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Studies on some engineering properties of dried egg powder reference to its bulk handling

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Abstract

This study investigated some physicochemical and engineering properties of dried egg powder concerning to its bulk handling with the view to promote its usage. The egg was deshelled to have whole egg, egg white and yolk; oven-dried in convective air at 60 °C (± 1 °C), milled and screened with a sieve size with a mesh size of 500 µm. The physicochemical and engineering properties analyses were carried out using standard procedures. The moisture contents ranged from 2.64 to 2.69%, loose and packed bulk densities ranged between 0.45 g/ml and 0.66g/ml (loose), 0.57 g/ml and 0.71g/ml, (packed). The least gelation concentration (LGC) of egg white and whole egg powder occurred at 10%, and, 12% respectively with egg yolk having poor LGC. The density ratio of egg white, whole egg and egg yolk powder were 92%, 76% and 77%, respectively. Egg white, whole egg and egg yolk powder samples had 7.80, 23.43 and 22.12% porosity, respectively The foaming stability of egg white, whole egg and egg yolk powder are 25.05, 28.41 and 26.01, respectively Similarly, the Carr index and Hausner ratio of dried egg white, whole egg and egg yolk powder are 24.48, 7.29 and 22.80; 1.18, 1.35 and 1.32, respectively indicating the egg powder samples were free-flowing. The emulsifying activity index of egg white, whole egg and dried egg powder are 3.84, 1.78 and 5.96, respectively while emulsifying stability index of the same samples are 503.30, 57.83 and 37.87, respectively. The colour intensity determined for egg white, whole egg and egg yolk powder was 61.75, 41,15 and 52.45, respectively Also, the thermal properties of the samples measured using differential scanning calorimeter ranged between 79.3 ^{0}C - 92.8 ^{0}C, 106.4 ^{0}C - 121.2 ^{0}C, 106.2 ^{0}C - 122.8 ^{0}C, 56.75 J/g - 278.6 J/g, 21.4 ^{0}C - 94.743.5 ^{0}C, 10.95 J/(gK) - 20.28 J/(gK), 0.50 w/m^{0}C - 0.70 5 w/m^{0}C, and 0.090 m2/s - 0.094 m2/s for onset temperature, peak temperature, end temperature, enthalpy, temperature range, specific heat capacity, thermal conductivity and thermal diffusivity respectively. The study therefore, provides engineering data about process design, control and bulk handling to extend the usage of dried egg powder samples in food process industries
.

Keywords: Dried egg powder, engineering properties, bulk handling, physicochemical properties.

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1.0 Introduction

Eggs are a low-priced source of high-quality protein, vitamins (B_6, B_{12}, and D) and minerals such as zinc, iron and copper (Surai and Sparks, 2001). It is also an excellent source of choline, folate, and selenium, which are required for the normal brain development and proper functioning of the nervous system (Herron and Fernandez, 2004). It is also a good source of quality protein after mother's milk (Asghar and Abbas, 2012). Egg performs multiple functions in food formulation and development: the success of many cooked foods is dependent on the coagulation of its proteins, especially the irreversible heat coagulation of egg which emulsifies as well as add colour, tenderness and flavour (Stadelman and Schmieder, 2013). Both egg white and yolk are utilized to coagulate and bind food materials together (Stadelman and Schmieder, 2013). Egg white is also a natural antioxidant added to ground meat to decrease oxidation during cooking (Stefanovic *et al.,* 2014). Egg yolk is an emulsion and also acts an emulsifying agent. Therefore, egg yolk or whole egg serves an essential ingredient in mayonnaise and salad dressings, and plays an important role in foods such as cake batter and cream puffs. Egg yolk contributes an appealing yellow colour to many foods, especially baked products, noodles, ice creams, custards, sauces and omelets. Egg foaming capacity plays an important role in the production of cakes and certain confections because of its ability to produce large volume, stable foams which coagulate during heating. It is also used majorly in candy to control the growth of sugar crystal and also for binding water (Surai and Sparks, 2001).

The global egg production between 2009 and 2019 increased by 31%, although contributions from different regions varied (FAO, 2019). Food and Agriculture Organization (FAO) predicted an astonishing production of 89.9 mt in 2030. Global production of egg stood at 88.1 mt in 2019, with China being the leading producer contributing about 28.45 mt which accounts for 34.5% of the world's production (FAO, 2019). Other major producers are the United States of America (USA), India, Indonesia, and Brazil. The countries mentioned above contributed more than 50% of the world egg production)19). Asia, America and Europe being the leading continents in egg production contributed almost 96% of world production while Africa and Oceania contributed the remaining quota. Although, egg production in Africa is estimated at 2.37 mt per annum (representing only 3.7% of the global egg output), leading egg-producing countries in Africa are Nigeria, South-Africa, Morocco, Egypt and Algeria (FAO, 2019). This low level of productivity translates into low per capita egg consumption of 36 egg/person/year, much lower than the world average of 145. The low performance of the poultry industry in Africa could be attributed to the inefficient scavenging management system that is predominant in most rural communities. Improvement in the industry's performance could be achieved by adopting a more efficient production system (FAO, 2019). Egg production varies throughout the year: in winter, it tends to be lower. It is stored at room temperature or refrigerated due to this variation in production and perishability (Cherian, 2008). However, in Africa, many poultry farmers do not have access to these appliances because they require electricity to power them, contributing to the enormous losses recorded in Africa. Transportation of fresh eggs to different countries accounted for considerable loss due to breakage. Therefore, it is essential to minimize this enormous losses to protect the price structure (Rao *et al.*, 1995). Hence, studying how eggs could be stored will promote local consumption and exportation (Koç *et al.,* 2011). Dried egg powder (egg white and egg yolk) is widely used in food preparation because it is microbiologically safe and easy to transport compared to unshelled or liquid eggs. Dried egg powder also is easier to store, handle, measure, and obtain uniformity. Thus, this work focuses on studying some engineering properties of dried egg powder with its bulk handling.

2.0 Experimental

Source of Materials

Fresh eggs were obtained from the Teaching and Research farm, Obafemi Awolowo University, Ile-Ife and all chemicals needed for this research work were of analytical grade.

Samples preparation

About 5 kg of fresh egg obtained from Teaching and Research farm were cleaned with portable water and dried. The lot was divided into two portions and eggs in each portion was carefully broken and deshelled into a container. In the first portion, egg yolk was separated from the albumen and this gave a whole yolk and whole white egg samples. In the second lot, there was no separation of yolk and albumen. Then, the liquid egg sample was thoroughly whipped for uniformity. The whipped egg sample was transferred into an oven dryer (Gallenkmp and Co Ltd) already set at 60 °C. Drying of the whipped egg sample was done at 60 °C (± 1 °C) using convective air flowing at a velocity of 2.2 m/s (Adebayo *et al.,* 2021). Before loading the egg sample, the dryer was run for 30 min. to reach the set drying air temperature conditions. The drying of the whipped egg sample was done in a thin layer form to ensure effective drying. The initial weight of the whipped egg was recorded before loading it into the already set oven. The whipped egg sample was dried for 5 h and subsequently, the drying whipped egg sample weight was measured at an interval of 30 min. until its weight was constant. The dried egg flakes were considered to have attained its equilibrium moisture content (EMC) of the drying conditions. The dried egg flakes were dry-milled using a laboratory milling machine (Falling Number 3100, Huddinge, Sweden) and screen with sieve with mesh size of 500 μm and stored in an air-tight bottle until usage (Figure 1).

Physiochemical properties of egg powder

Physicochemical properties such as moisture content, bulk density, emulsion stability, foaming stability, swelling and solubility index and colour were investigated using standard procedures.

Moisture content

Moisture content was determined using AOAC (2005) method. The dried egg sample (3 g) was placed in moisture cans of known weight and was dried in a hot air oven (H. B Selby and Co. Pty Ltd, Australia; serial number: A1589) at 105 ± 1 ^{0}C for 6 h, cool in a desiccator and subsequently re-weighed until there was no significant change in weight. The moisture content of the dried egg powder was calculated using equation 1:

$$MC_{db} = \frac{W_1 - W_2}{W_1} \times 100 \qquad (1)$$

Where: MC_{db}= moisture content on dry basis, %; W_1 = weight of the starch powder before drying, g; W_2 = weight of the starch powder after drying, g.

Bulk density

Packed bulk density: Packed bulk density was determined according to the method documented by Adebayo *et al.* (2021). A 10 ml graduated cylinder was filled with a known weight of the sample. The bottom of the cylinder was gently tapped several times on a laboratory work bench until there is no further diminution of the sample level after filling to the 10ml mark of the cylinder. Packed bulk density was then calculated using equation 2a:

$$PBD = \frac{\mathrm{Ws}}{\mathrm{Vs}} \qquad (2a)$$

Where: PBD = Packed bulk density, g/ml; W_s= Weight of egg powder sample, g; V_s= Volume of egg powder sample, ml.

Loose bulk density: Loose bulk density was determined using a method documented by Yusuf (2004). A 10 mL graduated cylinder was gently filled with dried egg powder sample. The volume occupied was recorded. Loose bulk density was then calculated as sample weight per unit volume of sample (g/ml) using equation 2b.

$$LBD = \frac{\mathrm{Ws}}{\mathrm{Vs}} \qquad (2b)$$

Where: LBD = Loose bulk density, g/ml; W_s= Weight of egg powder sample, g; V_s= Volume of egg powder sample, ml.

Density ratio and porosity

The density ratio (D_r) which is the ratio of the bulk density to true density expressed as a percentage was also determined using equation 3. While, porosity was determined using equation 4 (Mohsenin, 1986).

$$Dr = \frac{\rho_B}{\rho_T} \times 100 \qquad (3)$$

$$P = \left(1 - \left(\frac{\rho_B}{\rho_T}\right)\right) \times 100 \qquad (4)$$

Where: ρ_B = bulk density, g/ml; ρ_T= true density, g/ml;, g; P = Porosity expressed as a percent

Flowability properties

Flowability of the dried egg powder was determined using the data from the packed bulk density and the loose bulk density of the dried egg powder to determine its rate of compression and compaction. The Hausner ratio and Carr index values were calculated to ascertain the flow property of the sample. The Hausner ratio was calculated as a ratio of the packed density of the dried egg powder to its loose bulk density as shown in equation 5 (Adebayo *et al.,* 2021) while the Carr index as the ratio of the difference between the packed density and loose density of the sample to its loose density, expressed as a percentage as shown in equation 6 (Carr, 1965). The Hausner ratio values were then compared with the Carr index values to ascertain whether the flow was either excellent, good, fair, or poor.

$$H_R = \frac{\rho_\infty}{\rho_0} \qquad (5)$$

$$C.I = \frac{\rho_B - \rho_L}{\rho_L} \times 100 \qquad (6)$$

Where: H_R = Hausner ratio; ρ_∞ = Asymptotic constant density after certain amount of taps and

ρ_o = Initial bulk density; C.I = Carr Index; ρ_B = Packed bulk density, g/mL; ρ_L = Loose bulk density, g/mL

Gelation and least gelation concentration

A method documented by Adebayo *et al.* (2021) was used to determine the gelation concentration of dried egg powder. A known amount of dried egg powder was dispensed in distilled water to make a 5 ml total volume and dried egg powder concentration of 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20% (w/v) in test tubes. The mixture was stirred to ensure a homogenous mixture was formed. The mixture was placed in a laboratory mixing machine (Philip mixer Model A901) at speed 5 for 2 min after which centrifugation was carried out for 15 min to eliminate any air present, in the form of bubbles, in the sample. The dried egg powder was evaluated for gel formation by the least concentration end point method. For determination of least gelation concentration, a method documented by Sathe and Salunkhe (1981) was used. The test tubes which contained the dried egg powder were heated in a boiling water bath for 1 hour followed by rapid cooling under running cold tap water. The test tubes were cooled further in a refrigerator at 4 ^{0}C for 2 h. The strength of the coagulum was evaluated by inverting the test tube. The least gelation concentration was determined when the sample in the test tube did not fall out or slip.

Foaming properties

Foaming properties were determined in triplicate according to the method documented by Adebayo *et al.* (2013). The dried egg sample (2 g) was dispersed in 100 ml distilled water and whipped vigorously for 2min in a kitchen blender (Century Electric Products, China; Model No: CB-8231-M) having measuring cylinder as its holder operated at speed 1. The volumes were recorded before and after whipping and the percentage volume increase was calculated using equation 7:

$$FC = \frac{V_2 - V_1}{V_1} \times 100 \quad (7)$$

Where: FC = Foaming capacity, %; V_1 = volume of solution before whipping, ml; V_2 = volume of solution after whipping, ml.

Foam stability was determined as the volume of foam that remained after 4 h at room temperature (30 ± 2 °C) and expressed as the percentage of initial foam volume.

Emulsion properties

The method described by Adebayo *et al.* (2013) with little modification was used to investigate emulsifying activity index (EAI) and emulsifying stability index (ESI) of the sample. About 0.3 g of the dried egg sample was mixed with 30 ml of deionized water. The suspended solution was mixed with 10 ml of groundnut oil in a Qlink blender (Model No: QBL-20L40) at speed 3 to homogenize the mixture for 60 s. Fifty microliters of an aliquot of the emulsion obtained were transferred from the bottom of the blender after homogenization, and then mixed with 5 ml of 0.01% sodium dodecyl sulphate (SDS) solution. The absorbance of the diluted solution was measured at 500 nm using spectrophotometer (UV 1601- Spectrophotometer, Shimadzu Corporation, Kyoto, Japan). This was then used to calculate EAI and ESI using equations 8 and 9, respectively:

$$EAI\left(\frac{m^2}{g}\right) = \frac{2 \times 2.303 \times A_0}{0.25 \times P_w} \quad (8)$$

$$ESI\ (min) = \frac{A_{10} \times \Delta t}{\Delta A} \quad (9)$$

Where: A_0 = Absorbance at 0 min after homogenization; A_{10} = Absorbance at 10 min after homogenization; P_w = protein weight of each samples; $\Delta A = A_0 - A_{10}$ and; Δt = 10 min

Colour measurement

Dried egg sample colour (L, a, and b-value) was measured with a colorimeter (Minolta Chroma Meter CR 200, Minolta Camera Co., Japan) and results were expressed following the CIE Lab. system.

Thermal properties determination

Thermal properties of dried egg powder were measured using a KD2 Pro Thermal Properties Analyser (Decagon Devices Inc., Pullman, WA), a portable field and laboratory equipment that uses the transient line heat source method. The 30 mm long, 1.28 mm diameter, and 6 mm spacing dual needle SH-1 sensor measures the onset temperature, peak temperature, end temperature, gelatinization enthalpy thermal conductivity, thermal diffusivity and specific heat (heat capacity) concurrently. An interval of 5 min was provided between each reading. The thermal diffusivity was calculated using the equation 10 given by Leniger and Beverloo using the thermal read out from the differential scanning calorimeter (DSC). A semi logarithm plot of equation 10 gives a slope representing the thermal diffusivity.

$$\log \frac{T_p - T_0}{T_p - T} \quad (10)$$

Where: T_P = Highest processing powder temperature, T_0 = Initial powder temperature; T = temperature of powder at any time

Thermal conductivity was calculated mathematically using equation 11:

$$\alpha \rho C_P = K \quad (11)$$

Where: α = thermal diffusivity, m^2/s; k = thermal conductivity, w/m^0C; C_P= specific heat capacity, J/ (gK); ρ= density, g/mL

Coefficient of friction of dried egg powder

The coefficient of friction for the dried egg powder was determined using the method documented by Bahnasawy (2007). The coefficient of friction was tested against different materials such as plywood, stainless steel, galvanized steel and glass. A bottomless cylinder of 5 cm diameter and 10 cm height was filled with the dried egg powder and placed over the different surfaces placed in turn on an inclined plain system. The surfaces were gently raised using a jack and the angle at which the powder motion began as the plain inclined was read on a calibrated protractor in degrees. The coefficient of friction was calculated using equation 12:

$$\mu = \tan\alpha \quad (12)$$

Where: μ = coefficient of friction; α = angle, in degrees.

Angle of repose

The angle of repose of dried egg powder was determined using the method documented by Adebayo *et al*. (2021). A bottomless cylinder of 5cm diameter and 10 cm height was placed over a plain surface and dried egg powder was placed in the cylinder. The cylinder was raised slowly allowing the sample to flow and form a natural slope. The angle of repose was calculated from the height and diameter of the pile using equation 13:

$$\theta = \tan^{-1}\left(\frac{2h}{D}\right) \quad (13)$$

Where: θ = angle of repose, ^{0}; h = height, cm

Statistical analysis

All experiments were conducted in triplicate. Data reported were averages of three determinations. The data obtained were analyzed descriptively and inferentially using Design Expert 13 for Windows.

3.0 Results and Discussion

Physiochemical properties such as moisture content, bulk density, porosity, density ratio and flow parameters of whole egg powder, egg yolk and egg white powder are presented in Table 1. The moisture content of the whole egg, egg yolk and egg white powder are 2.69, 2.64 and 2.69% (d.b), respectively (Table 1). There was no significant difference in the moisture contents of the three samples ($p \leq 0.05$). The moisture content values obtained compared favourably with 1.83 – 3.35% but lower than 3.88 – 6.74% reported for a whole egg, egg yolk and egg white, respectively (Jay, 2000; Koc *et al.,* 2011; Asghar and Abbas, 2015). The higher values (6.74% for white egg) documented by Koc *et al.* (2011) may be attributed to maturity, egg source and season of its production. Moisture content is an important factor in controlling the shelf life of egg powder. Stadelman and Cotterill (1995)

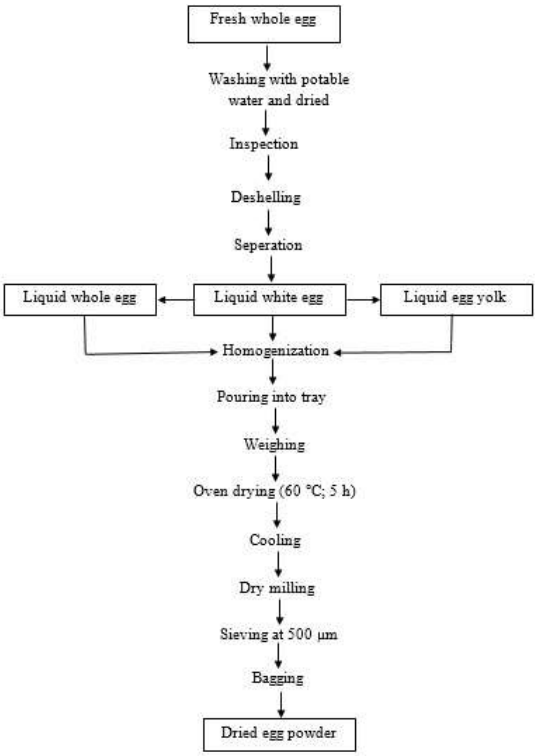


Figure 1: Flow diagram of whole egg processing into powder (Wong and Kitts, 2003)

Table 1: Physicochemical characteristics of egg white, whole egg and egg yolk powder

Parameters	Egg white	Whole egg	Egg yolk
Packed bulk density (g/ml)	0.71±0.025[a]	0.58±0.015[b]	0.57±0.015[b]
Loose bulk density (g/ml)	0.66±0.021[a]	0.45±0.011[b]	0.45±0.021[b]
Carr Index (%)	24.48±0.73[a]	7.29±2.56[b]	22.80±1.42[a]
Hausner Ratio	1.18±0.13[a]	1.35±0.09[a]	1.32±0.31[a]
Density ratio (%)	92.20±6.06[a]	76.57±0.67[b]	77.88±1.55[b]
Porosity (%)	7.80±6.06[b]	23.43±0.67[a]	22.12±1.55[a]
Moisture content (%)	2.69±0.058[a]	2.69±0.076[a]	2.64±0.010[a]
Foaming stability (%)	25.05±0.33[b]	28.41±0.60[a]	26.01±0.29[b]
Compressibility	Good	Very poor	Good
Flowability	Passable	Passable	Passable

Values are means ± standard deviation, values in the rows with the same superscripts are not significantly different at $p \leq 0.05$

Table 2: Gelation and least gelation of egg white, egg yolk and whole egg powder

Concentration (%)	Egg white	Egg yolk	Whole egg
2	-+	--	-+
4	-+	--	-+
6	-+	--	-+
8	-+	-+	-+
10	++	-+	-+
12	++	-+	++
14	-+	-+	++
16	++	-+	++
18	++	-+	++
20	++	-+	++
LGC	10%		12%

-- No gelation; -+ viscous; ++ Full gelation; LGC – Least Gelation Concentration

Table 3: Flowability classification using Carr standard (Carr, 1965).

Carr's index	Flowability	Hausner ratio
≤ 10	Excellent	1.00 – 1.11
11.0 – 15.0	Good	1.12 – 1.18
16 – 20	Fair	1.19 – 1.25
21 -25	Passable	1.26 – 1.34
26 -31	Poor	1.35 – 1.45
32 – 37	Very poor	1.46- 1.59
> 38	Awful	> 1.60

Table 4: Emulsion stability of egg white, whole egg and egg yolk powder

Sample	EAI	ESI
Egg yolk	5.96±1.11a	37.87±7.74a
Egg white	3.84±0.21b	503.30±465.67a
Whole egg	1.78±0.48c	57.83±6.10a

Values are means ± standard deviation, values in the columns with the same superscripts are not significantly different at p > 0.05
EAI = Emulsifying activity index of dried egg powder and; ESI = Emulsifying stability index of dried egg powder

Table 5: Coefficient of static friction and angle of repose

Sample	Plywood	Stainless steel	Galvanized steel	Glass	Angle of repose (°)
Egg white	0.45 ± 0.086^{a}	0.40 ± 0.021^{c}	0.43 ± 0.017^{b}	0.42 ± 0.047^{a}	23.33±0.38^{b}
Whole egg	0.48 ± 0.070^{a}	0.50 ± 0.023^{b}	0.500 ± 0.11^{a}	0.52 ± 0.11^{a}	29.33±0.29^{a}
Egg yolk	0.58 ± 0.070^{a}	0.61 ± 0.023^{a}	0.54 ± 0.36^{a}	0.55 ± 0.10^{a}	22.75±0.035^{b}

Values are means ± standard deviation, values in the columns with the same superscripts are not significantly different at (p>0.05)

Table 6: Colour analysis of dried egg white, whole egg and egg yolk powder

	ΔC	ΔE	H	W%
Egg white	21.36±0.90^{c}	61.75±0.19^{a}	-72.88±0.20^{c}	3278.41±90.71^{c}
Whole egg	23.76±0.23^{b}	49.15±0.47^{c}	81.31±0.10^{b}	4534.85±22.77^{b}
Egg yolk	27.99±0.25^{a}	52.45±0.50^{b}	84.81±0.06^{a}	4678.57±18.71^{a}

*ΔC – Delta chroma, ΔE – Colour intensity, H – Hue angle, W% - Degree of whiteness
Values are means ± standard deviation. Values in the columns with the same superscripts are not significantly different at p>0.05

Table 7: Thermal properties of egg white, whole egg and egg yolk powder

Parameter	Egg white	Whole egg	Egg yolk
Onset Temperature, T_o (°C)	33.31	33.64	33.38
Peak Temperature, T_p (°C)	143.53	112.00	110.85
End Temperature, T_E (°C)	192.53	195.69	119.48
Enthalpy, H (J/g)	293.14	84.72	62.84
Temperature Range (°C)	159.22	162.05	86.10
Specific Heat Capacity, C_p (J/gK)	8.03	3.54	2.33
Thermal conductivity, k (10^{-7}) (w/m°C)	4.21	1.49	0.96
Thermal diffusivity, α (10^{-6}) (m^2/s)	0.738	0.726	0.725
Density, ρ (g/mL)	0.71	0.58	0.57

documented that moisture content of 5% and below of egg powder will extend the shelf life in an environment of low humidity. Food powder is considered shelf-stable if its moisture content is below 11% (Gbadamosi *et al.,* 2012). Hence, the shelf stability of the egg powder investigated could be considered shelf-stable for moisture related deterioration.

The packed bulk density values of egg white, whole egg and egg yolk powder are 0.71, 0.58 and 0.57 g/ml, respectively (Table 1). The packed bulk density values showed a significant difference ($p \leq 0.05$) between egg white powder and the egg yolk and whole egg powder. The difference in packed bulk density may be attributed to interrelated factors such as attractive inter-particle forces and some contact points (Adebayo *et al.,* 2021). The packed bulk density values obtained compared favourably with 0.62 g/ml documented by Orishgbemi *et al.* (2017) for foam dried egg powder but higher than 0.34 g/ml reported by Koc *et al.* (2011) for whole egg powder. The differences may be attributed to moisture content differences of the various egg powder (Sreenivasula *et al.,* 2015). At the same time, the loose bulk density values ranged from 0.45 to 0.66 g/ml (Table 1). Egg white had the higher value (0.66 g/ml) while the remaining two samples have 0.45 g/ml. The bulk density either loose or packed; measures the quantity of material packed within a pre-specified packing space (Gbadamosi and Oladeji, 2013). Bulk density plays an essential role in the dispersion rate of food powder.

The density ratio of egg white, whole egg and egg yolk powder is 92, 76 and 77%, respectively (Table 1). The density ratio values showed a significant difference ($p \leq 0.5$) between egg white powder and the egg yolk and whole egg powder. The density ratio values obtained compared favourably with 73, 76, and 79% for breadfruit starch flour, *Musa* spp. starch flour and wheat starch flour, respectively (Paksoy and Aydin, 2004). The porosity values of egg white, whole egg and egg yolk powder are 7.80, 23.43 and 22.12%, respectively (Table 1). The porosity values showed significant difference ($p \leq 0.5$) between egg white powder and the egg yolk and whole egg powder. The porosity values obtained for both whole egg and egg yolk powders compared favourably with 24.1 and 23.8% reported for mung bean starch powder and sorghum starch powder respectively (Gupta and Das, 1997; Altuntas and Yildiz, 2007).

The foaming stability of egg white, whole egg and egg yolk powder are 25.05, 28.41 and 26.01%, respectively (Table 1).Whole egg has the highest foaming stability while the least foaming stability is exhibited by egg white. The highest foaming stability of whole egg powder may be attributed to its high protein content. The foaming stability values are higher than 17 – 18.2% reported for foam-mat dried egg powder (Orishagbemi *et al*. 2017). The variations in the foam stability values may be attributed to the difference in protein and fat content of the egg samples and protein denaturation during the dehydration process. High temperatures damage proteins in food, and protein plays an important role in the stability of foams, which represents a surface-active material (Adebayo *et al.*, 2021). Surface active properties include the formation and stabilization of the dispersed gas phase due to heating process, making the foam more stable (Chayatti and Ari, 2008). Thus, proteins denaturation affects foaming stability. The difference in foaming stability values may also be attributed to the drying process and conditions (Stadelman and Cotterill, 1995).The foam stability values obtained are lower than 38.70 – 73.0% reported for spray-dried egg powder (Koc *et al*., 2011). The foaming stability values of the dried egg powder samples decreased with increasing atomization pressure, fundamentally due to the physical denaturation of proteins (Koc *et al*., 2011).

Gelation and least gelation concentration (LGC) values of egg white, whole egg and egg yolk powder are shown in Table 2. The least gelation concentration of egg white, and whole egg powder occurred at 10 and 12%, respectively while egg yolk demonstrated no least gelation concentration. The LGC values are higher than 5 - 6% reported for foam-mat dried egg powder (Orishagbemi *et al*., 2017).

Carr index (CI) of dried egg white, whole egg and egg yolk powder are 24.48, 7.29 and 22.80 %, respectively (Table 1). The CI value of whole egg powder is significantly lower ($p \leq 0.05$) than that of egg white and egg yolk powder. The CI values obtained compared favourably with 26.98 and 28.89% documented for egg powder mixed gelatin and spray dried egg powder, respectively (Koc *et al.,* 2011; Koc *et al.,* 2012). The Hausner ratio values obtained are 1.18, 1.35 and 1.32 for dried egg white, whole egg and egg yolk powder, respectively (Table 1). There is no significant difference ($p \leq 0.05$) in Hausner ratio values for the three samples except for white egg powder. The Hausner ratio values obtained compared favourably with 1.41 for egg powder mixed gelatin and spray dried egg powder (Koc *et al.,* 2011; Koc *et al.,* 2012).The difference in CI and Hausner ratio values of the dried egg samples may be attributed to their different compositions. The flowability of powder is classified as very poor, poor, fair, good, and excellent (Table 3). Falade and Ayetigbo (2015) reported that most hydrocolloids are known to have good compressibility but very poor flow ability properties using CI as a basis.

As the Hausner ratio value increases, the material flowability property becomes poorer. Based on the Hausner numerical scale, flowability can be classified as excellent, good, fair, passable, poor, very poor, and awful. Hausner ratio values from 1.00 to 1.11 correspond to excellent flow characteristic, while a Hausner ratio > 1.60 corresponds to very poor flow characteristics. Based on this, all the egg samples had good flow characteristics of a powder. The CI provides an indirect measure of material fluidity, and the higher its value, the more cohesive the substance (Riley *et al*., 2008)

The emulsifying activity index (EAI) and emulsifying stability index

(ESI) of dried egg white, whole egg and dried egg yolk powder are 3.84 and 503.30; 1.78 and57.83 and 5.96 and 37.87, respectively (Table 4). There is a significant difference ($p \leq 0.05$) in the EAI values of all the dried egg samples. EAI value of egg yolk powder is significantly higher than whole egg and egg white powder. The ESI value of dried egg white powder is significantly higher than dried egg yolk and whole egg powder values. This may be due to the low emulsifying stability of egg yolk which about a low emulsifying stability index in whole egg powder and a great increase in the egg white powder. The high ESI value of dried egg white may be attributed to the absence of egg yolk. The differences in ESI values of the dried egg samples may also be attributed to the differences in pH of the dried egg samples. ESI values of 14.70, 72.40, and 44.86 reported for egg white, egg yolk, and whole egg, respectively are lower than the ESI values obtained for the dried egg powder samples (Ndife *et al*., 2010). The drying process improves the emulsion properties of whole egg due to the denaturation of protein (Anandharamakrishnan *et al*., 2007). The better stabilization effects of powders dried at higher temperatures may be attributed to the changes in protein conformation which contribute to the stability of the boundary surface (Kato *et al*., 1990). The coefficient of static friction values of dried egg white, egg yolk, and whole egg powders determined against the glass, plywood, galvanized steel, and stainless steel are 0.45, 0.48 and 0.58; 0.40, 0.50 and 0.61; 0.43, 0.50 and 0.54; and 0.42, 0.52 and 0.55, respectively (Table 5). The coefficient of static friction values of the dried egg samples are higher than 0.062 (plywood), 0.040 (galvanized metal) and 0.021 (glass) for dried eggs (Altuntas and Yildiz, 2007).

The angle of repose values of dried egg white, egg yolk, and whole egg powders are 23.33, 22.75 and 29.33°, respectively. The angle of repose value for whole egg powder is significantly higher ($p \leq 0.05$) than the values for dried egg white and egg yolk powders (Table 5). The angle of repose indicates the flow rate of the egg powder extracted. According to Carr (1965) and Raymus (1985), the angle of repose below 30^{o} indicated good flowability, 30 – 45° some cohesiveness, 45 – 55° true cohesiveness and above 55° sluggish or very high cohesiveness and limited flowability. This indicates the egg white, egg yolk and whole egg powder exhibit good flowability.

The colour intensity values for egg white, whole egg and egg yolk powder are 61.75, 41, 15 and 52.45, respectively (Table 6). There is a significant difference ($p \leq 0.05$) in the colour intensity values of all the egg powder samples. The difference in colour intensity may be attributed to the Millard reaction. The values obtained are higher than 20.7 – 27.5 reported for dried whole egg samples (Koc *et al.,* 2011). The differences in color intensity may be due to long drying time at high temperatures which can significantly decrease the quality of dried materials. This includes colour change (Asghar and Abbas, 2015). In the drying process, higher temperature and atomization pressure applications lead to oxidation of colour pigments (xanthophylls, lutein and zeaxanthin) and the formation of smaller particles after atomization causes a bleaching of the colour of whole egg powder (Stadelman and Cotterill, 1995). It is observed that Hunter L value, as lightness index, was the greatest among the three samples. On the other hand, the low moisture content (water activity) of the egg powder prevented the formation of excessive Maillard reaction, likewise preventing the increase in Hunter b value, since the optimal range of water activity is known as 0.520–0.750 for that reaction (O'Brien and Morissey, 1985).

The onset temperature, peak temperature, end temperature, gelatinization enthalpy, temperature range, specific heat capacity and density of egg white, egg yolk and whole egg powder are presented in Table 7.

The gelatinization enthalpy (ΔH) for the egg white is higher than the whole egg and egg yolk, with egg yolk having the least enthalpy value. Singh and Singh (2011) in their report, related gelatinization enthalpy to the degree of crystallization. The thermal conductivity of egg white is higher than whole egg and egg yolk powder with egg yolk having the least thermal conductivity. This may be due to the difference in moisture content and bulk density of the different powder. The thermal diffusivity of the three egg powder ranges from 0.738 to 0.725 with egg white having the greatest diffusivity, which may be due to the difference in bulk density (increase in bulk density) as reported by Boreddy and Subbaire (2015). The specific heat capacity of egg white is higher than that of whole egg and egg yolk with egg yolk having the lowest value, which may be due to increase in temperature as reported by Boreddy and Subbaire (2015). The density of the samples which is a function of mass and volume differed significantly between egg white, whole egg and egg yolk samples. The egg white density value is significantly different to that of whole egg and egg yolk sample.

4.0 Conclusion

The study therefore provides engineering data on process design, control and bulk handling needed by PLC logic controllers so as to enable sensors to detect, measure and interprets these data intending to extend the usage of egg powder samples in the food processing industries.

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Conflict of interest

None to declare.

Individual author's contributions

Conception: ADEBAYO W. A.

Design: ADEBAYO W. A.

Execution: ADEBAYO W. A. and OLADIPO, A. A.
Interpretation: ADEBAYO W. A. and OLADIPO, A. A.
Writing the paper: ADEBAYO W. A.
This article emanated from Miss. Oladipo's thesis, which was supervised by Dr. Adebayo. Adebayo conceived and designed the idea but experimentation, interpretation of results and data analysis were performed by the two authors. Adebayo was responsible for the writing up of the article while both authors then revised the manuscript.

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