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COMPOSITIONAL, PHYSICO-MECHANICAL AND FUNCTIONAL PROPERTIES OF TWO GHANAIAN COWPEA (*Vigna unguiculata*) VARIETIES

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ABSTRACT

Cowpea (Vigna unguiculata) is a legume that is cultivated throughout Africa and contributes a significant amount of plant-based protein to human diets. There are many varieties of cowpeas, and these have varying seed characteristics such as shape, size, colour and nutritional properties. The compositional, physico-mechanical, and functional properties of two new cowpea seed varieties were investigated in order to determine their full food-use potentials as well as key parameters for their postharvest machinery for processing, handling, and storage. The proximate composition of the two cowpea cultivars was determined using standard methods. Physico-mechanical analyses carried out were the hundred-seed weight and volume, bulk density, true density, size, aspect ratio, surface area, equivalent diameter, porosity and angle of repose. Functional properties determined were cooking time and water uptake of the grain as well as water and oil absorption, foam capacity and stability, and emulsion capacity and stability of the flour. The *Padi-Tuya* variety was longer, broader and thicker than *Wang Kae*. The results showed both varieties to be useful sources of macronutrients. The moisture, fat and fibre in *Wang Kae* were significantly higher ($p<0.05$) than *Padi-Tuya*. However, both cowpea varieties had comparable protein levels of 17.7 g/100 g. The cooking time, hydration capacities and indices of the two varieties were also significantly different ($p<0.05$), but their swelling capacities, swelling and water uptake indices were comparable. Cooking times were 40 and 62 min for *Padi-Tuya* and *Wang Kae,* respectively. The water and oil absorption capacities, as well as the swelling indices, were similar, but their emulsion capacities and stabilities were significantly different ($p<0.05$) for the flour. *Padi-Tuya* had a higher foam capacity, but was less stable, than *Wang Kae*. The physico-mechanical properties determined would aid in the design of cleaning, handling and other processing machinery as well as storage facilities for the new cowpeas. The functional and the compositional parameters would assist in the food formulations.

Key words: Cowpea (*Vigna unguiculata)* varieties; compositional; physico-mechanical and functional properties

INTRODUCTION

Cowpea (*Vigna unguiculata*) is an important source of plant protein and therefore used in several tropical and subtropical countries all over the world. In Ghana, cowpea is primarily prepared and consumed wholly or as a component of a meal. It is used in a variety of dishes, including *Koose* (cowpea fritters), gari and beans (roasted grated fermented cassava and cooked beans), *Tubani* (steamed bean cake) stews and soups. These qualities make it an ideal crop for catering for the food security needs of several communities [1]. In Ghana, cowpea is primarily grown in the savannah, coastal, and transition zones [2]. The rainfall pattern in Ghana is such that the northern sector receives little rain, whereas the southern sector receives a lot. Due to disease and pest infestation, the wet conditions in the southern sector make it unsuitable for cowpea cultivation. The majority of cowpea is thus grown in northern Ghana as they are well suited to harsh farming conditions systems [2, 3].

Unfortunately, the current challenges with climate change in most farming systems in the tropics have brought on several biotic and abiotic factors that have affected the production, storage and even the processing of cowpea. In response to these effects, the Council for Scientific and Industrial Research (CSIR)-Savanna Agriculture Research Institute bred climate-resilient and high-yielding cowpea varieties like *Padi-Tuya* and *Wang Kae*. *Padi-Tuya* was bred in response to the low yields and long cooking times of some earlier varieties, whilst *Wang Kae* was developed to be early maturing, resistant to aphids and striga infestation, as well as address the problem of low yields and long cooking times.

Numerous researchers, including Adu-Dapaah and Addison [4], David and Acka [5], and Appiah *et al*. [1], have examined properties of previous cowpea varieties grown in Ghana, but none on these two. It is important that their full food-uses potential as well as key parameters needed for processing and handling machinery for these cowpeas are determined. The purpose of this study was, therefore, to assess the compositional, physico-mechanical and functional properties of these newly developed cowpea varieties.

MATERIALS AND METHODS

Source of Cowpeas

Padi-Tuya and *Wang Kae*, the two cowpea varieties used in this study, were obtained from experimental plots of the CSIR-Savanna Agricultural Research Institute's Cowpea Improvement Program. When the grains arrived, they were cleaned and sorted before being packaged into sacks and stored at the Food and Drugs Authority's Physicochemical Laboratory in Accra at temperatures of 28 ± 2 ºC and relative humidity of 75 ± 5% until ready for use.

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Analyses of Physico-mechanical Properties

Weight and volume
Both the hundred seed weight and volume were determined according to methods as explained by Wani *et al*. [6].

Bulk and true density
Bulk density (*Db*) was determined by placing 100 randomly selected seeds into a measuring cylinder and recording the volume after gently tapping the cylinder on a table for a few minutes. The ratio of mass of seed to the volume recorded gave the bulk density [6]. True density (*Dt*), which is the ratio of mass of cowpea seed to the true volume of seeds, was determined by the toluene displacement method [6]. The volume of toluene displaced was determined by immersing a weighed quantity of cowpea seed in the toluene.

Dimensions
The length (L), breadth (B) and thickness (T), were determined using a digital vernier caliper with a least count of 0.01 mm (Mitutoyo, Japan). The length of the grains was determined by measuring the longest dimension (along the split of the cotyledon), while breadth and thickness were measured at the lateral and dorsal sides, respectively as described by Appiah *et al.* [1].

Sphericity and surface area
The sphericity of the cowpea seeds was calculated as a function of the three principal dimensions, as explained by Wani *et al.* [6], using the formula:

$$Sphericity = \left[\frac{\sqrt[3]{LBT}}{L}\right] \times 100; \quad \ldots \ldots (1)$$

Where:
L= Length of cowpea grain;
B= Breadth of cowpea grain;
T= Thickness of cowpea grain

The surface area was calculated using the formula:

$$Surface\ area = \frac{\pi B L^2}{2L - B} \quad \ldots \ldots (2)$$

Where:
B= Breadth of cowpea grain
L= Length of cowpea grain

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Porosity
The Porosity of the seeds was calculated using the formula:

$$Porosity = \left[1 - \left(\frac{Db}{Dt}\right)\right] x100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where:

Db= Bulk density
Dt= True Density

Angle of repose
Cowpea flour (250 µm) was poured gradually into a funnel suspended 3 cm above a bench to form a heap on a paper at the base of the funnel. The diameter of a circle drawn around the heap was measured at four different points. Angle of repose was calculated using the formula below [7]:

$$Angle\ of\ Repose = tan^{-1} \frac{h}{0.5xd} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where:

h= Height from the tip of the funnel to the bench
d= Diameter of the circle drawn

Proximate Composition
Compositional analyses carried out on the cowpeas were moisture, ash, crude fat and crude fibre, protein and carbohydrates. Moisture was determined according to AOAC methods 934.01 [8], ash by AOAC method 942.05 [8] and crude fat and fibre by AOAC [8] methods, 920.39 and 978.10, respectively. Protein was determined by the Kjeldahl method (AOAC method 988.05) where the nitrogen content determined was multiplied by the factor 6.25. Carbohydrate was estimated by difference.

Analyses of Functional properties
The functional properties determined were partly on the grains and partly on the flour. For the grains, the parameters determined were the hydration capacity and index, swelling capacity and index, water uptake ratio and cooking time. For flour, the parameters determined were water and oil absorption, foam capacity and stability, emulsion capacity and stability, swelling power and index.

Hydration capacity and hydration index
Five gram (5 g) of cowpea was soaked in 50 mL distilled water in a measuring cylinder [9]. The seeds were left to soak for 24 h at room temperature, drained and the excess water blotted with tissue paper. Thereafter, the weight of swollen seeds was measured and the hydration capacity and index were, respectively calculated using the formulae:

$$Hydration\ Capacity = \frac{Weight\ after\ soaking - Weight\ before\ soaking}{Number\ of\ grains} \ldots\ldots\ldots(6)$$

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$$Hydration\ Index = \frac{Hydration\ Capacity}{Weight\ of\ one\ seed} \qquad (7)$$

Water uptake ratio

About 20 g of cowpea seeds were cooked in 200 ml of distilled water for minimum cooking time [10]. Cooked seeds were removed, drained and excess water blotted with tissue paper. The seeds were weighed and the water uptake ratio determined as a ratio of weight gained after cooking to weight before cooking.

Cooking time

Cooking time was determined according to Wani *et al*. [10] with slight modifications. In brief, 200 mL distilled water was boiled in a flask fitted with reflux condenser to prevent water loss during cooking. Thirty gram (30 g) of cowpea seeds were added to the flask and boiled for 30 min. After this period three to five seeds were withdrawn using tweezers at 2 min intervals and tested for softness by pressing between fingers and the thumb. The time from addition of seeds till attainment of a desired softness was recorded as the cooking time.

Water and oil absorption properties

Water and oil absorption capacities, foam capacity and stability were determined according to methods described by Appiah *et al.* [1], emulsion capacity and stability by Sridaran *et al*. [11], and then finally swelling power and index of the cowpea flour by methods of Appiah *et al*. [1] and Adebowale *et al.* [9], respectively.

Statistical Analysis

Quantitative variables were summarized using means and standard deviations. Student's *t*-test was carried out using Minitab Release 17 statistical software (Minitab Inc., USA) to determine differences in means at 95% confidence level.

RESULTS AND DISCUSSION

Physico-mechanical Properties

The dimensional analysis of *Padi-Tuya* and *Wang Kae* showed that *Padi-Tuya* is significantly ($p<0.05$) longer, broader and thicker than *Wang Kae*, as indicated by the breadth and thickness (Figure 1).

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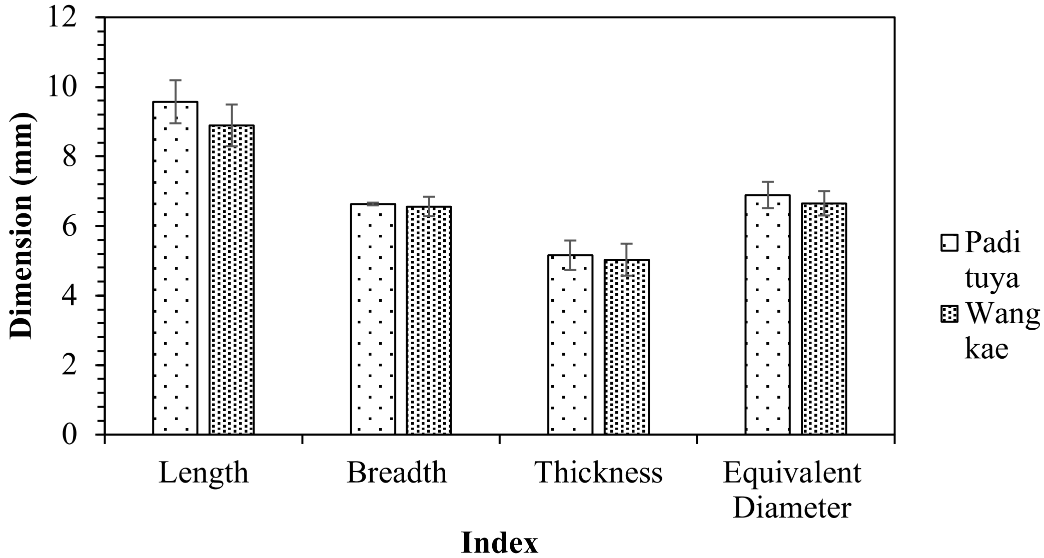

Figure 1: Spatial dimensions of *Padi-Tuya* and *Wang Kae* cowpea varieties (means with standard deviation (SD) error bars)

The dimensional sizes of all these new varieties were also significantly higher than those of previous Ghanaian cowpea varieties, *Nhyria, Tona* and *Adom*, as reported by Appiah *et al.* [1]. The lengths, breadths and thicknesses of these previous varieties were 7.6, 5.9 and 4.5 mm, respectively, for *Nhyira* variety; 7.7 mm, 5.8 mm and 4.6 mm, respectively, for *Tona* variety; and 7.7 mm, 6.3 mm and 4.9 mm, respectively, for *Adom* variety. These differences might influence the size of the screens used in rotary vibratory screens typically used for cleaning cowpeas during industrial processing [12]. Cleaning of cowpea is one of the critical unit operations during the processing of end products from cowpea. This is because cowpeas have high tendency to be contaminated with other materials such as earth, small pebbles, plant and insect waste as well as immature seeds.

An additional implication of the relatively bigger size of *Padi-Tuya* could be due to the use of hermetic systems to store these cowpeas. Cowpea is usually heavily attacked by storage pests and one method of eradicating such pests is through the use of hermetic storage, which creates an oxygen-depleted, carbon dioxide-rich atmosphere that is lethal to storage insects [13]. In hermetic storage systems, a modified atmosphere condition is created, in which the oxygen concentration is gradually reduced whilst the carbon dioxide concentration increases with time, through respiration of both the commodity and insects [14]. Cowpea grain size influences the movement of oxygen in hermetic containers used for cowpea grain storage. When grains are bulkier and bigger, they do not pack well in silos and therefore will create big spaces between grains facilitating easier movement of oxygen between the bigger grains than between the smaller grains. This means the time required to reach low oxygen levels in hermetic storage systems for *Padi-Tuya*, through respiration effects, may be longer than in those of *Wang Kae* and earlier cowpea varieties, with relatively smaller sizes.

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The 100 grain seed weights of *Padi-Tuya* and *Wang Kae* were 20.5 and 18.7 g, respectively (Table 1). These were heavier compared to those of *Nhyira*, *Tona* and *Adom* varieties that were 13.2 g, 14.2 g and 15.2 g, respectively [1], and 13.1 g and 9.9 g, respectively for red and black cowpea [15]. The grain bulk and true densities, grain weight and volume are important factors to consider when designing and using industrial rotary cleaning machines for these cowpea grains. The 100 grain seed weight and volume were significantly different ($p<0.05$) between *Padi-Tuya* and *Wang Kae*. Angle of repose was higher ($p<0.05$) in *Wang Kae* than *Padi-Tuya*. Previous values reported for other legumes were lower, and ranged between 17.7-19.0 ° for black gram [10], 26.6 – 31.1 for green gram [16] and 18 – 31 for pigeon pea [17]. A significantly higher porosity was observed for *Padi-Tuya*, implying that this variety would hydrate easier compared to *Wang Kae* [18].

Compositional Properties

Compositional properties of the two cowpea varieties are summarized in Table 2. There was no significant difference ($p>0.05$) between the ash, protein and carbohydrate content of the two varieties. However, the fat, fibre and moisture levels of the two varieties were markedly different. The moisture content of *Padi-Tuya* and *Wang Kae* in this study were comparable those of *Nhyira*, *Tona* and *Adom*, which had 9.79, 9.15 and 9.83 %, respectively [1]. Otitoju *et al*. [19] reported the moisture content of *Potiskum*, *Ife-brown*, *Orarudi* and *Aloka* varieties to be 13.48, 14.5, 11.5 and 12.91%, respectively. Affrifah [20] has observed that high moisture content (>13%) before storage could lead to the development of hard-to-cook defect in cowpea. Since their moisture contents were lower than 13%, the probability of these varieties developing the hard-to-cook defect is low, with *Padi-Tuya* being lower than *Wang Kae* in moisture content.

The protein content of *Padi-Tuya* and *Wang Kae* was comparable. These had lower protein contents compared to some varieties previously reported by Kaptso *et al*. [21], Appiah *et al.* [1], Tresina and Mohan [22] and Kaptso *et al.* [23]. The amount of protein in cowpea is important because proteins are the main molecules that imbibe water in seeds [4]. The high protein content of cowpea, has been known to reduce protein energy disorders such as *Kwashiorkor* [1]. The quality and quantity of protein in cowpea makes it a good complementary food with cereals.

Total ash for the two varieties was 3.7% and this was higher than the ash content reported for some other varieties. For instance, Appiah *et al.* [1] recorded 2.9, 3.0 and 3.2%, respectively, for *Nyhira*, *Tona* and *Adom*. The amounts of fat in *Padi-Tuya* and *Wang Kae* were lower than the values reported by Appiah *et al.* [1] for *Nhyira* (2.5%), *Tona* (2.5%) and *Adom* (4.0%) varieties of cowpea The fat content of cowpea paste-based foods like *Koose* or *Akara* improves their palatability [1, 21]. The 4.6 percent mean fibre content in this study was comparable to values reported for the *Nhyira*, *Tona*, and *Adom* cowpea varieties [1]. The dietary fibre has been shown to help with digestion, blood sugar regulation, and diabetic patients [24].

Cooking Characteristics

Table 3 shows that *Padi-Tuya* had a significantly ($p<0.05$) shorter cooking time of 42 minutes compared to *Wang Kae* which required 62 minutes to cook to desirable texture. This indicates that *Padi-Tuya* would require less energy for processing. The difference in cooking time may be attributed to differences in their hydration properties, and this may be linked to differences in their protein content [25], even though this was marginal. Additionally, the higher porosity of *Padi-Tuya* seeds may have played an influential role. High hydration and swelling capacities are desirable in cowpea processing as they reduce cooking time by increasing energy transfer to the grain [24]. Cooking time of the cowpea in this study was longer than the range (24 – 42.5 minutes) reported by Addo *et al.* [26], but comparable to some varieties (35 – 57 minutes) studied by Olapade *et al*. [27] and *Nhyira* (57 minutes) and *Tona* (65 minutes) as reported by Appiah *et al.* [1]. Other varieties reported by Olapade *et al*. [27] and Appiah *et al.* [1] had longer cooking times of 80 and 84 minutes, respectively, compared to *Padi-Tuya* and *Wang Kae*. Compositional, structural and genetic variations may be responsible for these reported differences. Even though cooking improves the digestibility of proteins and carbohydrates, prolonged cooking is undesirable and may affect protein quality. Long cooking time may also lead to loss of nutrient and undesirable quality [20]. The seed swelling capacity, swelling index and water uptake ratio did not necessarily affect their cooking time. Swelling capacity and index for these two varieties were higher than 0.05 mL/seed and 0.001 reported correspondingly for these indices by Tresina and Mohan [22]. The swelling capacity was, however, lower than 2.3 – 3.2 mL/seed reported by Olapade *et al.* [27].

Functional Properties of cowpea flour

Cowpea flour is a versatile food ingredient with wide application in the production of *Akara*, *Moinmoin* and bakery products [28]. Its performance in these products depends on the flour functionality, and this is largely dictated by protein and carbohydrate composition. In this study, results of some key functional properties evaluated are summarized in Table 4.

A mean of 1.4 and 1.1 g /g flour was, respectively, recorded for water absorption capacity and oil absorption capacity in the two cowpea varieties. For these parameters, there were no significant differences ($p>0.05$) between the two cowpea varieties. Higher water absorption capacities of 1.6 – 1.9 g/g flour and 2.1 – 2.8 g/g flour have been respectively reported by Chinma *et al*. [29] and Olaofe *et al.* [30] for some Nigerian varieties. Ghanaian varieties studied by Appiah *et al*. [1] also had higher water absorption capacity (1.9 – 2.2 g/g flour) and oil absorption capacity (2.0 – 2.3 g/g flour) than the varieties used in the present study. While swelling power and true density differed significantly, the bulk densities of the cowpea were quite similar. The swelling power was higher than the 2.7 reported in a similar study [1]. The emulsion capacity of *Padi-Tuya* and *Wang Kae* was approximately the same, but the latter formed a more stable emulsion. Proteins in flour aid in the formation of emulsions and, therefore, the low emulsion stability of *Padi-Tuya,* could be due to the slow diffusion of the proteins to the interfacial area to stabilize the emulsion [31]. The emulsion capacity observed in this study was much lower than that observed by Hamid *et al.* [32] for red and black

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cowpea varieties, which were 35 and 34%, respectively. The emulsion stability of the cowpea varieties by Hamid *et al.* [32] was also higher (96% and 74%) than what was observed in this study, which could be due to differences in protein structure and functionality.

Foaming properties were significantly different ($p<0.05$) for the two varieties, with *Padi-Tuya* having higher foam capacity with less stability compared to *Wang Kae* (Figure 2).

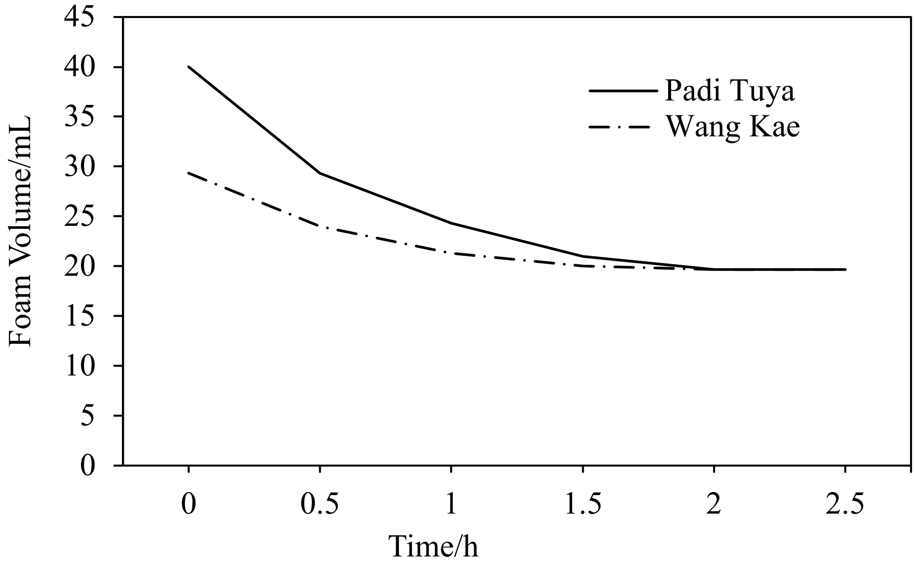

Figure 2: Foam stability of flour of *Padi-Tuya* and *Wang Kae* cowpea varieties

Foaming in cowpea is associated with the high- water solubility of cowpea protein and its ability to form stable layers around gas bubbles in a liquid phase [33]. As indicated by Kethireddipalli *et al*. [34], foaming is important for the development of desirable texture in *Akara*, a product made from cowpea flour. Foaming capacity of the varieties used in this study was higher than the reported range of 10-21% [1] but within 40 – 80% for cowpea flour [30]. Variations in the functional properties of two varieties and others reported in related literature may be ascribed to compositional differences, physical properties, genetic variations and growing conditions.

CONCLUSION

The two cowpea varieties had differences in their physico-mechanical, compositional and cooking properties as well as marked differences in the functional properties of their flours.Their compositional properties indicate that they are valuable sources of macronutrients, making them potentially useful in diets. While their functional properties exhibit the suitability of the two cowpea varieties in processing, the physico-mechanical properties of *Padi-Tuya* and *Wang Kae* provide data that would influence the design and operations industrial cleaning machinery for the cowpea grains.

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DECLARATION OF COMPETING INTEREST
The authors declare that they have no interest to declare for this publication.

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Table 1: Physico-mechanical properties of *Padi-Tuya* and *Wang Kae* cowpea varieties

Physico-mechanical property	Cowpea varieties	
	Padi-Tuya	***Wang Kae***
Grain Bulk density (g/cm^3)	0.72 ± 0.01^a	0.75 ± 0.01^a
Grain True density (g/cm^3)	1.13 ± 0.05 ^{a}	1.15 ± 0.05 ^{a}
Porosity (%)	35.59 ± 2.83^a	33.72 ± 4.26^a
100 Grain seed volume (cm^3)	16.67 ± 0.58 ^{a}	14.67 ± 0.58^b
100 Grain seed weight (g)	20.54 ± 0.18 ^{a}	18.69 ± 0.14^b
Sphericity (%)	72.09 ± 2.91 ^{a}	74.71 ± 3.43^b
Surface area (mm^2)	152.95 ± 15.78 ^{a}	145.29 ± 12.24^b
Angle of Repose (°)	40.24 ± 1.67^a	45.30± 1.22^b

*Within a row, means bearing different superscripts are significantly different ($p<0.05$)

Table 2: Proximate composition of *Padi-Tuya* and *Wang Kae* cowpea varieties

Proximate	Cowpea varieties	
	Padi-Tuya	***Wang Kae***
Moisture (g/100g)	10.11 ± 0.06^a	10.79 ±0.14^b
Ash (g/100g)	3.66 ± 0.04^a	3.68 ± 0.08^a
Fat (g/100)	0.89 ± 0.03^a	1.51 ± 0.14^b
Protein (g/100g)	18.31 ± 0.77^a	17.16 ± 0.93^a
Carbohydrate (g/100g)	62.01 ± 0.08^a	63.17 ± 0.73^a
Fibre (g/100g)	5.03 ± 0.05^a	4.12 ± 0.23^b

*Within a row, means bearing different superscripts are significantly different ($p<0.05$)

Table 3: Cooking characteristics of *Padi-Tuya* and *Wang Kae* cowpea varieties

Cooking characteristics	Cowpea varieties	
	Padi-Tuya	***Wang Kae***
Hydration capacity (mL/seed)	0.24 ± 0.01^a	0.19 ± 0.01^b
Hydration index	0.53 ± 0.01^a	0.52 ± 0.01^b
Swelling capacity (mL/seed)	0.24 ± 0.01^a	0.29 ± 0.01^a
Swelling index	0.56 ± 0.01^a	0.62 ± 0.01^a
Water Uptake ratio	2.21 ± 0.02^a	2.26 ± 0.03^a
Cooking time (min)	42.33 ± 2.52^a	62.33 ± 2.52^b

*Within a row, means bearing different superscripts are significantly different ($p<0.05$)

Table 4: Functional properties of flour from *Padi-Tuya* and *Wang Kae* cowpea varieties

Functional Property	Cowpea varieties	
	Padi-Tuya	***Wang Kae***
Water absorption capacity (g/g flour)	1.42 ± 0.11^a	1.31 ± 0.04^a
Oil absorption capacity (g/g flour)	1.14 ± 0.05^a	1.15 ± 0.03^a
Swelling power	8.35 ± 0.10^a	7.90 ± 0.03^b
True density (g/cm^3)	1.39 ± 0.01^a	1.43 ± 0.02^b
Bulk density (g/cm^3)	0.87 ± 0.01^a	0.89 ± 0.01^a
Emulsion capacity (%)	6.11 ± 0.10^a	6.11 ± 0.96^a
Emulsion stability (%)	34.03 ± 3.18^a	47.92 ± 3.61^b
Foam capacity (mL)	40.00 ± 2.00^a	29.33 ± 1.15^b

*Within a row, means bearing different superscripts are significantly different ($p<0.05$)

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