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Moisture sorption isotherm and shelf-life estimation of blue butterfly pea (*Clitoria ternatea* linn.*)* Powder using gab model

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Abstract
Eastern Visayas Food Innovation Center has continually developed products using under-utilized resources for innovation, value-addition, and product and process improvement. One commonly available and underutilized plant is the blue butterfly pea flower (*Clitoria ternatea* Linn.). They are good source of ternatin antioxidant and other nutritional components. The fresh edible flowers are highly perishable, deteriorating at less than 48 hours even at cold temperatures. Drying as one of the oldest methods of prolonging shelf-life was employed to increase the flowers' availability and stability, making a powder for direct reconstitution, also as potential food ingredient and as natural food colorant. To establish suitable storage conditions of the powdered flower, this study aimed to determine the moisture sorption isotherm (MSI) using standard gravimetric method at 30ºC and 40ºC with six (6) saturated salt solutions and to estimate the shelf-life using three (3) different packaging materials stored at 29ºC / 80%. Observed Equilibrium Moisture Content (EMC) values were fitted to GAB mathematical model by a generated polynomial equation. Water Vapor Transmission Rate (WVTR) and Permeability Coefficient (P) of the packaging materials used were also investigated in estimating the shelf-life together with the MSI data. The isotherms exhibited Type II curve or were sigmoidal in shape. GAB as the model used showed to be a best fit model to describe experimental data with coefficient of determination, $R^2>0.9$, mean relative percent deviation modulus, %E and root mean square percent error, %RMSE of <10%. Based on Heiss-Eichner linear model overlaid to the predicted sorption isotherms, product packed in VMPET/PE was the most effective packaging compared with MOPP/PET/AL/PE and NYLON/PE. This accelerated and simulated approach in estimating shelf-life is beneficial to food companies with food safety concerns, for proper storage recommendation, process improvement at shorter time and lower cost of investigation.

Keywords: blue butterfly pea, gab model, moisture sorption isotherm, shelf-life, water activity

Introduction

Regional Food Innovation Center (FIC) is a center for innovations, research and development (R&D), and support services for value-adding fresh produce, exploration of untapped resources, and creation of processed foods in each region of the country. One promising prototype of the Eastern Visayas Food Innovation Center is the Blue Butterfly Pea flower powder.

Blue butterfly pea (*Clitoria ternatea* Linn.) or "blue pea" is widely distributed in Tropical countries like India, Sri Lanka, Malaysia, and the Philippine Islands (Lakshan, et. al., 2019 and Mukherjee, et. al., 2008) [1] which in Tagalog is called "Pukingan" that translates as the female external genitalia (Stuart, 2019) [2]. It is a pantropic, perennial twinning herbaceous plant belonging to the Fabacaea family, which has the potential to be used in modern medicine and agriculture (Oguis, et. al., 2019) [3]. Traditionally, blue pea is well known as Ayurdevic medicine and are extensively researched as antioxidant, antimicrobial, anti-inflammatory, antidiabetic, antiasthmatic, analgesic, diuretic, antilipidemic among others (Jeyaraj, et. al., 2020 and Oguis, et. al., 2019) [3, 4]. In the Philippines, the intense blue-colored petals are naturally used as food colorants and as ornamentals. The flowers are edible, adding an appealing sensory property to salads, soups, desserts, beverages and entrees in gourmet dishes. Even with its wide positive contributions, they are still considered underutilized commercially as they easily wither due to senescence and typically deteriorate in about two (2) days after harvesting (Hawa, et. al., 2021 and Kou, et. al., 2012) [5, 6]

One of the oldest and widely used preservation methods to extend the shelf life of food products is through drying. It removes moisture simultaneously through heat and mass transfer and decreasing moisture content and water activities. The inaccessibility of water inhibits microbial proliferation and biochemical degradation, namely, enzymatic, and non-enzymatic browning (Singh and Heldman, 2009) [7]. Furthermore, drying makes products convenient with reduced bulk weight that decreases shipping, transport and storage costs (Heldman and Hartel, 1999 and Fellows, 2000) [8, 9]. As dried products affect moisture content and water activity of food, they are best described and evaluated by their sorption isotherms (Al-Muhtaseb, et. al., 2002) [10].

Moisture sorption isotherm of foods helps to: a) determine concentration and dehydration processes; b) formulate complex food mixtures; c) identify suitable packaging material; d) classify microorganism of interests based on what moisture content will restrict growth; and e) predict chemical and physical stability of food as a

function of water content (Damodaran,2017) [11]. Isotherm curves are widely fitted into the GAB (Guggenheim-Anderson-DeBoer) model, which is a multilayer equation with two (2) constants describing food with water activities of up to 0.94 (Okos, et. al., 2007). The linear points of the curve together with the package information, permeability, and water vapour transmission rate, the shelf-life of moisture-sensitive powders can be estimated (Hernandez, 1997) [13].
Shelf life testing, at times, is conducted at longer periods and is generally expensive. Also, this must be conducted throughout the cycle of a product development, reformulation and process changes. Thus, an accelerated test through simulated approach is advantageous in profiling food products' keeping quality. Generally, this study aimed to evaluate the moisture sorption isotherm (MSI) and estimate the shelf-life of blue butterfly pea powder *(Clitoria ternatea)*.

Materials and Methods

Powder Processing

Washed and sorted fresh blue ternate pea flower petals were cabinet dried at 60ºC for four (4) hours and ground to powder. The determined process scheduled was experimentally chosen by identifying the effects of different time-temperature drying combinations to moisture content, water activity, bulk and tapped densities, porosity, as well as microbial quality of the powders produced. Moreover, samples were packed in VMPET /PE for further analysis.

Determination of Initial and Critical Moisture Content and Water Activity

Initial Moisture Content (%MC_{wb}) was determined through a rapid method using a Moisture Analyzer (Kern, DBS-BA-def-1714, Germany) at 105ºC with two (2) grams per sample. On the other hand, initial water activity was determined using Smart Water Activity Meter (HA-002375) with five (5) grams per sample. Both analyses were done in triplicate. Critical water activity (Aw) was obtained from literature review while, critical moisture content was calculated using the generated polynomial equation.

Determination of Equilibrium Moisture Content and Sorption Isotherm

Standard gravimetric method was employed in the determination of the equilibrium moisture content (Al-Muhtaseb, *et al*. 2002 and Wolf, et. al., 1985) of the product using six (6) saturated salt solutions (Tab. 1) with water activity ranges of 0.0758 to 0.97 and 0.0626 to 0.9641 at 30ºC and 40ºC respectively.

Table 1: Equilibrium Relative Humidity (ERH) for various saturated solutions

Salt Solutions	Saturation Temperature, ºC	
	30	**40**
Sodium Hydroxide (NaOH)	7.58 ± 1.70	6.26 ± 1.20
Magnesium Chloride ($MgCl_2$)	32.44 ± 0.14	31.60 ± 0.13
Potassium Carbonate (K_2CO_3)	43.17 ± 0.50	43.51 ± 0.51
Sodium Chloride (NaCl)	75.09 ± 0.11	74.68 ± 0.13
Potassium Nitrate (KNO_3)	92.31 ± 0.60	89.03 ± 1.20
Potassium Sulfate (K_2SO_4)	97.00 ± 0.40	96.41 ± 0.38

Source: *(Greenspan, 1977)*

The saturated solutions were poured in 250 mL glass jars up to 1.5cm deep. A one (1) inch cut PVC pipe with one (1) inch diameter and mesh screen were also placed at the center of each jar to serve as the platform and sample holder. One (1) gram of sample in triplicate per solution were prepared and weighed on sterilized aluminum foil placed on top the PVC pipe and aluminum wire gauze and were tightly closed. The experimental set-up is presented in Fig. 1. The set-ups were placed in temperature-controlled incubators at 30ºC and 40ºC. Constant weighing was done until three (3) consecutive weight gain or lost sample were either less than 0.001 gram or 1% (Mesias &Tan, 2015, Bastioĝlu, et. al., 2016, and Kizmaz, *et al*., 2019) [16], thus considered its equilibrium weight.

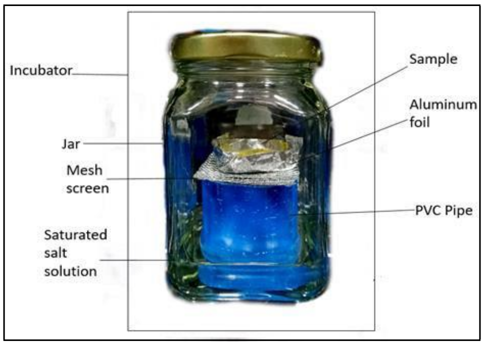


Fig 1: Moisture Sorption Isotherm Set-up.

After the equilibrium weights of the samples were reached, the Equilibrium Moisture Content was measured using the moisture analyzer. Dried weights after each analysis were recorded and the results taken were in wet basis and converted to dry basis using the formula.

$$\%MC_{db} = \frac{\%MC_{wb}}{100 - MC_{wb}\%} x100 \tag{1}$$

$$MC_{\boldsymbol{db}} = \frac{w-d}{w} x\ 100 \tag{2}$$

Where:
MC_{db}=Moisture content in dry basis
MC_{wb}= Moisture content in wet basis.

The experimental Equilibrium Moisture Content (EMC, M_e) values were then graphed in scatter plots with Aw on the x-axis and EMC_{db} on the y-axis. This determined what type of sorption isotherm the product exhibited.

Modelling Sorption Isotherm Data using GAB Model

The experimental Equilibrium Moisture Content (M_e) at different water activities and storage temperatures were fitted to Guggenheim-Anderson-Boer (GAB) Mathematical Model. Two (2) fittings were conducted, namely using Aw of <0.95 which GAB model is known to be successful in fitting sorption isotherms and Aw of >0.95 to make use of all the six (6) data points and compare their differences. The GAB equation is (Chang, et. al., 2019):

$$Mp = \frac{CKM_oA_w}{(1-KA_w)[1-KA_w+CKA_w]} \tag{3}$$

Where:
Mp = predicted EMC
Mo = Monolayer Moisture Content
K = multilayer water molecules and bulk liquid GAB constant
C = monolayer thermal effects GAB constant
Aw = water activity

Rearranging the equation and considering Aw as a function of the moisture content, form a polynomial or quadratic equation:

$$\frac{Aw}{(1-KAw)Mp} = \frac{1}{MoCK} + \frac{C-1}{MoC}Aw \tag{4}$$

$$\frac{Aw}{Mp} = \frac{K}{Mo}\frac{1}{C-1}Aw^2 + \frac{C-2}{MoC}Aw + \frac{1}{MoCK} \tag{5}$$

$$\frac{Aw}{Mp} = \alpha Aw^2 + \beta Aw + \gamma \tag{6}$$

Polynomial or quadratic graphs were constructed with Aw on the x-axis and A_w/M_e on the y-axis, the equation generated represents the GAB values and constants as follows (Maroulis, 1988 and Singh and Heldman, 2009):

$$\alpha = \frac{K}{Mo}\frac{1}{C-1}\ ;\ \beta = \frac{C-2}{MoC}\ ;\ \gamma = \frac{1}{MoCK} \tag{7-9}$$

$$\delta = \frac{\beta^2}{-\alpha\gamma} + 4\ \ ; C = \frac{\delta + \sqrt{\delta^2 - 4\delta}}{2} \tag{10-11}$$

$$Mo = \left(1 - \frac{2}{C}\right)\frac{1}{\beta}\quad ;\quad K = \frac{1}{\gamma CMo} \tag{12-13}$$

Determination of the Goodness of Fit of GAB Model

Using Eq. 6, GAB values were calculated, which were then used to calculate the predicted EMC (M_p) with the same water activities (Aw) as the experimental. Scatter plots of the experimental and predicted EMC were made depicting their trends, fitness, and coefficient of determination (R^2). Moreover, the mean relative percentage deviation (%E) and percent root mean square error (%RMSE) were also calculated to determine goodness of fit of the model, with formula (Yaptenco, et. al., 2017 and Gichau, et. al., 2020) [21];

$$\%E = \frac{100}{n}\sum_{i=1}^{n}\frac{|Me - Mp|}{Me} \tag{14}$$

$$\%RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Me - Mp/Me)^2}{n}}\, x\, 100 \tag{15}$$

Where:
Me = EMC experimental
Mp = EMC predicted
n = number of data points

The model was considered a good fit if R^2 values were higher than 0.9, while %E and %RMSE values were less than 10% (Bastioĝlu, et. al., 2016). The lower the calculated values for these parameters indicated better fit of the model used.

Determination of Water Vapor Transmission Rate and Permeability Coefficient

Water Vapor Transmission Rate (WVTR) and Permeability Coefficient were determined through gravimetric method according to ASTM E 96 as cited by, Robertson, 2013 and Slamet, *et al*., 2020. Five (5) samples of different packaging materials (Fig. 2) were prepared, and ten (10) grams of desiccant or silica gels were placed into three (3) of the five (5) samples, while the other two (2) served as controls. All the packaging materials were sealed using a band-sealer. Moreover, thickness was taken using a vernier caliper, while surface areas were measured using a ruler and calculated.

Fig 2: Different Packaging Materials used, a) MOPP/PET/AL/PE; b) NYLON/PE; and c) VMPET/PE

The experimental set-up was conducted at room temperature with mean storage condition readings of 29ºC and at 80% relative humidity using saturated Potassium Nitrate (KNO_3) solution inside a desiccator cabinet. A thermohygrometer was also placed inside to record the temperature and RH aside from the dial of the cabinet. The packaging material samples were weighed constantly with at least six (6) data points (Yaptenco, *et al*., 2017). Samples were placed horizontally without overlapping each other. Visual representation of the whole set-up is shown in Fig. 3.

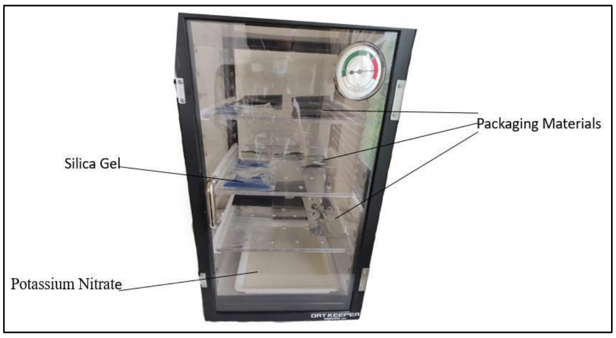


Fig 3: Accelerated Shelf-Life Testing (ASLT) Set-up

Weight gains of the packaging materials subtracted with the weight gain of the controls were plotted and the slope (weight gain vs time in days) determined the water vapor transmission rate (WVTR) and permeability coefficient (P) with formula:

$$WVTR = \frac{Q}{tA} \tag{16}$$

$$P = \frac{Q}{tA}\frac{X}{\Delta p} \quad or \quad P = \frac{WVTR(X)}{\Delta p} \tag{17}$$

Where:
Q/t = slope
A = surface area
X = thickness
Δp = partial pressure change
Po = saturated vapor pressure of pure water, ºC
RH = storage relative humidity

$$\Delta p = p_o - p_i \tag{18}$$

According to ASTM E 96 as cited by Hernandez, 1997, P_i = 0 because vapor pressure inside the packaging is in equilibrium with the desiccant, thus:

$$\Delta p = \frac{p_s}{100}(RH) \tag{19}$$

Estimation of Product Shelf-Life Using GAB Model
Initial and critical moisture content from the initial and critical water activity were calculated using the generated GAB equations. Slope of the initial to the critical values were overlaid to the GAB sorption isotherm and recorded. Together with the packaging materials information, calculated WVTR and P; shelf life was determined through Accelerated Shelf-Life Testing through critical water content approach or the Heiss-Eichner model, using the formula (Labuza, 1984 as cited by Anandito, et. al., 2017, Gichau, et. al., 2020, Labuza and Contreras-Medellin, 1981 and Labuza and Altunakar, 2007 as cited by Roudaut, 2011):

$$\ln\frac{(M_i - M_e)}{(M_c - M_e)} = \frac{P\ A\ p}{X\ m\ b}\theta \quad or \quad \theta = \frac{ln\frac{(M_i - M_e)}{(M_c - M_e)}}{P\ A\ p^{\circ}}\ X\ m\ b \tag{20}$$

Where;
0 = time in days
M_i = initial moisture content, db
M_c = critical moisture content,db
M_e = moisture content at storage condition, db
P = permeability coefficient, gH_2O m2 day-$_1$ mmHg-$_1$
P_o = saturated water vopor pressure (30C), mmHg
X = packaging material thickness, mm
A = surface area, m^2
m = product weight, g
b = slope

Data Analysis
All the data, generated graphs and equations, as well as calculations were through the use of Microsoft ® Excel 2010 with Kutools Add-In. ANOVA and Tukey HSD were conducted using IBM® SPSS® Statistics Version 25, in determining the significant differences between the means of WVTR and estimated shelf-life of the different packaging materials.

Results and Discussion
Equilibrium Moisture Content (EMC) and Sorption Isotherms
After more than two (2) weeks of weighing the samples, the equilibrium moisture content at each specified relative humidity (RH) conditions based on Eq. 1 and Eq. 2 are shown in Tab. 2. The results revealed that Aw

and EMC were directly proportional, thus as water activity values increased, the equilibrium moisture content values also increased.

Table 2: Equilibrium Moisture Content (EMC) of Blue Butterfly Pea Powder

Temperature (ºC)	Water Activity (Aw)	Average EMC (g/g db)
30	0.0758	0.1129
	0.3244	0.1243
	0.4317	0.4761
	0.7509	0.7032
	0.9231	1.0805
	0.9700	1.4194
40	0.0626	0.1122
	0.3160	0.1313
	0.4351	0.4200
	0.7468	0.6586
	0.8903	1.0934
	0.9641	1.4931

Plotting these data points with water acidity (Aw) on the x-axis and EMCdb on the y-axis (**Fig. 4**), revealed the sorption isotherms at both 30ºC and 40ºC follow Type II S-shaped or sigmoidal pattern with combination of adsorption and desorption curves. According to N. Aviara (2020), the moisture sorption isotherms of most foods are nonlinear, sigmoidal in shape, and classified as type II. Both adsorption and desorption characterized the isotherms generated since equilibrium were reached at both moistures lost and gain as observed using the initial moisture

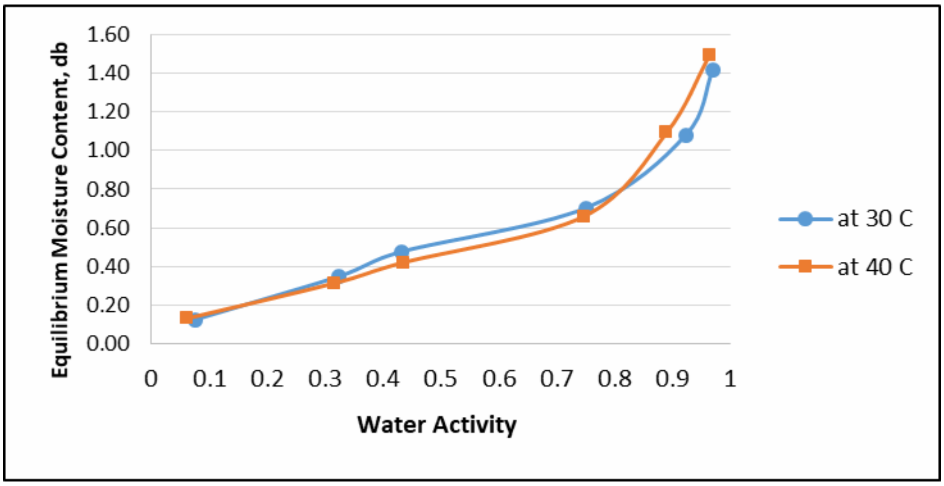


Fig 4: Sorption Isotherm of blue butterfly-pea powder at different temperatures

Content of the flower of 0.43 to 0.48. Asymptotic trend can also be observed at high Aw values, particularly at Aw ~0.75 were hygroscopicity can be depicted or the rapid gain in moisture with small increase of relative humidity (de Man, *et al*., 2018). These results were also true from the MSI studies of plant-based products of Chen, 2019, Hawa, *et al*., 2020, and Saad, *et al*., 2014 using *Chrysanthemum morifolium*, blue ternate flowers, and ziziphus leaves respectively.

Generally, as temperature increases, food products at constant Aw sorb less moisture since it affects the mobility of water molecules and the dynamic equilibrium between the vapor and adsorbed phases. However, chemical changes of products such as solubility and water dissociation shifts Aw values. Moreover, in some studies, EMC increased with temperature at Aw>0.7 (Al-Muhtaseb, *et al*., 2002 and Labuza, *et al*., 1985).

Sorption Isotherm Modelling using GAB Model

The Guggenheim-Anderson-de Boer (GAB) model has been regarded as the most satisfactory, semi-theoretical, multimolecular, localized, homogenous adsorption model and has been recommended as the standard model for use in food laboratory (Aviara, 2020 and Al-Muhtaseb, *et al*., 2002) [27, 10].

In determining the polynomial Eq. 6 and the constants using Eq. 7 to Eq. 9, graphs of the sorption isotherms (Fig. 4) were converted to quadratic forms by plotting water activity on the x-axis and the ratio of the EMC and Aw on the y-axis. Adding a second order polynomial trendline generates the GAB equation roots (α, β, and γ). Two (2) kinds of graphs per set temperature were generated since GAB Model are majorly successful in foods with water activities at <0.95 (Damodaran, 2017) [11]. From these curves, equations generated and their coefficients of determination (R^2);

Table 3

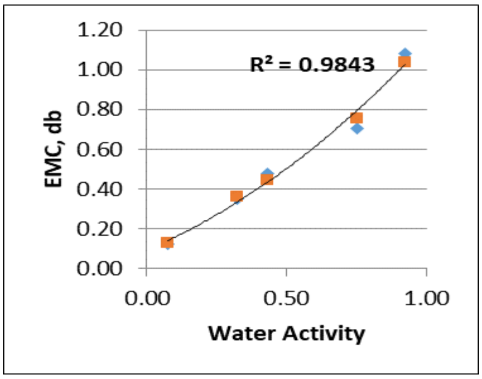
0 to <0.95 at 30°C	$Aw/M = -1.4486Aw^2 + 1.7836Aw + 0.4762$	$R^2 = 0.8966$
40°C	$Aw/M = -2.7099Aw^2 + 3.0475Aw + 0.2912$	$R^2 = 0.9511$
0 to >0.95 at 30°C	$Aw/M = -1.767Aw^2 + 2.034Aw + 0.4454$	$R^2 = 0.8371$
40°C	$Aw/M = -2.8541Aw^2 + 3.16Aw + 0.2782$	$R^2 = 0.9537$

The GAB roots at different temperatures, monolayer moisture content (M_o), GAB constants C and K were also calculated using Eq. 10 to Eq. 13 and are summarized in Tab. 3. While, predicted EMC using GAB Model compared to experimental EMC is presented in Tab. 4.
The monolayer moisture content which determines the chemical stability of most dry foods, ranged from 0.28 to 0.41 gH_2O/g db. While constants C and K ranged from 7.4 to 15.5 and 0.69 to 0.84 respectively, which describes enthalpy in the monolayer and multilayer adsorption processes (Chang, 2019). It was found out that the values were temperature dependent, constants C and K increased almost twice with increased temperature. This was opposite with the monoloayer moisture content values, which decreased as the temperature was increased, this may be because of breaking away of water molecules from sorption sites (Palipane and Driscoll, 1992 as cited by Mesias and Tan, 2015) [16] and gain kinetic energy (Diosady, *et al*., 1996) [32].

Table 4: GAB model coefficients at different temperatures

Isotherm Model	Coefficients	Temperature, °C	
		30	40
GAB (<0.95)	α	-1.4486	-2.7099
	β	1.7836	3.0475
	γ	0.4762	0.2912
	Mo	0.4103	0.2835
	C	7.4567	14.6961
	K	0.6864	0.8243
GAB (>0.95)	α	-1.767	-2.8541
	β	2.034	3.1600
	γ	0.4454	0.2782
	Mo	0.3705	0.2756
	C	8.1162	15.5072
	K	0.7466	0.8409

Using the generated roots, EMC were predicted using the GAB Model, summarized in Tab. 4. Fitting the sorption isotherms of the EMC experimental data to the GAB predicted EMC generated polynomial trendlines of multiple series using Kutools™ in Microsoft Excel (Fig. 5) with coefficients of determination (R^2) above 0.9.



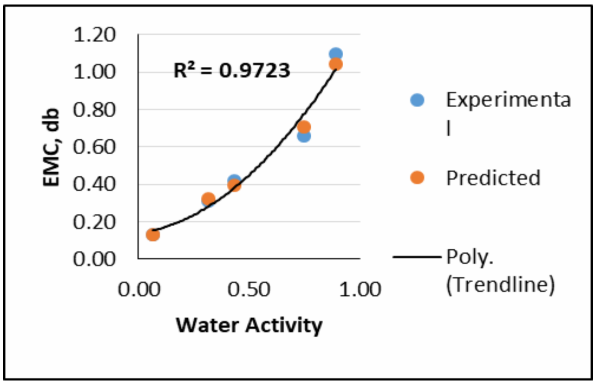


Fig 5: Moisture sorption isotherm fitted to GAB Model at Aw<0.95 (left) 30°C (right) 40°C

Table 5: Experimental EMC vs Predicted EMC (GAB)

Isotherm Model	Temperature	Water Activity	Experimental EMC (Me)	Predicted EMC (Mp)
GAB (<0.95)	30°C	0.0758	0.1243	0.1257
		0.3244	0.3488	0.3595
		0.4317	0.4761	0.4422
		0.7509	0.7032	0.7519
		0.9231	1.0805	1.0392
	40°C	0.0626	0.1313	0.1328
		0.3160	0.3128	0.3213

		0.4351	0.4200	0.3941
		0.7468	0.6586	0.7074
		0.8903	1.0934	1.0395
		0.0758	0.1243	0.1286
		0.3244	0.3488	0.3529
		0.4317	0.4761	0.4342
		0.7509	0.7032	0.7690
		0.9231	1.0805	1.1294
		0.9700	1.4194	1.2834
		0.0626	0.1313	0.1347
		0.3160	0.3128	0.3186
		0.4351	0.4200	0.3910
		0.7468	0.6586	0.7137
		0.8903	1.0934	1.0736
		0.9641	1.4931	1.4349

Goodness of Fit of GAB Model

In Tab. 5, the relative percent deviation modulus (%E) and percent root mean square error (%RMSE) for Aw<0.95 and Aw>0.95 at different temperatures were all less than 10%, while coefficient of determination were greater than 0.80. This indicated GAB Model as a good fit or was suitable in describing the moisture sorption isotherms of blue ternate powder (Chang, et. al., 2019 and Bastioĝlu, et. al., 2016). This was also reported by Hawa, *et al*. (2020) for dried blue pea flowers, however, aside from GAB, the best curve fitting was the Peleg model.

Table 6: R^2, %E and %RMSE at different temperatures (Me vs Mp)

Isotherm Model	Coefficients	Temperature, °C	
		30	40
GAB (<0.95)	R^2	0.9843	0.9723
	%E	4.41	4.47
	%RMSE	4.98	5.01
GAB (>0.95)	R^2	0.9843	0.9603
	%E	6.15	4.24
	%RMSE	6.96	4.94

Initial and Critical Moisture Content and Water Activity

Mean initial Water Activity (Aw) analyzed using the moisture analyzer was 0.48, while the critical water activity was identified based on the relationship of Water Activity and Growth of Microorganisms in Foods by Damodaran, 2017; indicated that microbial growth starts at Aw 0.60. Also, as cited by Gichau, *et al*., 2020, at this water activity, microbiological stability is guaranteed. The initial, critical and storage (80% RH) moisture contents (Mi, Mc and Me) were calculated using the different polynomial GAB equations generated.

Water Vapor Transmission Rate (WVTR) and Permeability Coefficient (P)

Mean weight gain of all packaging materials including the control throughout the 17 days of weighing at storage temperature of average 29°C and storage relative humidity of average 80% were recorded. While the mean WVTR of the different packaging materials were identified by the absolute difference in the weight gain of the packaging with desiccants and the control (without desiccants).

The differences in weight gain were plotted with time in days on the x-axis and weight gain in grams in y-axis (Fig. 6). The slopes (Q/t) were used in determining the WVTR, revealed that Nylon/PE as a packaging material with lesser number of layers for barrier properties had the highest weight gain. As experimented by Kenawi *et al*., 2015, Nylon/PE has higher WVTR than other packaging materials.

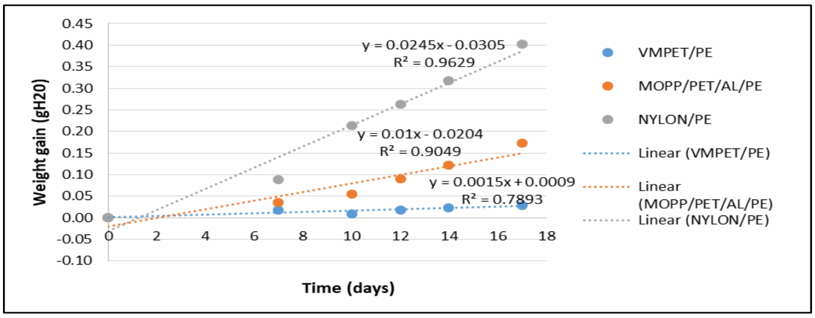


Fig 6: Different packaging materials gain weight over time.

There were significant differences of between and within the different packaging materials used using ANOVA and Tukey HSD. This established further that dissimilar materials or components layered in a packaging material contributes to its moisture uptake and WVTR.

Using the slopes of the three (3) packaging materials, permeability coefficient (*P*) was calculated together with the identified surface area (m^2), saturated vapor pressure of water at 29ºC (30 mmHg) and storage relative humidity (80%RH).The WVTR and permeability of each packaging materials is presented in Tab. 7 using Eq. 16 to Eq. 19. VMPET/PE is composed of Polyethylene terephthalate (PET) that has been aluminum-metalized and polyethylene (PE) as a bonding agent in wet lamination. It has light and oxygen barrier (Robertson, 2013) that revealed the least permeable packaging material, even though apart from Nylon/PE, both packaging materials has metallized layer for light and oxygen barrier, VMPET/PE had the least surface area which follows that it has the least headspace

Table 7: WVTR and Permeability Coefficient of the different Packaging Materials

Material	Q/t (g H_2O / day)	Surface Area (m^2)	WVTR (g H_2O / day m^2)	Δp (29 C at 80%) mmHg	*P* (g mm / m^2 day mmHg)
Vmpet/pe	0.0015	0.0157	0.0955	24	0.000358128
Mopp/pet/al/pe	0.0100	0.0290	0.3446	24	0.001340322
Nylon/pe	0.0245	0.0219	1.1167	24	0.002171392

For water vapor accumulation. Its thickness also helped in its the low water vapor transmission rate. Consequently, the most permeable packaging material was Nylon/PE, this was expected since it has no light and oxygen barrier layer and also the thinnest material.

Shelf-Life Estimation

The shelf life of the blue butterfly pea powder was calculated using Eq. 20, where the initial, critical and storage moisture content were identified by the polynomial equation at 30ºC Aw<0.95 and Aw>0.95. A straight line connecting the initial and critical moisture content were overlaid to the graphs of each sorption isotherms and the linear trendline generated identified the slope (Fig. 7) which was also used in the equation.

Using all the values, the WVTR and permeability results estimated the shelf-life of each packaging materials (Tab.7). At average 29ºC and 80% RH storage condition, Nylon/PE had the shortest shelf life of all the packaging materials since it has the largest potential of allowing moisture to travel through it due to its high WVTR and permeability. On the other hand, because it contains an oxygen and light barrier to prevent moisture absorption as well as because of its small surface area, VMPET/PE has the longest shelf life. All the shelf lives at two (2) water activity groups were significantly different from each other.

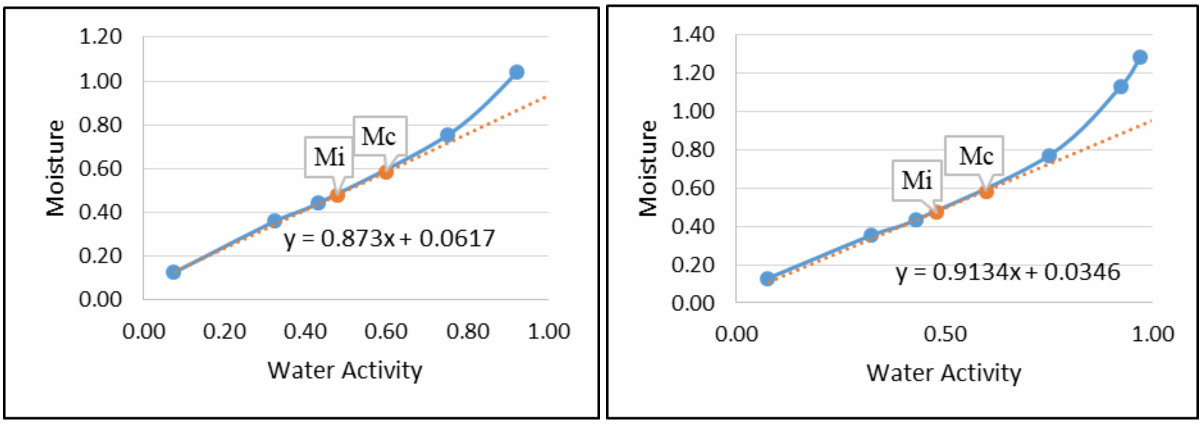


Fig 7: Linear overlay to MSI, (left) Aw<0.95 and (right) Aw>0.95

Table 8: Estimated shelf-life of the product of different packaging materials

Parameters	Packaging Materials		
	VMPET/PE	MOPP/PET/AL/PE	Nylon/PE
b (slope)	(Aw<0.95) – 0.873; (Aw>0.95) – 0.9143		
m (weight)	30 grams		
Shelf-life, days (Aw<0.95)	5157.38	732.17	277.09
Shelf-life, days (Aw>0.95)	5020.05	710.59	266.58

Conclusion

The shelf lives of blue pea powder packed in VMPET/PE, MOPP/PET/AL/PE and NYLON/PE stored at 29oC and 80% were estimated. The MSI results showed blue pea powder exhibiting Type II or sigmoidal shape isotherm curve. Monolayer moisture content (Mo) ranged from 0.28 to 0.41 gH_2O/g db. Low calculated %E and

%RMSE values together with R^2>0.95 indicated suitability of GAB model in fitting MSI data. This study demonstrated that Nylon/PE was the most permeable and the highest WVTR, which resulted to shortest shelf life. On the other hand, VMPET/PE with its barrier properties was the least permeable, lowest WVTR resulted to the longest shelf life, and therefore the most favorable packaging material for a 30-gram blue butterfly pea powder stored at ambient conditions.

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