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Moisture sorption behaviour and sensory profile of fruit pulp powders of four mango varieties

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mango powder; monolayer capacity; sensory profile; sorption isotherm

KEY CONTRIBUTION
Palmer mango variety was identified, among three other varieties, as the most suitable for powder production for reconstitution.

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ABSTRACT

Moisture adsorption isotherms and monolayer capacity of freeze-dried fruit pulp powders of four mango varieties (Keitt, Kent, Palmer and Local), cultivated in Ghana, were determined at 31 °C for a water activity (a_w) range of 0.3 and 0.8, using the standard static gravimetric method. The sensory profile was also determined by Principal Component Analysis (PCA). The mango pulp powders' sorption characteristics followed type III (J-shaped) isotherm and the curves suggested storage conditions of less than 60% relative humidity as appropriate. The experimental equilibrium moisture content (EMC) data were fitted to the GAB model using non-linear regression analysis to evaluate the monolayer capacity and the results revealed that there were differences among the varieties with the highest observed in Kent variety. Sensory profile of the reconstituted powders of the mango varieties showed that Palmer variety was vividly associated with yellow colour, sweet taste, sweet after-taste and aroma characteristic of fresh Palmer mango fruit, which makes it more likely to be accepted by consumers.

Introduction

Mango is a highly flavoured fruit rich in vitamins A and C and essential minerals, and it can be converted into a particulate form to reduce bulk and improve shelf-life stability. The stability and quality of dry food products during storage largely depend on the water activity (a_w), which is subject to relative humidity and temperature (Yu et al., 2011). The relationship between moisture content and a_w in a food material at a given temperature provides the food's moisture isotherm (Aviara, 2020). Graphical presentation of the food's equilibrium moisture content and its a_w establishes a moisture sorption isotherm curve.

Moisture sorption isotherms are beneficial thermodynamic tools for determining the interaction of food substances, the water within and the surrounding. The information on the interaction can be used in the selection of appropriate storage conditions (Akoy et al., 2013; Arslan-Tontul, 2020) and packaging systems that reinforce the preservation of colour, texture, aroma and nutrient stability (Rizvi et al., 1981; Jha et al., 2014).

Different kinds of isotherm models, which have been proposed and compared to predict a_w in food materials, are found in literature. Some of the models with theoretical basis have been developed to describe adsorption mechanisms, while others are empirical or simplified forms of more elaborate models (Andrade et. al., 2011; Yadav and Mishra, 2023). The mathematical models are important in predicting moisture content at a given a_w and are also used to evaluate thermodynamic functions of water in foods. The most common model used for describing sorption in food products over a wide range of a_w (0.1-0.90) of most practical interest is the Guggenheim-Anderson-de Boer (GAB) (Timmermann et al., 2001; Mafuyai, 2021). The coefficients in the GAB model additionally have theoretical physical meanings such as providing monolayer capacity (monolayer moisture content) and two constants related to the heat of sorption in the monolayer and multilayer regions of the food material (Peleg, 2020).

Fruit powders are deemed convenient and economical substitutes to fresh fruits in many applications, particularly in infant formulas, instant fruit juice mixes, pharmaceutical and cosmetic products. The key contributors to acceptance of a high-quality mango fruit by consumers are colour, flavour, aroma, texture and chemical constituents (Farina et al., 2020). The sensory profile, particularly with regard to attributes such as colour and aroma, has great impact on consumers' decisions to purchase a product (Spence, 2015) serving as suitable indices of the quality of the product. This study determines the moisture sorption isotherms and monolayer capacity of fruit powders of four major mango varieties cultivated in Ghana. It also identifies the principal components (PC) contributing to the sensory profile of the mango fruit powders.

Materials and methods

Preparation of mango fruit powder

Four different mango varieties (Keitt, Kent Palmer and Local) at matured green stage were obtained from a commercial farm in the Eastern Region of Ghana and allowed to ripen naturally. They were washed and sanitized with sodium hypochlorite solution (200 ppm), then peeled, pulped and homogenized using a blender. The homogenized pulp was freeze-dried in a condenser and subliming temperatures of-35 °C and 30 °C, respectively, under a vacuum pressure of <66.7 Pa using a freeze dryer (Harvestright®, USA). The freeze-dried pulp was pulverized using a blender (Mitsui, Japan).

Determination of moisture sorption isotherm

Moisture sorption isotherms were determined by the static gravimetric method and humidity condition established by using the method described by Sobowale et al. (2017); Awoyale (2022); and Wilson (1921). Concentrated sulphuric acid (conc. H_2SO_4) was used to create the humidity chambers in six desiccators (each with 15 cm deep and 21 cm wide). The acid and distilled water quantities were made up to 250 mL, corresponding to relative humidities of between 30% and 80%. The equilibrium relative humidity (ERH), which is the relative humidity of the atmosphere in equilibrium with the powder material, was used to calculate the water activity (a_w) (Lutovska et al., 2016) (Table 1). Water activity is equal to % equilibrium relative humidity divided by 100:

$$ERH = \%\ equilibrium\ relative\ humidity$$

$$a_w = \%\ equilibrium\ relative\ humidity \div 100$$

The desiccators were then positioned in a fairly stable storage enclosure under ambient conditions. The average environmental temperature was 31 °C. Triplicate samples of 1 ± 0.001 g of the freeze-dried mango pulp powder were placed inside previously weighed petri dishes and then quickly transferred into the desiccators and the lid was sealed with grease. Samples were weighed daily until constant weight was achieved in two consecutive readings. The samples were then covered and the equilibrium moisture content (EMC) was determined using the oven-drying method. The equilibrium between samples and their environment (the desiccator chamber) was evidenced by the constant weight after two successive weighing of the samples. The equilibrium moisture content (EMC) of the samples was determined after sorption by drying in a laboratory oven at a temperature of 135 ˚C for 2 hrs until constant weight was achieved (AOAC, 2000; Akoy et al., 2013). The EMC was calculated on dry basis (d.b.) as an arithmetic mean of the values obtained from the triplicate sample measurements as follows:

$$EMC = \frac{W1 - W2}{W2} \cdot 100$$

where,
W1= Weight of powder at constant weight after sorption (g).
W2= Weight of powder after drying to constant weight (g).

Table 1 Dilutions of Conc. H_2SO_4 used to establish equilibrium moisture content

Water activities (a_W) (ERH)	Volume of conc. H_2SO_4 (mL)	Volume of distilled water (mL)
0.3	136	114
0.4	123	127
0.5	112	138
0.6	99	151
0.7	86	164
0.8	71	179

Determination of monolayer capacity

The experimental results for the EMC and a_W (equilibrium relative humidity) were subjected to analysis using the modified Guggenheim-Anderson-de-Boer (GAB) model (Timmermann et al., 2001) in order to determine the parameters *Mo, K* and *C*.

The GAB equation is given by the following:

$$M = \frac{MoKCa_w}{(1 - Ka_w)\,.\,(1 - Ka_w + CKa_w)}$$

where:
M = equilibrium moisture content, % d.b.
Mo = GAB monolayer capacity % d.b.
C = constant related to the monolayer heat of sorption
K = factor related to the heat of sorption of the multilayer
a_w = Water activity

The GAB equation can be transformed into the modified GAB model (Timmermann et al., 2001) as follows:

$$a_w/M = \alpha a_w^2 + \beta a_w + \gamma \ \text{(modified GAB equation)}$$

Where:

$$\alpha = K/Mo(\frac{1}{c} - 1)$$
$$\beta = 1/Mo(1 - 2/C)$$
$$\gamma = 1/MoCK$$

Substituting for α, β and γ above;

$$a_w/M = (K/MoC(1 - C)a_w^2 + (C - 2/MoC)a_w + 1/MoCK$$

From a polynomial non-linear regression of a_w/M against a_w of the experimental data, using the statistical software Statistical (version 10, StatSoft, USA), the values for *Mo*, *K* and *C* for the fruit powders were obtained.

Sensory evaluation of mango fruit powder

Freeze-dried mango powders of the four varieties (Keitt, Kent, Palmer and Local) were reconstituted by adding distilled water to achieve similar solid contents as the fruit pulp and then subjected to sensory (Quantitative Descriptive Analysis-QDA) tests using eight (8) trained panel members. The panelists assessed the products for the following modalities: appearance, aroma, flavour, mouth feel and aftertaste/aftereffects. Terms for the description of the appearance, texture, taste and aroma of the reconstituted mango powder samples were developed and references were provided to clarify ambiguous descriptors and align panel agreement. Twenty descriptors were used to describe the sensory profiles of the four varieties of the reconstituted freeze-dried mango powders. Two (2) appearance descriptors, four (4) aroma descriptors, six (6) flavour descriptors, four (4) mouth-feel descriptors and four (4) aftertaste descriptors were generated for all four varieties. The descriptors characterize the individual varieties and show how they differ from one another for the defined attributes. Intensity scoring of the descriptors was carried out using 10 cm scales (0 is not intense/not present and 10 is very intense/present). Trial evaluations in duplicates were carried out to assess panel performance prior to final evaluation. Final sensory evaluation was carried out in triplicate and the duration for the study was 9 days (each day comprised 3 hours).

Sensory determination, data collection and analysis

Each variety of fruit powder was reconstituted to one (1) litre using the moisture content values of the fresh pulp (Table 2). For each variety, the appropriate amount of powder was weighed into a blender (Philips Problend 6, Netherlands) and mixed with cool distilled water (20 °C) at low speed for 40s. The sessions were conducted in the sensory evaluation laboratory of the Department of Nutrition and Food Science, University of Ghana. The laboratory is equipped with separate tasting booths for panelists with white lighting and a well-ventilated environment. Assessors were served 30 mL of each variety in 80 mL disposable plastic cups with lids at a serving temperature of 20±2 °C. Samples were served according to a balanced random order design in Compusensecloud® SaaS in a monadic way (i.e., one after the other). Water was provided to assessors as a palate cleanser to use in between tastings. Principal Component Analysis was employed to reduce the dimensionality in the data and determine associations among the variables.

Table 2 Mango powder and distilled water proportions for a litre of reconstituted mango

Variety	Amount of powder (g)	Amount of distilled water (mL)
Keitt	160	840
Kent	160	840
Palmer	160	840
Local	190	810

Results and discussion

Moisture sorption isotherms

Moisture sorption isotherm for the mango fruit powders of the four varieties was established to determine how the powders will behave in an environment of varying equilibrium relative humidities (ERH) or a_w. The equilibrium moisture conditions in the mango powder were attained after 3-14 days of storage at an average ambient temperature of 31 °C.

Generally, there were gradual increases of EMC at lower a_w (0.3-0.5) and a sudden surge of EMC at a_w of 0.6 in all the varieties (Figure 1). The implication for the surge is that an environmental relative humidity (RH) of less than 60% may be required for preservation, in addition to primary packaging material of low permeability such as aluminium laminated plastic packaging.

The sorption curves followed type III (J-shaped) isotherm characteristics of high-sugar products (Rangel-Marrón et al., 2010; Moreira et al., 2017). This might be due to the fact that vapour pressure of water present in the mango fruit powder samples increased with that of the surrounding atmosphere until equilibrium was attained. Dry food sample exposed to moist or dry atmosphere of constant relative humidity absorbs or loses water respectively until constant weight, that is, no detection in weight change and equilibrium is reached at that point (Tejada-Ortigoza et al.,2020). Rangel-Marrón et al. (2010), found that the equilibrium moisture content in high sugar foods increases sharply when exposed to high water activities, as a result of the dissolution of fruit sugar.

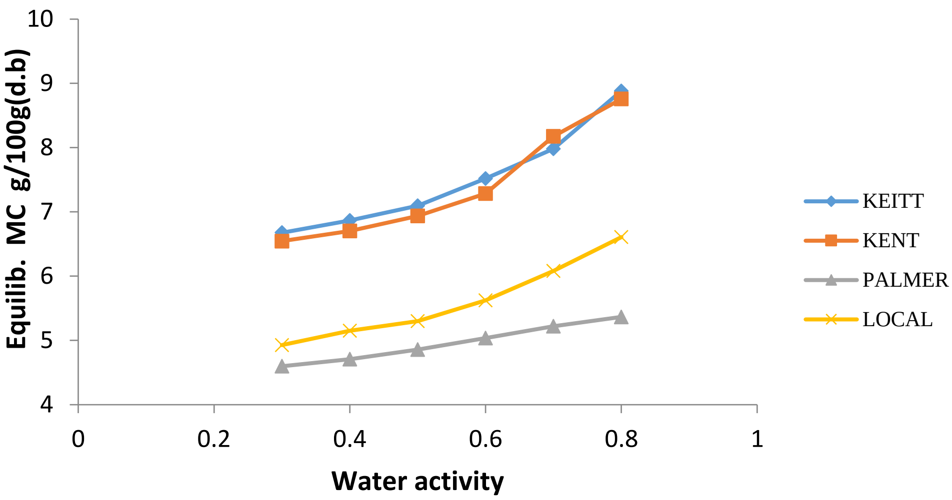

Figure 1 Moisture sorption isotherms of fruit powders of four mango varieties at 31 °C

Monolayer capacity

The monolayer capacity (*Mo*) of the fruit powders ranged between 17 and 23 g H_2O/100 g solids with the highest and the lowest being Kent and Palmer varieties, respectively (Table 3). The *Mo* is the minimum amount of water bound to active sites and guarantees the stability of the powder during storage (Iglesias et al., 1975). The larger the *Mo*, the more stable the product. Kent and Keitt had the highest *Mo* and were expected to be more stable in storage under an ambient temperature of 31 °C than the rest of the varieties. Specifically, Kent and Keitt varieties had higher capacity to adsorb moisture. Rangel-Marron et al. (2010), and Caparino et al. (2017), reported 124 g H_2O/100 g and 45 g H_2O/100 g solids in freeze-dried Ataulfo mango and Carabao mango powder, respectively, at 25 °C using the GAB model. Thus, the *Mo* values obtained in this study were comparatively lower and this might be due to varietal differences.

Table 3 Estimated parameters for adsorption isotherms for fruit powders of four mango varieties

Mango Variety	GAB Parameters			R^2
	Mo (g H_20/100 g solids)	K (10^6)	C (10^5)	
Keitt	22	8.4	3.5	0.86
Palmer	17	7.8	4.1	0.95
Kent	23	3.3	1.2	0.93
Local	18	2.1	1.0	0.92

Mango fruit powder sensory profile

Principal Component Analysis (PCA) was employed to determine how the sensory characteristics of the varieties are spread out in the sensory space. The PCA results revealed that the first Principal Component (PC1) explained 55.5% of the variance, while the second Principal Component (PC2) explained 34.9% of the variance. In total 90.4% of the variance in the sensory data was explained by PC1 and PC2 (Figure 2). The varieties loaded in three different quadrants. Keitt and Local varieties loaded in the same direction or quadrant, while Palmer and Kent were in two adjacent quadrants and opposite to Keitt and Local.

Palmer variety is vividly associated with yellow colour, sweet taste and sweet aftertaste as well as a lingering Palmer mango aroma and taste after swallowing. This might be an indication that the freeze-drying process did not significantly alter the volatile compounds responsible for the sensory characteristics of the fresh Palmer mango pulp. Kent was predominantly characterized by garden egg and velvet tamarind aroma and taste, slippery (slimy) mouth feel, puckering sensations as well as salivation after-taste. Processing might have reduced the intensity of the volatiles responsible for the characteristic aroma of Kent fresh pulp and rather accentuated other compounds that give off velvet tamarind and garden egg aroma and taste. Munafo et al. (2016), quantified thirty-four previously identified aroma-active compounds in tree-ripened fruits of mango (*Mangifera indica* L. 'Haden') using the odour activity value (OAV-ratio of its concentration in the mangoes to its odour threshold in water) of each compound. The study observed that several aromas unrelated to that of Haden mango were present. Some of the compounds were (3E,5Z)-undeca-1,3,5-triene (pineapple- like; OAV 1900), (2E,6Z)-nona-2,6-dienal (cucumber-like), (E)-β-damascenone (cooked apple-like), 4-hydroxy-2,5-dimethyl-3(2H)-furanone (caramel-like), γ-decalactone (peach- like) and 4-methyl-4-sulfanylpentan-2-one (tropical fruit-like). Therefore, the drying process of Kent variety might have resulted in loss of some compounds and subsequent unmasking of the volatile compounds with velvet tamarind-like and garden egg-like aromas. Local and Keitt varieties shared similar characteristics of aroma and taste. This might be due to the continuous grafting of Keitt variety on the Local variety in seedling production. According to Warschefsky et al. (2015), grafting influences the phenotype of the grafted plants including resistance to pests and pathogens, tolerance to stress, changes in fruit quality and other physiological disorders. Birkás et al. (2021) indicated that grafting influenced the sensory parameters of sweet pepper. This might explain the Local variety aroma exhibited by Keitt because in Ghana, the rootstock used for grafting during seedling production is mainly obtained from the seedlings of the Local variety. The chalky mouth-feel is an off-flavour which might be caused by high calcium salts which were exposed as a result of loss of other compounds leading to the expression of the chalky taste (Labuza, 2000). None of the varieties were perceived as distinctly sour or characterized by viscous appearance, puckering sensation, or viscous mouthfeel, based on their positioning within the sensory space (Figure 2).

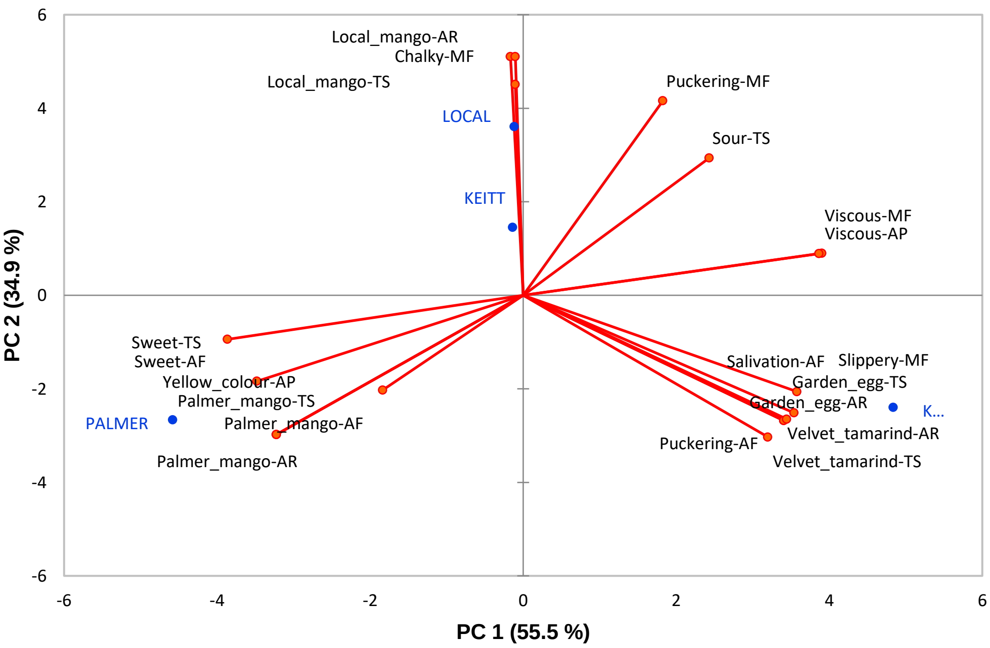

Figure 2 Bi-plot of Principal component (PC) analysis for attributes of reconstituted fruit powders of four mango varieties (Key; TS-taste, AR-aroma, MF-mouth-feel, AF-after-taste, AP-Palmer aroma)

Conclusion

The sorption isotherms of all mango varieties followed type III (J-shaped) isotherms and revealed that the powders should be stored below 60% relative humidity for longer shelf-life. Palmer variety is more associated with yellow colour, sweet taste and sweet after-taste characteristic of fresh Palmer mango fruit and therefore more likely to be acceptable to consumers.

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