisture meter

Technical Performance Evaluation of the PHilMech-developed Coffee Moisture Meter

The activity was conducted to establish the technical feasibility of the developed non-destructive coffee moisture meter. Performance evaluation was done in a controlled laboratory setting for precision and accuracy. Measured MC for both GCB and parchment coffee were compared to oven-dried samples with three replicates of 15-grams and oven temperature set at 105^{O}C, based on ASAE Standards S352.2 (2000) MC determination method. A total of 30 samples each for GCB and parchment coffee with different MC levels were used as test samples.

Test Samples

Well-cleaned GCB and parchment coffee samples comprised of three adjacent 2% MC intervals within a range of 6% MC as stated in the test procedure of the International Organization of Legal Metrology (OIML, 2009) were used for the evaluation. For uniformity of application, each 2% MC intervals were used including 14%, which is considered to be the most critical MC level in seeds and grains.

Accuracy and Precision

Three sets of 10 samples each for the 2% MC intervals or a total of 30 samples were used to test the performance of the PHilMech-developed coffee moisture meter. Coffee samples were subjected and compared to the reference oven method to evaluate the performance of the coffee moisture meter in terms of accuracy and precision.

Accuracy of the coffee moisture meter was measured in two parameters: (1) moisture error, $\bar{y}$ and (2) Standard Deviation of the Difference (SDD) between the developed non-destructive coffee moisture meter and the standard oven method. Procedures and method for both parameters were based on OIML TC17 (2006) with the given equations [1] and [2] below:

$$\bar{y} = \frac{\sum_{i=1}^{n}(\bar{x} - r_i)}{n} \qquad (1)$$

$$SDD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}} \qquad (2)$$

Precision was measured by (1) Repeatability and (2) Reproducibility. Repeatability is defined as the Standard Deviation, SD of three replicates calculated for each sample in a 2% MC interval and pooled across samples (OIML, 2006). The equation used is given equation [3] below:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{3}\left(x_{ij} - \bar{x}_i\right)^2}{2n}} \qquad (3)$$

where:

xij = coffee moisture meter value for sample i and replicate j

$\bar{x}_i$ = average of three moisture values for sample i

n = number of samples per 2% moisture content interval, (n=10)

Likewise, reproducibility expressed as SDD1, was measured between readings of the coffee moisture meter operated by two different persons at the same time, place and condition. The tests were done in three replicates with 10 sets each of the 2% moisture content intervals. The equation used is shown in equation [4] below:

$$SDD_1 = \sqrt{\frac{\Sigma_{i=1}^{n}(d_i - \bar{d})^2}{n-1}} \qquad (4)$$

where:

$d1 = \bar{x}_i^{(1)} - \bar{x}_i^{(2)}$

$\bar{x}_i^{(1)}$ = mean of three replicates for sample ^{i} on operator 1

$\bar{x}_i^{(2)}$ = mean of three replicates for sample ^{i} on operator 2

$\bar{d}$ = mean of the d_1

n = no. of samples in all 2% MC ranges

RESULTS AND DISCUSSION

Description of the PHilMech-developed Coffee Moisture Meter

Hardware Component

After a series of design concepts, the project came up with the prototype unit as shown in Figure 3. The prototype unit is a non-destructive, capacitance type moisture meter composed primarily of three parts: (a) two-concentric cylinder test chamber where samples are placed; (b) an encasement which contains the circuit, menu panel (for overall control and measurement) and other peripheral parts; and (c) a discharge outlet where measured test samples are disposed. A handle was also provided for ease of handling and mobility

The menu panel as shown in Figure 4 is provided with five-button selector panel for coffee type (GCB or parchment coffee) and varieties of coffee to be measured. Each button is numbered from one to five with corresponding legend (measure button, parchment selector, enter button, bean selector ans reset button). It is micro-controller based with LCD read out panel.

Figure 3. The developed non-destructive coffee moisture meter.

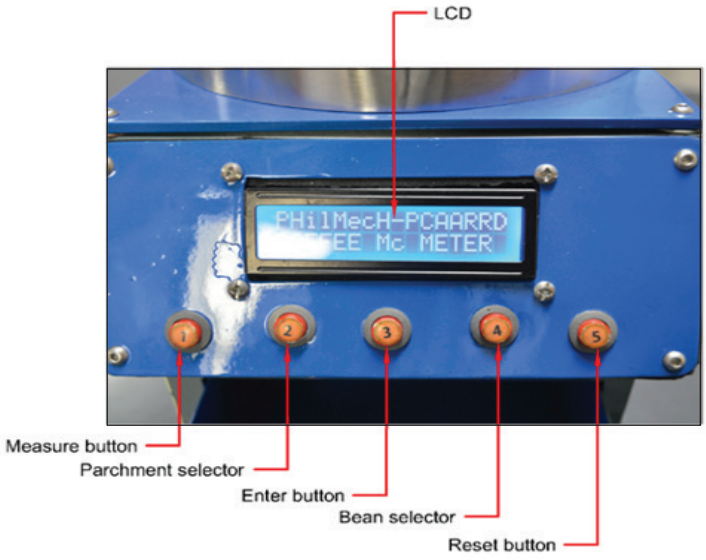

Figure 4. Menu panel and legend of the developed coffee moisture meter.

Circuit System and Software Component

Shown in Figure 5 is the functional block diagram of the coffee moisture meter. The developed non-destructive coffee moisture meter adopted a capacitive oscillator circuit which measures the dielectric constants of coffee samples. It is provided with two-concentric cylinder test container which acted as capacitor. The circuit was designed to oscillate the voltage when subjected to fixed voltage. A 9V DC battery was fed through a 5V voltage regulator to provide power to the whole circuit.

The system also used a trimmer resistor in determining the capacitance of the coffee samples placed inside the test cell with varying level of MC. The generated frequency was calibrated by the internal calibration of the PIC micro-controller. The microcontroller would then convert the frequency reading into MC values based on the calibration equation developed. The 4-digit computed MC values are transmitted to the LCD display provided. The system selected assembly programming language to facilitate the code of the prototype unit of the non-destructive coffee moisture meter.

Calibration Tests

Calibration data points generated from Arabica variety during the laboratory experiments are shown in Figures 6 and 7 for GCB and parchment coffee, respectively. Results showed that the oven MC values decreased with increased frequency values for both GCB and parchment coffee. The relationship appeared non-linear over the data points generated for GCB while a linear relationship was generated for parchment coffee.

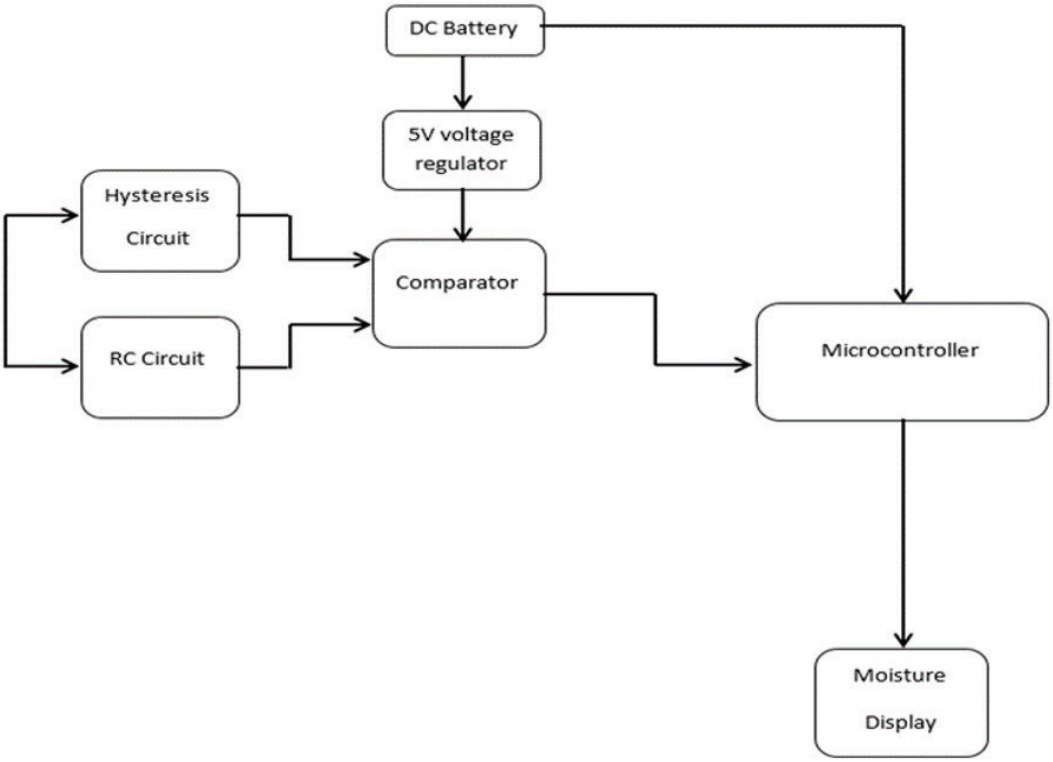

Figure 5. Functional block diagram of the circuit system

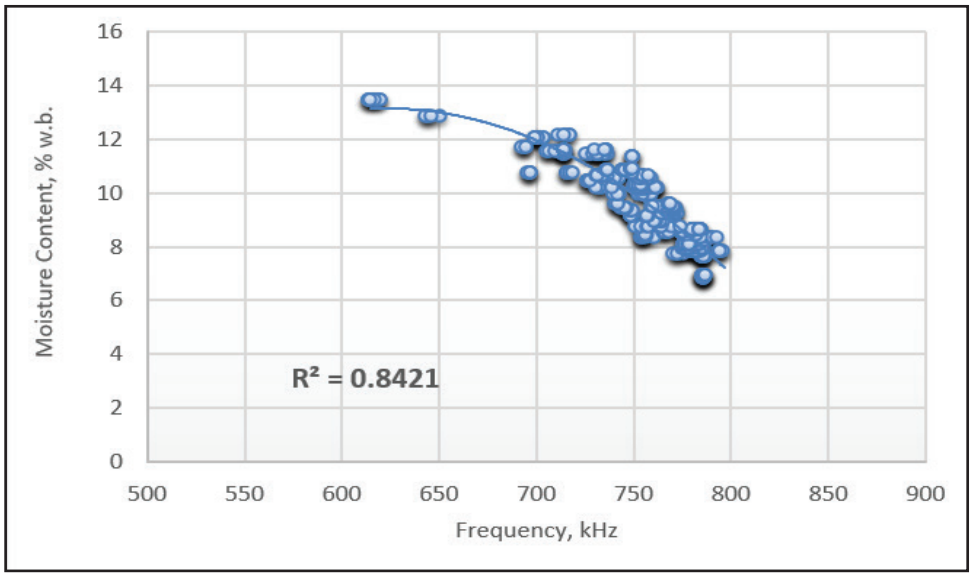

Figure 6. Calibration data generated for GCB, *Coffea arabica*

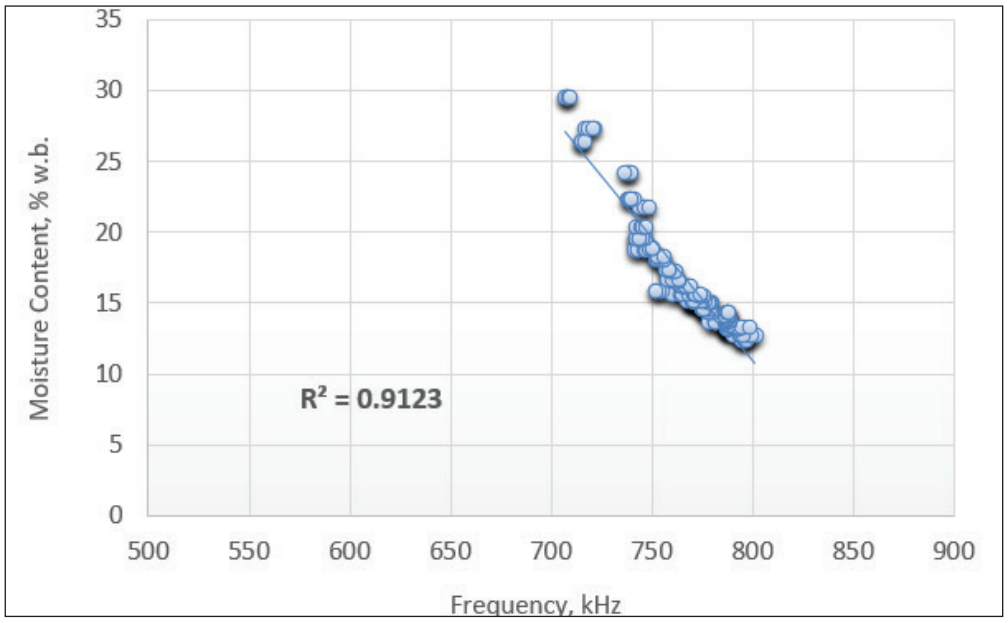

Figure 7. Calibration data generated parchment coffee, *Coffea arabica*

Using regression methods, the following calibration models were developed for green coffee beans (5) and parchment coffee (6), respectively:

$$MC = - 0.0002F^2 + 0.2401F - 61.46 \quad (5)$$
$$MC = - 0.1719F + 148.6 \quad (6)$$

where:

MC = moisture content, % wet basis
F = frequency measured, kHz

The equations have relatively high coefficient of determination (R^2) of 0.84 and 0.91 for gcb and parchment coffee, respectively. Likewise, the equations have reasonably low standard error of estimates (SEE) at 0.83 and 0.85 for GCB and parchment coffee, respectively. The results seem to indicate that the calibration equations as fitted over the frequency and MC data points were relatively adequate for both GCB and parchment coffee.

Validation Tests

Laboratory tests using a new set of coffee samples were done to validate the performance of calibration equations of the developed test chamber. Presented in Figures 8 and 9 were the resulting comparative tests for the developed coffee moisture meter and the standard reference oven MC measurement, and the residual plot against predicted MC values of moisture content, respectively.

A total of 96 data points for GCB were generated and indicated relatively good fit. The residual plot shown in Figure 9 appeared to indicate that the residual values are randomly distributed with a mean square value of 0.63, still an indication that the calibration model of the developed coffee moisture meter was relatively adequate in predicting the MC of green coffee beans.

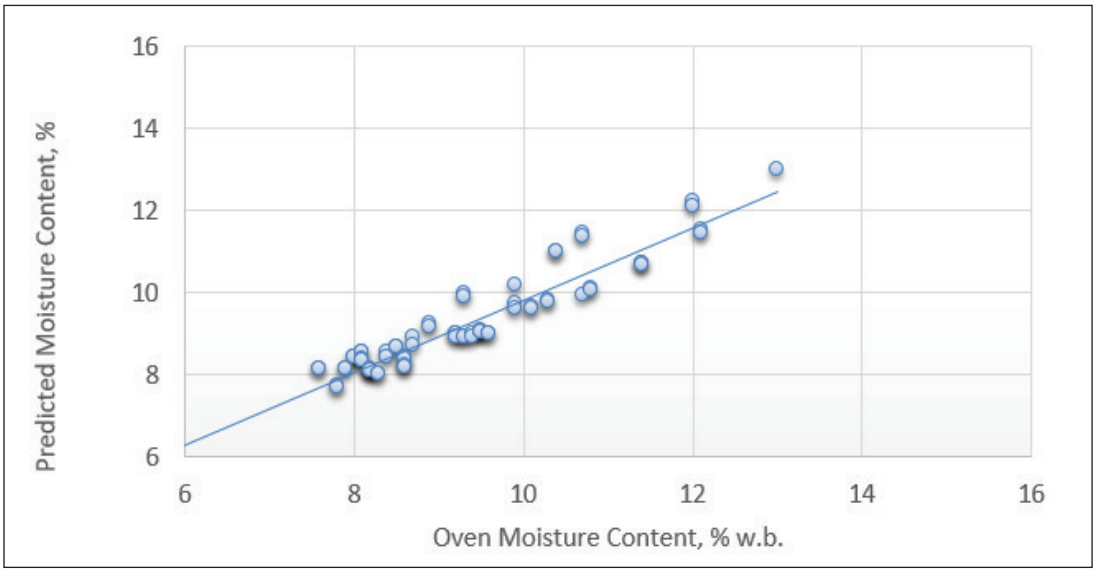

Figure 8. Comparison of green coffee beans moisture contents measured between oven method and developed coffee moisture meter

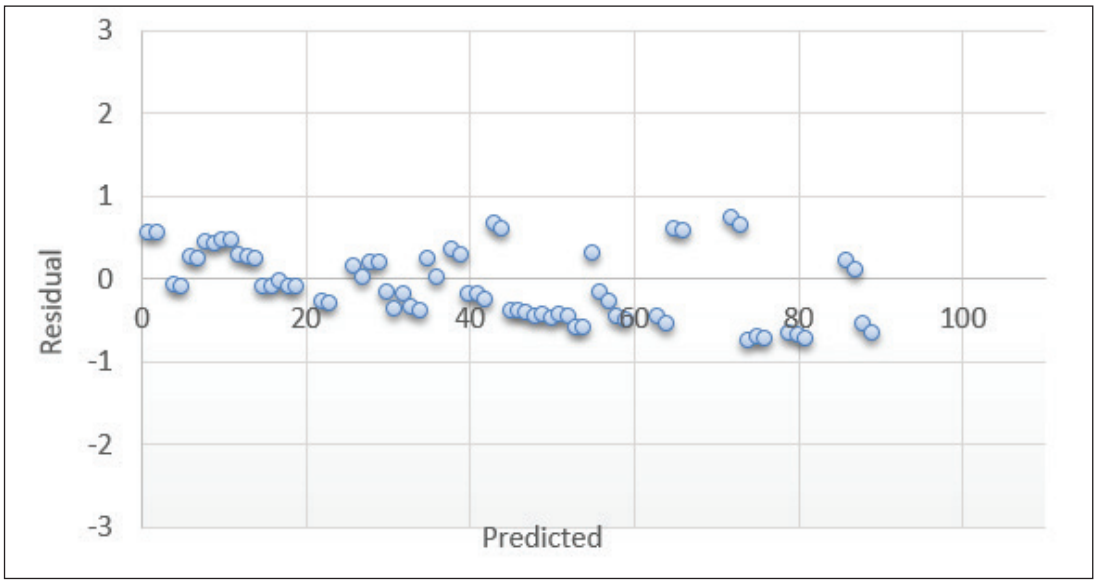

Figure 9. Residuals plot against the predicted values of green coffee beans moisture content using the developed coffee moisture meter

Accuracy and Precision

Performance evaluation results for GCB shown in Table 1, generated an indicative accuracy of the prototype unit of a non-destructive coffee moisture meter. Moisture Error ($(\bar{y})$) as a function of accuracy was computed to be on the average of 0.14% while Standard Deviation of Differences (SDD) was measured to be at 0.4. Both findings were within the set standards of 0.70% maximum permissible measurement error (MPEs) of 0.70%, for field evaluation (OIML, 2009).

Likewise, the same evaluation for parchment coffee resulted to a relatively accurate performance of the non-destructive coffee moisture meter with 0.22%. SDD was also measured to be 0.55 %. It can be noted that SDD for MC ranges of 10% to 12%, was slightly above the maximum permissible mean errors (MPE) that can be attributable to the insufficient number of samples for the specific MC level. However, average findings were still within the set standards of 0.70% permissible error for field evaluation as defined by OIML (2009).

Repeatability and Reproducibility tests as a measure of precision for the coffee moisture meter were done for GCB only. Shown in Table 3 is the result of precision tests conducted for GCB; the coffee MC has proven its technical viability in terms of repeatability computed at an average of 0.09% which is within the maximum permissible measurement error of 0.35%. However, SDD1=0.62% falls short of meeting the maximum permissible measurement error for reproducibility set at 0.42% (OIML, 2009) It could be attributed to insufficient volume of samples during the conduct of the test.

Table 1. Test of accuracy of the developed coffee moisture meter for green coffee beans.

Moisture Range, %	No. of Sample per 2% MC interval	MC Reading, %			
		Reference (Oven)	Developed coffee MC Meter	MC Error, % ($\bar{y}$)	SDD, %
8 to 10	10	8.93	8.70	0.12	0.37
10 to 12	10	11.00	10.76	0.16	0.47
12 to 14	5	13.21	12.97	0.14	0.40
			Mean	***0.14***	***0.41***

Table 2. Test of accuracy of the developed coffee moisture meter for parchment coffee.

Coffee Variety	Moisture Range, %	No. of Sample per 2% MC interval	MC Reading, %			
			Reference (Oven)	Developed coffee MC Meter	MC Error, % ($\bar{y}$)	SDD, %
	10 to 12	4	11.59	11.88	0.29	0.50
Arabica	12 to 14	10	13.15	13.35	0.20	0.61
	14 to 16	10	15.21	15.03	0.18	0.55
				Mean	***0.22***	***0.55***

Table 3. Precision tests conducted for green coffee beans.

Coffee Variety	Moisture Range, %	No. of Sample per 2% MC interval	Precision, %	
			Repeatability Std Dev. (SD)	Reproducibility Std Dev. of Diff. (SDD[1])
	8 to 10	10	0.03	0.58
Arabica	10 to 12	10	0.04	0.51
	12 to 14	5	0.17	0.78

SUMMARY AND CONCLUSION

A non-destructive, capacitance type coffee moisture meter developed by PHilMech was tested for *Coffea arabica* variety. The system adopted the capacitive sensor oscillator circuit to measure MC of both GCB and parchment coffee. Calibration experiments presented a very good relationship between frequency and MC readings with relatively high coefficient of determination and low standard error of measurements. Validation results indicated that the developed MC meter is sufficiently accurate for GCB and parchment coffee, respectively. Further, accuracy and precision tests conducted, yielded a MC error, $\bar{y}$ of 0.14% and 0.22% for green coffee beans and parchment coffee, respectively. Likewise, repeatability tests (SD) was computed at 0.08% for green coffee beans. Both results have met the standard set by the International Organization of Legal Metrology (OIML, 2006).

The conduct of further studies is recommended for other coffee varieties.

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AUGMENTATION RELEASES OF WAREHOUSE PIRATE BUG *Xlocoris flavipes* (REUTER) (HEMIPTERA: ANTHOCORIDAE) FOR THE CONTROL OF INSECT PESTS IN STORAGE

Mia V. Dela Cruz[1], Vicky G. Mesa[2] and PJ De Vera[3]

ABSTRACT

Augmentation releases of biological control agent, *Xylocoris flavipes* to manage insect pests in stored commodities needs the use of appropriate protocol to achieve maximum control. Protocols on release location, rate and augmentation time must be investigated and established. The efficiency of *flavipes* to search for prey with location-distances of 1.0 and 2.0 meters both in horizontal and vertical linear directions, appropriate rate and time of release were evaluated to determine the predatory capacity of *X. flavipes* in the suppression of insect pests population. Results showed that the percentage of *X. flavipes* that have reached patches of prey was higher at horizontal 1 and 2 meter distances than the percentage of *X. flavipes* that have reached the vertical 1 and 2 meter distances with the former have been 26.33, 34.33% and 28.83, 34.33% and the latter with 14.66, 9.0 and 14.66 and 11.16% after 24 and 48 hours, respectively.

X. flavipes that traveled at one meter-distance caused higher percentage rate of prey mortalities than those that had traveled at 2 meter-distance. Those that foraged at 1.0 meter distance either horizontal and vertical caused 85.33, 35.83, 73.33 and 34.1, 30.0, 35 % mortalities after 48 hours on *Oryzaephilus surinamensis*, *Rhyzopertha dominica* and *Tribolium castaneum*, respectively.

Results showed that all of the density treatments caused suppression in prey progenies. Highest reduction was recorded in *O. surinamensis* with 90.44, 92.61 and 89.5 % at a release rate of 216, 144 and 108, respectively.The most appropriate time for augmentation that suppressed prey was after 0 h, 1, 3, 6, and 14 days of insect infestation, with reduction of 32, 37, 41, 33, and 31 % in *R. dominica*, 48, 67, 77, 72, and 64 % in *T. castaneum* and 70, 79, 81, 81,and 75 % in *O. surinamensis* populations, respectively.

Keywords: Xylocoris flavipes, Warehouse pirate bug, Bio-control agent, Augmentation releases, Prey

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INTRODUCTION

Insect infestations in stored commodities mostly originate from insects that are already contained within the storage facilities or from previously infested stocks. Management of several species of insects in warehouses and retail stores traditionally has depended on the application of insecticidal fogs, sprays and fumigants (Cox and Bell, 1991). The most widely used chemical control against insect pests in storage is phosphine fumigation, because of ease of application and efficacy. However, there have been reports on the development of resistance of certain species of insect pests in this fumigant (Holloway, 2008). In the Philippines approximately a thousand fold resistance of *R. dominica* to phosphine was found and recorded and recently resistance was found tripled (Acda et al., 2016).

Residual population of insect pests after fumigation may become the source of resistant strains because of the selection for the resistant traits. Due to this, it is imperative to reduce or manage residual populations in warehouses and retail stores. With the rising problem on the development of resistance and the risk of harmful residues on stored commodities necessitates the need to search for other alternative control methods.

The application of biological control agents such as insect predator for suppression of residual populations of insect pests in empty warehouses and retail stores is potential alternative to chemical control (Brower et al., 1996). Certain predators of storage pests are notable for their potential as biocontrol agents. Recent laboratory studies in PHilMech by Dela Cruz et al., (2017 unpublished) showed that warehouse pirate bug *X. flavipes* caused 36.0, 70.0 and 45.6% suppression in *R. dominica*, *O. surinamensis* and *T. castaneum* populations, respectively.

Releases of this predator, suggested that it can prey on a variety of insects such as *R. dominica* (F.), *T. castaneum* (Herbst) *O. surinamensis* (L.), and *C. ferrugineus* (Steph.) Both male and female *X. flavipes* were capable of preying on different species of insect pests.

Previous studies suggested that *X. flavipes* can be used to prophylactically disinfest emptied storage facilities of residual populations of insect pest eggs and early instar larvae (Arbogast, 1979). Due to this, *X. flavipes* could play a valuable role in preventive disinfestation of emptied storage facility by reducing the threat of contamination in freshly stored grains by residual populations.

To effectively achieve the maximum control of insect pests by predator, a need to increase *X. flavipes* population is imperative. The means to increase the suppressive effect of a natural enemy can be achieved by increasing their number through augmentation, when natural enemies are absent or not sufficient in numbers to provide effective pest control. Inoculative augmentation is the release of few biocon agent and the expected benefits of releases are expected to come from the progeny of the release organism. Inundative augmentation on the other hand involves releasing relative large quantity of biocon and the benefit are expected to come from the released agents.

In the study conducted by Brower and Press (1992) showed that residual populations of several species of small beetles in empty grain bins can be reduced by 70-100 % with weekly releases of a small number of *X. flavipes.*

A major difficulty in the development of augmentative biological control, for insect pests in retail stores and warehouses is the absence of practical guidelines about appropriate time, point and frequency of release of *X. flavipes* so that maximum pest control will be achieved at minimal expense.

Augmentation of predator such as *X. flavipes* for suppression of residual population of insects in Philippine storage condition may not have been studied yet since there was no published article found, hence this study was conducted. The objective of the study is to develop alternative technique and protocol in appropriate augmentation releases of *X. flavipes* for the control of residual population of insect pests in storage.

METHODOLOGY

Mass rearing of test insect prey

The three test prey *O. surinamensis*, *R. dominica*, and *T. castaneum* were mass reared in cracked yellow corn and rice bran as media. Prior to rearing, culture media were sterilized for eight hours at 60^0C and the moisture content was adjusted to recommended safe level (14%) for prevention of mould growth.
Around 200 adults of each prey were introduced separately, into 400 grams of media contained in glass jar (15 cm x 9.5cm x 8cm). Parent preys were allowed to oviposit for seven days at rearing chamber with a temperature of 28-30^0C.

After oviposition, the parent preys were separated from the culture through the use of sieves, then culture bottles were held back again in rearing chamber with the same temperature until the emergence of adult progeny, or until the larval stage appropriate for experimental purposes were reached. Six culture bottles were prepared for each experimental set-up to ensure sufficient number of prey for the succeeding experiments.

Mass rearing of X. flavipes

The predator *X. flavipes* was mass reared with the use of second instar larva of *O. surinamensis* as prey medium. The chosen prey for rearing purposes was based on the high preference of *X. flavipes* against the said insect. One thousand adult *O. surinamensis* were introduced as parent in approximately 400g of sterile cracked corn contained in glass jar of one liter capacity. The culture set-up was held at rearing chamber with temperature of 28–30^0C and with relative humidity of 70%. *O. surinamensis* were allowed to oviposit for seven days. After oviposition, 50 adult *X. flavipes* were introduced in each culture bottle a nd held for 18-20 days until emergence of *X. flavipes* progenies. Said activity has ensured sufficient number of *X. flavipes* for the subsequent bio-assays.

Determination of maximum distance in which warehouse pirate bug can easily locate/detect and immediately reach prey patches

The longest distance that *X. flavipes* can easily and immediately detect and reach prey patches at a given time was determined in this study. The experimental arenas were consisted of enclosed wooden structure of different floor areas that served as treatments. In Treatment 1, a group of 15 adult *X. flavipes* was released with the experimental arena at one meter linear distance away from the patch of 75 early instar larva of the three species of prey. In Treatment 2, the same procedure was followed except that the distance between the group of *X. flavipes*and the patch of prey is two meter linear distance. Control set up was likewise carried out. Each treatment was replicated three times and conducted for three consecutive trials.

The experimental set-ups were evaluated every two hours, to determine the speed of the predator in locating and consequently reach the patches of insect prey, and eventually kill the prey. The number of successful *X. flavipes* that were able to search/reach the location of prey in every evaluation period of two, four, six, eight, 24 and 48 hours after release were counted and recorded for each treatment. The number of prey consumed by the predator were likewise counted and recorded for each treatment.

Determination of the appropriate density of X. flavipes for augmentation release to achieve maximum control of insect pests

This experiment was conducted under Philippine condition to determine if the suppression of insect pests population growth would be affected by the density of the predator released. The experiment was summarized in Table 1, 25 of each of the species of adult *O. surinamensis*, *R. dominica* and *T. castaneum* (with a total of 75 and assumed that 36 of them were female) were placed together in plastic container, and artificially introduced at one corner of experimental arena (one meter linear distance). The number of offered prey was assumed to produce a total of 864 eggs/day as this was based on the previous studies that one female prey will lay a maximum

of 24 eggs per day, *Xylocoris* density treatments were as follows 216, 144 and 108 which corresponded to the rate of predation of four, six and eight prey per one *X. flavipes* per day. Those rate of predation was based from results of previous study in PHilMech conducted by Dela Cruz et al, 2017. Each treatment was replicated three times, and conducted for three consecutive trials.

Suppression of insect pests by *X. flavipes* was determined after adult emergence of the first progenies which ranged from 20 to 35 days. Percent suppression was calculated using the formula below.

$$\% \text{ suppression} = \frac{\text{Number of prey in untreated - number of prey in treated}}{\text{Number of prey in untreated}} \times 100$$

Determination of optimum time for augmentation release of X.flavipes for effective control of insect prey

In this experiment the most appropriate time of release in which warehouse pirate bug can suppress insect population was determined. The interval between insect infestation and the time of predator release (augmented) were investigated. Experimental arenas consisted of plastic containers filled with thin layer of combination of cracked and powdered corn as media. Fifty newly emerged insects of each species (*O. surinamensis*, *R. dominica* and *T. castaneum*) were artificially introduced to each of three replicate arenas per treatment.

The treatments were composed of predator single release interval: 0 hour, 1-, 3-, 6-, 14, 20, and 30 days after insect infestation. Each treatment was replicated three times, and conducted for three consecutive trials. The optimum time of release of predator for controlling population of insects pests was based on the percent suppression of prey progenies recorded from the different times of augmentation tested.

A set of protocol for the augmentative release of the predator *X. flavipes* shall serve as guide to adopters in the use of this technology, and was based on the results of the current study. The appropriate place of release, density and time that were found effective in this study was followed in the establishment of the protocol.

The level of insect infestation in specific storage facility is essential in measuring the effective and cost-effectiveness in the control of insect pest. Therefore, it should be determined before and after the augmentation of predator.

Table 1. Summary of teatments for experiment in the determination of the appropriate density of warehouse pirate bug for augmentation release to achieve maximum control of insect pests.

Treatments (predator density)	Offered prey per day (Assumption)	Rate of predation	% Suppression
216	864	4	-
144	864	6	-
108	864	8	-

RESULTS AND DISCUSSION

Distance of release preferred by X. flavipes for immediate detection of prey patches in a habitat

The foraging efficiency of the predator *X. flavipes* to detect and search for short and long distant patches of prey in certain area was investigated. In this experiment, two specific prey location-distances (1.0 and 2.0 meter linear distance) were evaluated.

Results of the study showed that both groups of *X. flavipes* that were released at two treatment distances were able to detect, reach and invade patches of prey after 48 hours. However, the percentage of predator that immediately detect and reach patches of prey was higher at 1 meter distance, than the percentage of predator that were able to detect and reached patches of prey situated at two meter distance. Results indicated that the shorter the prey distance the higher the chances of more, if not all predators will be able to immediately search prey location (Table 2).

Those patches of prey, situated at 1 meter away from released point of predator in the horizontal and vertical direction, were immediately tracked by 6.67 and 5.66 % of the total number of predator augmented in just a span of two hours, respectively. A maximum percentage of 28.83 and 14.66 % of the released predator have successfully arrived at target prey after 48 hours, respectively.

The span of search time spent by predator released at two meter distance away from prey patch was longer compared to the time spent by predator at one meter arena. The percentage of predator that spent four hours before they were able to reached the target prey was only 5.6 %. Result of the present study agreed with the report of Vet and Dicke in (1992),when they reported that natural enemies locate prey via chemical and physical cues emitted by prey. The predator *X. flavipes* used in this study was mass reared in eggs and small larva of *S. surinamensis*, then probably that may have adapted to chemical or physical cues associated with the species of prey used in this study. As such, this may have facilitated predatory behaviour of *X. flavipes* (Singh and Arbogast, 2008).

Table 2. Percentage number of predator that have successfully located and reached the patches of prey at different evaluation time

Time of evaluation	Test distance of prey			
	1.0 meter foraging direction		2.0 meter foraging direction	
	Horizontal	Vertical	Horizontal	Vertical
2-hr	6.67^{ab}	5.66^{b}	1.2^{a}	0^{a}
4-hr	20.16^{bc}	7.83^{b}	5.67^{ab}	0^{a}
6-hr	21.16^{bc}	8.33^{b}	2.33^{b}	1.16^{ab}
8-hr	22.16^{bc}	12^{b}	13.5^{b}	9^{ab}
24-hr	26.33^{c}	14.66^{b}	34.33^{c}	9^{ab}
48-hr	28.83^{c}	14.66^{b}	34.33^{c}	11.16^{b}

Means with the same superscript letters within a column indicate no significant difference ($p \leq 0.05$)

Successful *X. flavipes* that have reached the prey habitat also found their prey and eventually consumed them. The rate of mortalities caused by each group of *X. flavipes* at two treatment distances were shown in Figure 3 and 4. Both groups of thriving predator that travelled in horizontal direction for the two treatment distances were able to kill and cause mortalities in all species of prey.

However, the percentage mortalities caused by predators that have reached the 1.0 meter distance prey was higher compared to the mortalities caused by those predators that have reached 2.0 m distance prey, as the former have provided an initial mortalitities of 3.33, 0.83, and 0.83 % as early as two hours after and continue to increase with time until final mortalities of 85.33, 35.83 and 73.33 % at the end of 48 hours in *O. surinamenis*, *R. dominica*, and *T. castaneum*, respectively (Fig.1).

On the otherhand, the level of mortalities provided by predators at 2.0 meter treatment distance have only 4.2, 1.67 and 4.16 % after four hours and at a maximum of 62.25, 52.5, and 58.33% in *O. surinamensis*, *R. dominica* and *T. castaneum* after 48 hours of predation, respectively (Fig.2).

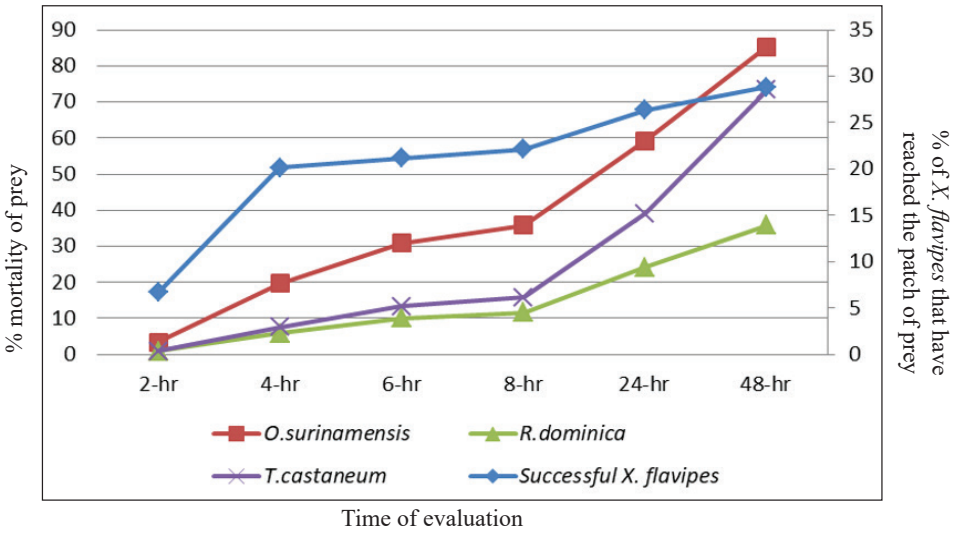

Figure 1. Percent mortality of three species of prey caused by *X. flavipes* that have travelled at 1 meter linear distance at horizontal direction

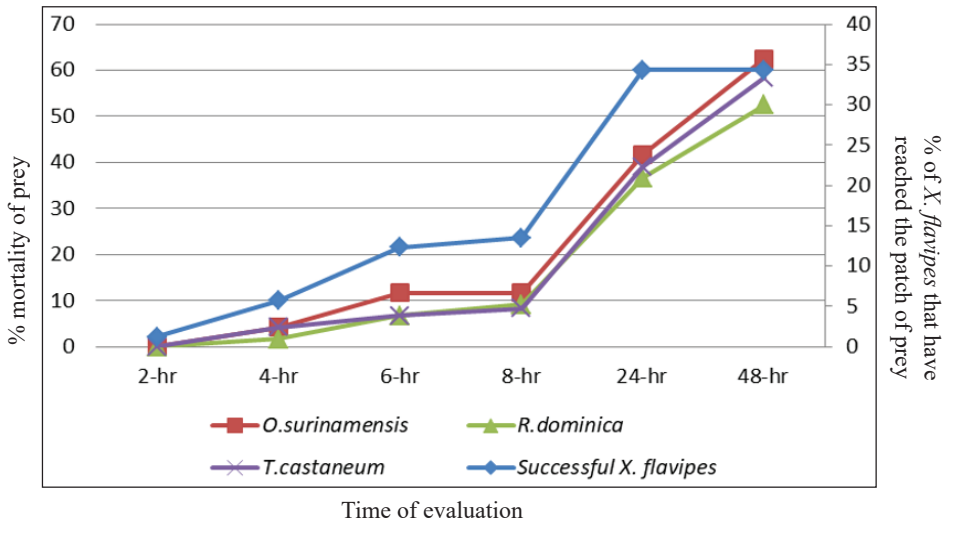

Figure 2. Percent mortality of three species of prey caused by *X. flavipes* that have travelled at two meter linear distance at horizontal direction.

Foraging *X. flavipes* that have located and searched in vertical direction to get into the prey situated at one and two meter linear -distance, have caused mortality in all species of prey after 48 hours of observation period. However, the *X. flavipes* at one meter distance have immediately killed prey after two hours of searching with 1.67% mortality both of *O. surinamensis* and *T. castaneum*. It was observed that mortalities increased with times as the number of *X. flavipes* that have reached the patch increased until the end of 48 hours observation period, with 34.1, 30.0, and 35.83% of *O. surinamensis*, *R. dominica* and *T. castaneum*, respectively (Fig.3).

On the other hand, *X. flavipes* at 2.0 meter treatment- distance have caused low initial mortalities of 5.83, 3.33, and 2.5% only after eight hours and got into a maximum mortality of 33.33, 11.0, and 30.8% after 48 hours in *O. surinamensis*, *R. dominica* and *T. castaneum*, respectively (Fig.4).

Results of the study showed that long delay in *X. flavipes* to search the prey eventually caused delay in the control of prey population. Based on this study, better control of insect pests in certain storage facilities, the augmentation release of predator *X. flavipes* should be made in close-proximity of at least 1 meter in the suspected patches of prey. In this way, the predator can easily locate the prey and immediately cause control of the pests. Appropriate point of release of *X. flavipes* in storage facility should be every one meter apart.

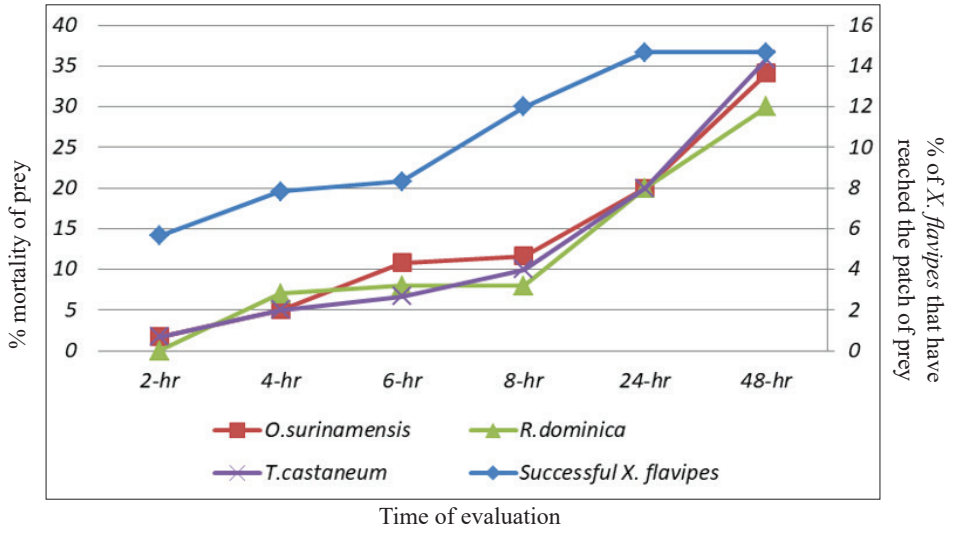

Figure 3. Percent mortality of three species of prey caused by *X. flavipes* that have travelled at 1 meter linear distance at vertical direction.

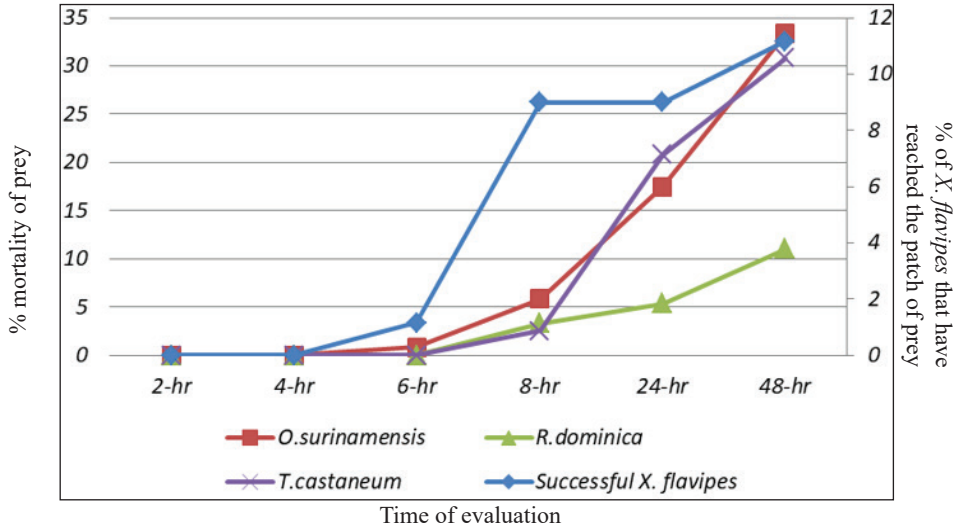

Figure 4. Percent mortality of three species of prey caused by *X. flavipes* that have travelled at two meter linear distance at vertical direction.

Based on the results of this present experiment, *X. flavipes* can easily detect, reached and feed on short- distant prey, but encountered difficulties in detecting long distant prey habitat. Generally, natural enemies of insects pests such as predator, find and forage potential victims with the use of various stimuli (cues) emitted or produced by the prey themselves, or other organisms within the environment (Jervis, 2005). The stimuli are visual, acoustic or olfactory cues which induce a changé in forager behaviour, that results in orientation to areas that either contain prey or are likely to contain prey (Dugathin and Alfari and Meiners et al., 2003).

Result of this study was consistent with the work of Harmon et al., (1998), as he investigated the role of colour and vision in the short distant-foraging adults of four coccinellid species (*Coccinella septempunctata*, *Hippodamia convergens*, *Harmonia axyridis* and *Coleomegilla maculata*). The first three species were more efficient foragers in the light, supporting the conclusion that vision plays an important role in prey capture.

Appropriate density of X. flavipes release to achieve maximum suppression of insect prey population

The experiment was undertaken to evaluate the effect of *X. flavipes* rate of release, on the population growth of each species of prey. An initial population of the combined culture of the three species of prey, introduced in experimental arenas were assumed to produce a total of 864 eggs per day. With that assumption, the rate of release of *X. flavipes* were based on the rate of predation such as 4, 6 and 8 prey per day which correspond to total number of 216,144 and 108 *X. flavipes*, respectively.

Results showed that all of the treatments (density treatment) caused highly acceptable reduction in the number of emerging F1 progenies in the three species of prey (Table 3). Analysis of variance among treatments indicated that there was no significant difference in the percent suppression of progenies in each species of prey, recorded in all treatments (released density of predator).

However, the highest reduction in F1 progenies was found in *O. surinamensis* with 90.44, 92.61 and 89.5 % suppression at a release density of 216, 144 and 108, respectively. Consistent high preference of predator *X. flavipes* to *O. surinamensis* was again proven in this experiment, and this is primarily attributed to the fact that this species of prey developed outside the grain, that made them readily accessible to foraging predator.

R. dominica on the other hand, developed inside the grain, which only the eggs and the newly emerged first instar larva were only the potential victim of haunting predator. *T. castaneum* showed the least percentage in reduction of F1 progenies across all treatment densities of *X. flavipes* as this species also developed externally. But, the neonate has semi-sclerotized body that makes them less preferred by *X. flavipes* but in the absence of preferred prey, it also attacks the said species to evade starvation.

Table 3. Percent suppression of progenies of different prey as influenced by the different density of X. flavipes releases

Treatment (density)	Percent suppression (%)		
X. flavipes	*R. dominica*	*T. castaneum*	*O. surinamensis*
216	75.53	36.4	90.44
144	70.79	32.24	92.61
108	59.98	44.02	89.5

Analysis of variance among means indicate no significant difference ($p \leq 0.05$)

Optimum time for augmentation release of X. flavipes to achieve maximum suppression of prey population

The experiment was further undertaken to evaluate the biological control efficacy of *X.flavipes* in the suppression of emerging progenies of three species of prey. Seven different "timing of release" of the predator *X.flavipes* were tested to determine if they have influence on the reduction of F1 progenies of prey (Table 4).

Results showed that *X. flavipes* released in all treatments (timing of release) were able to cause reduction in the density of F1 progenies accross all species of prey. However, significantly highest percentage of suppression was obtained when predator was released after 0,1,3,6h, and 14 days of insect infestation, with reduction of 32,37, 41,33, and 31 % in *R. dominica*, 48,67,77,72, and 64 % in *T. castanem* and 70, 79,81,81,and 75 % in *O. surinamensi*s, repectively.

The least effective among timing of release, was observed when predator was released after 20 and 30 days of insect infestation in experimental arenas, and this observation was consistent accross all species of prey.

Among the three species of prey, *O. surinamensis* has the highest progeny suppression in all treatments, indicating that the said species was the most preferred prey. Said results is attributed species because it develops externally and have comparatively small as in size and their neonate have soft body structure.

Based on the results, *X.flavipes* can control population growth of insect prey in storage if released at the most strategic time of zero hour, one, three, six and 14 days after prey infestation. The level of control brought about by *X. flavipes* was attributed with the fact that said predator has highest preference to newly laid eggs, early instar larva, and soft- bodied neonate of externally developing insects.

The predator *X. flavipes* evaded prey that has hard sclerotized body. Said feeding behaviour make them less efficient in controlling adults of many species of storage insects. The observation in this present study was consistent with the report of several reaserchers, such as LeCato and Davis (1973), Sing (1997), Sing and Arbogast (2008) that *X. flavipes* predatory response was low and consistent on the adult stage of all prey species and much higher on the eggs and neonate larvae of *Acanthoscelides obtectus*. The predator also exhibited more preference to insect species that develop outside of the grains than those prey that develop inside the grains (Hill 2002; Howe and Currie 1964).

Table 4. Effect of various augmentation release (add-on time) of *X.flavipes* on the percent (%) suppression of the population of F1 progenies of three species of prey.

Time of Release after insects infestation	Percent suppression (%)		
	R. dominica	***T. castaneum***	***O. surinamensis***
0 hr	32^{bc}	48^{bc}	70^{cd}
1-day	37^{c}	67^{cd}	79^{d}
3-day	41^{c}	77^{d}	81^{d}
6-day	33^{bc}	72^{d}	81^{d}
14-day	31^{bc}	64^{cd}	75^{d}
20-day	9^{ab}	48^{bc}	49^{bc}
30-day	7^{ab}	43^{b}	32^{b}

Means with the same superscript letters within a column indicate no significant difference ($p \leq 0.05$)

Establishment of protocol based from the results of this study for the purpose of augmentation releases of predator *X. flavipes* for the management of insect pests in storage.

Protocol I

Mass rearing of the predator X. flavipes

X. flavipes will be mass- reared with the using 1st to 2nd instar larva of its most preferred medium, *O. surinamensis*.

a. Collect adult *X. flavipes* from previous culture using appropriate sieves to separate media and adult predator;
b. Introduce 1,500 adult *X. flavipes* to culture set-up containing seven days old *O. surinamensis* and cover rearing container with the lid that has opening at the center and lined with a very fine wire mesh allowing exchange of gases from inside and out of the culture;
c. Label culture container; indicate the date of inoculation of *X. flavipes*;
d. Place the culture set up on aluminium/plastic trays previously smeared with mineral oil to prevent contamination with other crawling insects;
e. Incubate cultures in rearing chamber with a temperature of 28-30^{0}C and 70-75% relative humidity;
f. To obtain homogenous age of *X. flavipes*, remove all parents predator after seven days of incubation with the use of appropriate sieves;
g. Incubate again the culture set up in rearing chamber with the same temperature and relative humidity as above for 18-21 days until emergence of *X. flavipes* progenies.

Preparation of X. flavipes for release in storage facility

X. flavipes that will be released in storage facility for the control of insect pests should be healthy and vigorous. Due to this, only the newly emerged adult will be used in augmentation releases.

Steps in preparation of *X. flavipes* for release in storage facility

a. Separate and collect one to three day old predator from culture medium through the use of appropriate sieves;
b. Prior to release, the predator should be starve for 24 hours to ensure more efficient foraging and predation;
c. Cannibalism is prevalent when food was in adequate. To prevent this, confine *X. flavipes* individually in clean small plastic vials with a thin layer of powdered corn;
d. After 24 hours of starvation, *X. flavipes* are ready for release.

Protocol II

Manual augmentative release of predator X. flavipes in storage facilities

The efficiency of predator to locate insect prey depends on the part of the distribution pattern of the predator within the facility, the release

point, the density and time. The distribution pattern should bring the predator as close as possible to patch of prey to reduce searching time.

Release point of predator *X. flavipes*

For the successfull management of insect pests in a storage facility, augmentation release of *X. flavipes* should be made in proximity of one meter linear in the suspected patches of insects. In this way, the predator can easily locate the insects and immediately cause control of the pests.

a. Patches of insect pests are not confined only in one area of the facility but they are scattered in the entire facility; To disinfest a whole ware house, the entire floor area should be divided into one sq. meter quadrant, and the middle portion of the quadrant shall serve as the release point of *X. flavipes*;

b. The walls, pillars and trusses of a warehouse may have small cracks and crevices that can serve as breeding sites of insects. These areas can also be disinfested following the same procedure as above.

c. All equipment that are inside the warehouse shall also be disinfested by releasing a number of *X. flavipes* at one linear meter distance apart.

Appropriate density of predator X. flavipes for augmentation release in storage facility

In this protocol, the procedure for general inspection and sampling developed by Ashman in 1966 and 1970 in the Ministry of Agriculture, Fisheries and Food Inspectorate, Britain, will be adopted as it has international sanction and are therefore recommended for any general inspections of the commodity, structural condition of the warehouse, silo or mill, or any handling and conveyance equipment that may serve as breeding sites for residual infestations. The degree of infestation as described by Ashman in 1966 and 1970 and the corresponding density of predator are shown in Table 5. The various degree of infestation served as basis for the density of predator release.

Table 5. Various degrees of insect infestation and the recommended density of *X. flavipes* for release.

Degree of infestation in storage facility	**Number of insect sampled**	**Density of *X. flavipes* for release in every 1m² linear distance**
very light	Insects are not easily observed on the structure of storage facility and on the sacks or samples before sieving. <20 insects per 90 kg sieved (Will need disinfestation treatment soon)	30 adult *X. flavipes*
Light	Insect collected ranges from 20-50 per 90 kg sieved sample (Immediate disinfestation measure for anything above this population density)	75 adult *X. flavipes*
Moderate numbers	Ranges from 50-300 insects per 90 kg sample	450 adult *X. flavipes*
Heavy numbers	300-1,500 insects per 90 kg of samples	2,250 adult *X. flavipes*
Very high numbers	>1,500 insects collected for every 90 kg sample sieved	2,400 adult *X. flavipes*

RESULTS AND DISCUSSION

Results of the study showed that the predator *X. flavipes* can easily and immediately locates and reached the exact location of its targeted prey when they were released at a distance of one meter linear distance away from a patch of prey. Moreover, the immediate detection of prey patch resulted in rapid mortality of prey. The rate of foraging efficiency of predator was slowed down when it was applied or release at two meter linear distance away from patch of prey.

The study showed that all *X. flavipes* density treatment of 216,144, and 108 tested in this experiment, (based on the rate of predation of four, six, and eight preys per day respectively) was proven effective in the suppression of all prey progenies. Releasing just an appropriate number of predator would result in more efficient and economically beneficial augmentative biological control.

The most effective time for augmentation releases, or add-on of predator in storage facility that can effectively suppressed the population growth of emerging adult F_1 progenies of the three species of prey, were at one, three, six, and 14 days after insect infestation of grains. Moreover, simultaneous or 0 hour release, likewise have great influence on the reduction of the number of F_1 progenies across all species of prey. The reason behind the effectiveness of the identified best "time of releases" of *X. flavipes* was that it coincides with the time in which the preys' progenies were in the developmental stages that was preferred by predator. In this connection, too much delay in the release/application of *X. flavipes* in the storage facility by 20 and 30 days will eventually cause low suppression of insect pests' population. Appropriate timing of the application of this predator in storage facility is very essential, because if the timing of release was not synchronized with the time wherein insect prey were most vulnerable to predation of *X. flavipes* the ultimate purpose of augmentation will not be served.

The laboratory established protocol for augmentation of *X. flavipes* in this study is recommended for further field testing to arrive at a more complete information on the biological control potential of this predator.

RECOMMENDATION

Based on the results of this study, *X. flavipes* can significantly control population growth of insect prey in storage if they will be applied at the most strategic time.

- The most efficaceous time for release of predator *X. flavipes* in controlling residual infestation in empty storage facility is 14 days before the intake of new stocks. Release can be carried out for two consecutive weeks to ensure maximum control.

- For desinfestations of stored commodities, release of predator should be done immediately after detection of insect infestation. A weekly release for two consecutive weeks will suffice.

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