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Research Article

Nutritional and physico-chemical properties of egg powder are affected by different drying methods

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Abstract - This research aimed to determine the effect of solar and freeze drying methods on nutritional and physico-chemical properties of egg powder. Fresh egg samples were dried separately using solar and freezing drying, and the physico-chemical properties, proximate and mineral content were determined using standard methods. For the physico-chemical properties, solar drying caused a reduction in the TSS and pH from 0.83 °Brix and 7.95 for fresh egg to 0.55 °Brix and 6.89 (solar dried egg powder) compared to that (0.95 °Brix and 7.73) of freeze drying, though both methods had no effect on TTA. The drying methods reduced the color characteristics (L*-41.62, a*-2.68 and b*-15.88) of the fresh egg to (L*-34.27, a*-0.51 and b*-13.29) and (L*-28.08, a*-0.91 and b*-5.74) for freeze and solar dried egg powders, respectively. Except for moisture (75.98%) which decreased significantly to 2.32% (freeze drying) and 6.70% (solar drying), protein (54.40-55.93%), fat (27.75-29.49%), ash (4.14-4.58%), carbohydrate (7.03-7.69%) and energy (485.41-519.83%) increased greatly for the egg powders compared to the fresh egg which had 10.62%, 8.32%, 1.54%, 2.21% and 130.56 kcal correspondingly. The two egg powders had comparable concentrations of K, Ca, Fe, Zn and Mg, indicating equal effects of freeze and solar drying methods on mineral composition. The freeze drying was more efficient in moisture removal, and maintaining high nutritional profile as well as color characteristics of the egg powder, and therefore presents a high potential for commercial

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production of egg powder to promote food and nutrition security.

Keywords: Egg powder, freeze drying, solar drying, physico-chemical properties, nutritional content

1. Introduction

Egg is one of the most versatile and nutritious food commodities in nature (Mine et al., 2023). It provides the body with proteins, amino acids, vitamins, mineral substances such as phosphorus, chlorine, potassium, sodium, sulfur, calcium, magnesium and iron, and has a high biological value with easy digestibility (Kiczorowska et al., 2015). According to Gautron et al. (2022) more than 1200 billion of eggs are produced worldwide. China is the world leading producer of eggs, with 31 million MT contribution, followed by US (6.3 million MT) and Japan (2.6 million MT). Nigeria, South Africa, Egypt, Ghana, Morocco, Algeria, Tunisia, Kenya, and Libya are the major egg producing countries in Africa with annual growth rate equivalent to 77% of egg output (Gautron et al., 2022; Tukur, 2011). Despite the nutritional benefits of egg, its availability, and accessibility all year round in Ghana and Africa is a challenge, due to its high perishable nature (Kiczorowska et al., 2015). This phenomenon translates into the low per capita egg consumption of 36 eggs/person/year, much lower than the world average of 145 eggs (Tukur, 2011). The shorter shelf-life of egg presents the need for value addition to enhance its storability.

Egg powder is a shelf-stable product obtained from drying of fresh egg, and plays a crucial role in the control of national and international egg markets (Miranda et al., 2015). Egg powders are very useful ingredients with superior technological properties when compared to liquid egg products, and find applications in many segments of the food industry for customers' product formulations (Lechevalier et al., 2013; Miranda et al., 2015). Processing of egg into egg powder saves transportation and storage costs, facilitates easy handling, reduces its vulnerability to bacterial growth, and allows for accurate measured quantity to be added in meal formulations as well as possess aesthetic qualities. Egg powders are widely used in bakery products, mayonnaise, salad dressings, confectionaries, pasta, and a variety of convenience meals (Akdağ et al., 2023; Miranda et al., 2015; Lechevalier et al., 2013). It is rich in protein (Daramola-Oluwatuyi et al., 2021) and minerals such as phosphorus, calcium and iron (Asghar & Abbas, 2015), which give the skin and hair a good amount of nourishment, soften dry skin and promote shiny hair. Egg powder has the potential to be an active element in pharmaceutical and nutraceutical products, due to its bioactive properties such as anti-inflammatory, anti-hypertensive, anti-microbial, acne fighting, moisturizing, and penetration enhancers which promotes skin elasticity and plumpness as well as protect the skin against bacterial damages, and helps in the treatment and prevention of wide range of diseases (Roberts, 2017; Mondal et al., 2021).

The global egg powder market stands at 205,000 MT, with annual growth rate of 4.8%, and has been projected to reach 294,000 MT by 2026 (EMR, 2020). Currently, while there is little trading with countries outside the EU in shell eggs and liquid egg products, the situation is different for egg powder. The demand for egg powder has stayed inclined not because of its availability for diverse food application, nutritional and therapeutic benefits alone, but also because of its long shelf-life property and low transportation cost (Sharif et al., 2018). West Africa countries including Ghana spend over $2 billion annually on importation of egg powder due to high demand from food processing and beverage industries owing to its emulsifying, foaming, thickening capacities, and significant culinary roles suitable for the production of food products such as custards, mayonnaise, ice cream, bread, cakes, and among others (Patel et al., 2009). Drying is the oldest method of food preservation, and has been identified as the one of the easiest means of egg processing. According to Donald (2014), dehydration or drying of eggs into powder comes with many advantages including, measured quantity for use as ingredients in food preparation and formulations, ease of transportation, proper storage and provision of safety against microbial growth. The shelf-life of egg can be extended for a period of six months to one year depending on the storage environment to maintain both sensory and nutritive qualities if processed into powder (Lechevalier et al., 2013). Spray drying employs convection drying process which consist of four stages – atomization of liquid feed mixture into small drops, contact of drops and dry air/gas, evaporation of solvent from drops, and the separation and collection of powder (Banožić et al., 2023). It is an environmentally friendly drying method widely employed for commercial egg powder production since its mechanism of drying is able to maintain the quality characteristics of the egg powder (Ma et al., 2013). However, it has a major disadvantage of high investment cost with regards to equipment purchase and operationalization (Banožić et al., 2023), and also limited application in yolk powder due to evidence of thermal denaturation of yolk protein (Koç et al., 2011; Chen et al., 2012). Study by Daramola-Oluwatuyi et al. (2021) showed that freeze dried and dehydrated whole egg powders compared favorably with the commercial spray dried whole egg powder in all spheres of evaluation. Research by Lili et al. (2015) concluded that, different drying methods have different effects on the functional properties of egg powder. The application of solar energy (solar drying) for drying is recommended since it is inexpensive, time-saving, environmentally friendly, sustainable, and allows for more volume of product to be dried at the same time compared to other drying methods, including traditional sun drying (Yahya et al., 2008; Fadhel et al., 2010). Solar dried products have excellent quality characteristics because of their indirect interaction with sunshine (Tiwari, 2016). Kenawi et al. (2015) also reported that solar drying of whole egg, white egg, and egg yolk into powder demonstrate good quality attributes, nutritional and functional properties. However, there is limited information on the impact of freeze and solar drying on egg powder production. This study therefore aimed at determining the effect of freeze and solar drying methods on both nutritional and physico-chemical properties of egg powder. Investigation into solar and freeze drying methods in egg powder production will provide alternative methods for processors and farmers in egg powder manufacturing to help reduce egg losses and contribute more to food and nutrition security.

2. Materials and methods

2.1 Experimental design

A completely randomized design was adopted to study the effect of two different drying methods on the nutritional and physico-chemical properties of egg powder, using the pretest-posttest control approach.

2.2 Source and preparation of egg samples

Fresh eggs of broiler chicken of 17 weeks' maturity were procured from Akro Farms Depot at the Koforidua Central Market, Koforidua, Ghana. The eggs were observed through a candle light to confirm their freshness (uniform mass and color, and without cracks) after which they were cleaned by dusting, washing, and allowed to dry prior to storage at room temperature (25-30 °C, 50-60% RH). The eggs were deshelled, homogenized using a blender

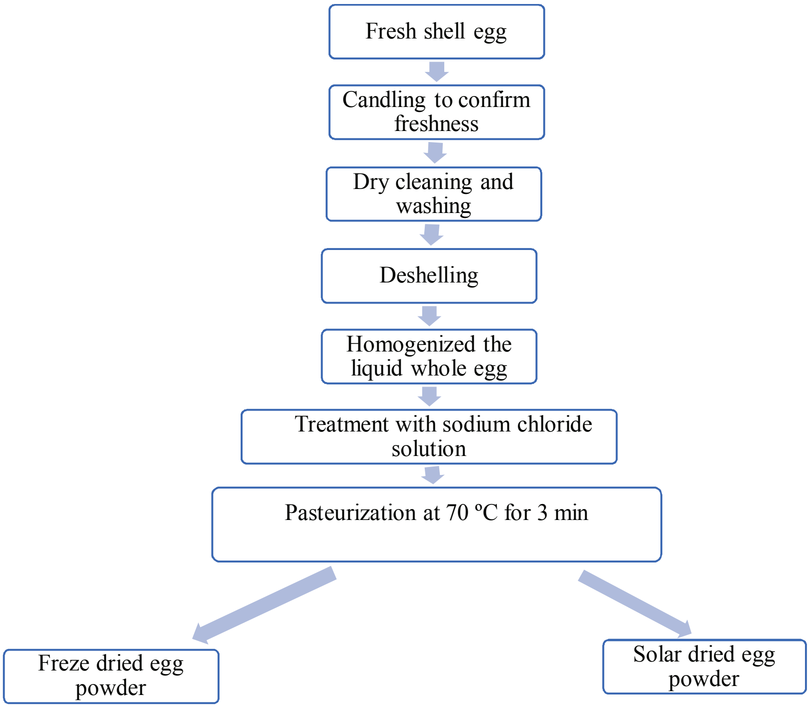

Figure 1. Flowchart for the preparation of egg powder

(Vitamix A2500, US) operating at 1500 RPM and 25 °C, followed by the addition of sodium chloride (1 g) to stabilize protein molecules and improve the efficiency of the dehydration process (Kaewmanee et al., 2013), and pasteurized using a water bath at 70 °C for 3 min to sterilize liquid egg (Cunningham, 2017), prior to freeze and solar drying (Figure 1).

2.3 Drying of egg samples

Freeze drying of egg sample (4 kg) was carried out following the method described by Shukla (2011), with the use of harvest right freeze dryer (UT 84054, USA). The freeze-dryer operated at condenser and sample temperatures of -35 °C and 30 °C respectively, under a vacuum pressure of <500m Torr and tray size of 675 sq. inches. About 4 kg of egg sample was dried according to a direct solar drying method described by Kumar et al. (2016), using a locally developed research solar dryer (60 to 70 °C for 72 h) at the Department of Agricultural Engineering of the Kwame Nkrumah University of Science and Technology, Kumasi. Prior to the actual studies, a preliminary trial was done to optimize the drying conditions which established a temperature of 65 °C, material thickness of 10 mm, and wind speed of 6.6 m/s.

2.4 Determination of egg powder yield

The percentage yield of the egg powder was determined using the equation below (Daramola, 2018).

$$\text{Egg powder yield (\%)} = \frac{\textit{weight of extracted flour}}{\textit{weight of whole egg used}} \times 100$$

2.5 Determination of physico-chemical properties of egg powder

The pH and Total Soluble Solids were determined using a digital pH meter (Orion 2 Star, UK), and refractometer (HI 96801, UK), respectively. In the case of the pH, 10 g of the dried sample was mixed with 50 mL of distilled water, the pH electrode was placed in the sample and values were recorded. For total soluble solids, the refractometer was calibrated with distilled water and a drop of the egg sample was placed on the prism of the refractometer and the reading was taken. Titratable acidity of the fresh egg and the different dried egg powders were determined using the standard methods of AOAC (2012). Color of the whole egg and dried samples were determined using a colorimeter (WR-10QC, China) as described by Rao et al. (2012). Sample was spread on a Petri dish, and the color reader was pointed directly to the sample by maintaining a distance of 1 cm between sample and reader. The values of L*, a* and b* displayed were recorded where L* describes the brightness of the color (0 to 100), a* defines the green-red green color type (-120 to +120) and b* for blue-yellow blue (-120 to +120).

2.6 Proximate analysis of fresh egg and egg powder

Fresh egg and the different egg powders were determined for moisture, ash, crude fat, protein and crude fiber contents according to AOAC (2016). Carbohydrate and energy contents were determined according to AOAC (2010).

2.7 Determination of mineral content of egg and egg powder

Minerals such as calcium, potassium, magnesium, zinc and iron in the samples were determined using the official method of AOAC (2010). Briefly, 1 g of egg powder was ashed at 550 °C for 4 h in a muffle furnace (Sheffield s30 2RR, England). The ash was dissolved in 5 mL of 6 M HCl, following addition of 15 mL of 3 M HCl and subsequent heating till boiling. The digested sample was cooled, filtered, and adjusted to the suitable amount with demineralized water. The mineral concentration was measured using an atomic absorption spectrophotometer (AAS 4200, USA). Phosphorus was determined using a UV-Vis spectrophotometer (JENWAY 6300, UK) at 690 nm (Latimer, 2016).

2.8 Data analysis

The data obtained from the study was analyzed for mean, standard deviation and significant difference using One-way Analysis of Variance from statistical package for social science (SPSS) version 25. The results were expressed as means and standard deviations presented in tables and charts, while significant differences were established at $P < 0.05$.

3. Results and discussion

3.1 Yield of egg powder

The egg powder yield (69%) for freeze drying method was significantly ($P < 0.05$) higher than that (27%) of solar drying method (Figure 2). The lower yield of the solar dried egg powder can be linked to the higher moisture lost resulting from the high temperature, and sticking of the dried egg powder on the surface of the drying trays.

Although no previous studies have reported on the yield of egg powder for both freeze and solar drying methods, Wei et al. (2019) study on freeze dried egg yolk powder reported 46.51% for Leghorn eggs and 42.77% for Serama eggs, which were higher than the yield obtained from the solar drying method (27%) but lower than that of the freeze-dried method (69%) reported in this study. Also, the egg powder yield observed in this study was lower than the > 97% for both spray and oven dried egg powder reported by Abreha et al. (2021) for local (Ethiopian) and exotic (imported) chicken breeds. The variation in quantity of egg yield may be attributed to the egg type used, the bred of fowls and processing method. According to Liu et al. (2017) one kilogram of egg yolk powder is equivalent to 100-150 egg yolk. Commercially, higher

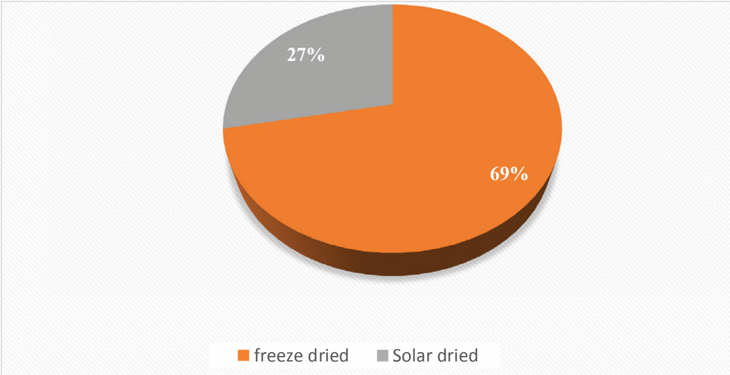

Figure 2. Yield of egg powder of different drying methods

yield of egg powder can be obtained when egg is dried using freeze drying method, hence will offer a better yield if applied in egg powder production aside its initial high capital investment and operational cost.

3.2 Effect of different drying methods on the physico-chemical properties of egg powder

The physico-chemical properties determined were, pH, TSS and TA. The pH value of a food substance is a direct function of the free hydrogen ions present, and the value obtained for the samples ranged from 6.89 to 7.95 (Table 1).

Table 1. Physico-chemical properties of egg samples

Samples/Parameters	pH	TSS/ ºBrix	TTA/ gL^{-1}
Raw egg	7.95 ± 0.06^a	0.83 ± 0.03^a	1.384 ± 0.04^a
Freeze dried egg	7.73 ± 0.01^b	0.95 ± 0.01^b	1.351 ± 0.01^a
Solar dried egg	6.89 ± 0.01^c	0.55 ± 0.01^c	1.385 ± 0.04^a

Note: each value is presented as mean ± standard deviation. Means within a column with the same letter superscript are not significantly different ($P > 0.05$) whereas those with different superscripts are significantly different ($P < 0.05$). TSS = Total Soluble Solids, TTA = Titratable Acidity

The pH of the raw egg (7.95) was higher, followed by freeze dried egg powder (7.73) and the lowest (6.89) for solar dried egg powder. The observed differences between the pH of the two egg powder products were significant ($P < 0.05$) compared to the raw sample, and this can be attributed to water removal or evaporation and the formation of volatile basic nitrogen compounds (Bekhit et al., 2018). According to Sturm and Hensel (2017), drying can also trigger chemical reactions that may alter pH, with some substances (organic compounds) likely to undergo hydrolysis or oxidation reactions during the drying process, leading to changes in pH. A decrease in pH has been associated with enzymatic breakdown of molecular compounds (proteins and lipids), moisture loss and heating effects which cause changes in ion mobility and dissociation (Tontul & Topuz, 2017; Tavano, 2013; Mechlouch et al., 2012), and this may account for the lower pH of the solar dried sample due to the high temperature application compared to the freeze-dried samples. The pH of the solar and freeze-dried egg powders were consistent with 7.50 to 7.80 reported by Abreha et al. (2021) for spray- and oven-dried whole egg powders.

The total soluble solids of the egg samples were identified as 0.95, 0.83, and 0.55 ºBrix for freeze dried egg powder, raw egg and solar dried egg powder, correspondingly. There were significant differences ($P < 0.05$) between all the samples when compared. While the drying methods remain the cause for the TSS variations in the various samples when compared to the raw egg, the increase in the TSS value of freeze-dried egg can be hugely attributed to the breakdown of long chain carbohydrate compounds into soluble sugars via the sublimation process (Darniadi, 2017), though no studies have reported on TSS of egg powder. Sublimation process has been shown to cause cell pores widening and membrane disintegration which leads to higher moisture lost and breakdown of the carbohydrate chains into sugar (Rungpichayapichet et al., 2016; Nguyen & Chuyen, 2020). TSS is dominated by total sugar content, and a small portion of soluble proteins, amino acids and other organic materials (Hadiwijaya et al., 2020). As water evaporates by sublimation, the remaining solids become more concentrated, leading to higher TSS in freeze dried samples, whilst the decrease in TSS in the solar dried samples might be due to the degradation of sugars during the drying process (Farooq et al., 2020). TSS levels can act as a natural preservative by reducing water activity and inhibiting the growth of spoilage microorganisms to help extend the product's shelf life (Fan et al., 2019). TSS reflects the carbohydrate metabolism involving soluble sugars in cells (Jiang et al., 2013).

The solar dried egg powder attained the highest (13.90 g/L) titratable acidity (TTA), whilst the freeze dried egg powder recorded the lowest (13.51 g/L). The results showed that the titratable acidity value of the solar dried sample was slightly higher than freeze-dried sample even though they were insignificant ($P > 0.05$), and this could be due to the differences in the drying mechanisms. Both freeze and solar drying methods did not significantly influence the degradation and breakdown of organic acids which leads to decrease in the overall acidity. There were slight differences in the TTA of the egg powders and the raw eggs (13.84 g/L) even though they were insignificant ($P > 0.05$). The insignificant differences observed in TTA could be due to the controlled drying process which does not involve chemical reactions or significant changes in the material's composition (Harnkarnsujarit et al., 2012). The phenomenon suggests that the drying process was successful in preserving the acid content of the food. This can be advantageous when maintaining the quality, stability, or functional property of food. The titratable acidity content of all the dried samples was appropriate for the extension of shelf-life of the egg powders since food product with titratable acidity values less than 1% or 10 g/L have been shown to have a longer storage life and excellent keeping quality (Dissanayake et al., 2017).

3.3 Effect of different drying methods on the color characteristics of egg powder

Drying at high temperature can have a significant impact on the quality of dried material; color change (Koc et al., 2010). Also, solar drying at a higher temperature can lead to Maillard browning between glucose and the amino acid present in the egg. All the egg powders and the raw egg recorded lower values (28.08 - 41.62) for lightness (L*) (Table 2).

Table 2. Color Characteristics of the Raw and various Egg Powder samples

Parameter/ Samples	Color coordinates L*	a*	b*
Raw egg	41.62 ± 0.02[a]	2.68 ± 0.03[a]	15.88 ± 0.03[a]
Freeze dried	34.27 ± 0.02[b]	0.51 ± 0.03[b]	13.29 ± 0.03[b]
Solar dried	28.08 ± 0.02[c]	0.91 ± 0.03[c]	5.74 ± 0.03[c]

Note: Values are expressed as mean ± standard deviation. Mean values in the same column with different superscripts are significantly different (P < 0.05). L* = Lightness, a* = redness/greenness, b* = yellowness/blueness

The degree of lightness decreased significantly (P < 0.05) from 41.62 for raw egg to 38.27 and 28.08 for freeze and solar dried egg powders, respectively. This reduction could be attributed to high temperature processing which has been found to reduce the lightness of food substances due to Maillard reaction as explained by Rannou et al. (2015). Again, Diamante et al. (2010) stated that drying at a higher temperature for longer time darkens the color of some food products. It is important to note that the color of egg yolk powder does not affect nutritional value, as it is not an indication of protein, fat, or carbohydrate content (Wenzel et al., 2010). However, food color influences consumer perception about the quality of the food, and their purchasing decision. Although Hutchings (2011) revealed that consumers are reluctant to accept inappropriately colored foods, many people favor deep colored foods because they associate it with high nutrition than lighter colored foods. As revealed in this present study, the raw egg was the lightest among the samples, the freeze-dried egg had a lighter color than the solar dried egg powder. The significant (P < 0.05) difference in the two egg powders can be ascribed to the differences in the drying temperature (40 °C) for freeze dryer and (65 to 70 °C) for solar dryer since drying at high temperatures for an extended period of time causes thermal decomposition or oxidation of pigmented compounds which contribute immensely to color changes in food (Engin, 2019; Sagrin & Chong, 2013). Comparatively, freeze drying method prevented color damage because it involved a controlled lower temperature and conversion of ice directly to vapor (Ali et al., 2016). The Lowest L* value recorded for the solar dried egg indicates that solar dried egg became darker during the drying process. This may be due to prolong drying time and presence of oxygen (Ali et al., 2016), with same darker observation made by Mnyandu (2014) for sun dried eggs. Solar drying involves vigorous heat application which can cause the development of non-enzymatic, caramelization and maillard reactions in the final product leading to a reduction in the L* value, which results in dark color formation (Zalpouri et al., 2021; Shende & Datta, 2019; Tontul & Topuz, 2017). Kumar and Sagar (2014) also reported freeze drying as the best method in terms of preservation of nutrients and color quality. As explained by Romano et al. (2012), light dispersion, scattering area, and surface area color pigment degradation caused by drying temperature and time influence color of food products, and therefore accounting for the observed variations in the freeze and solar dried powders since they were subjected to different processing temperatures and times. Although oxidation and evaporation of pigment during freeze-drying can contribute to decrease in lightness, it recorded a higher L* value compared to the solar dried sample which could be due to retention of carotenoids as well as prevention of browning reaction occurrence during the freeze-drying process (Orak et al., 2012).

Also, for red color (a*), both freeze dried (0.513) and solar dried egg (0.913) powders had values significantly ($P < 0.05$) lower than the raw egg (2.683). The reduction in redness for both dried samples could be attributed to depletion of carotenoid pigment responsible for the reddish coloration in egg (Bignardi et al., 2016; Song et al., 2020; Bi et al., 2022), caused by the different drying temperature in relation to time (40 ^{o}C for 12 hr) and (65 to 70 ^{o}C for 72 hr) for freeze and solar dryer, respectively. Again, the decrease in the yellowness (b*) of freeze dried egg powder was not very great as compared to solar dried sample, though there were significant ($P < 0.05$) differences between them and the raw egg (Table 2). The reduction in the yellowness could be attributed to the degradation of lutein or xanthophylls, which are responsible for the production of the yellow color in eggs, caused by the thermal process. According to Oliveira et al. (2015), the duration of drying is a primary factor affecting the preservation of a product's yellowness. The primary cause of yellowness change during drying is carotenoid degradation, non-enzymatic (Maillard reaction), enzymatic reaction or prolonged drying times (Akoy, 2014a; Deng et al., 2017). Egg white contains glucose; a reducing sugar, and an amino group which are known to undergo Maillard reaction during drying impacting yellowness of the egg powder (Hayuningtyas et al., 2022). The high degree of unsaturation of these carotenoids which give egg the yellow, orange or golden color makes them susceptible to oxidation and degradation during thermal drying, thus resulting in the loss of color (Topuz et al., 2011). The low-oxygen environment in the drying chamber during freeze drying inhibits oxidation of these compounds and thus preserves the yellowness in the dried product (Deng et al., 2018).

3.4 Effect of different drying methods on the proximate composition of egg powder

The moisture content of raw egg, freeze and solar dried egg powders were found to be 75.98, 2.32 and 6.70%, respectively. Generally, the moisture content of raw egg has been established as 75.4-76.90% (UK Department of Health, 2013) and 47.20-87.30% (Roe et al., 2013) depending on the egg type. The values obtained from this present study were found to be in the range of the reported values. There was a significant difference ($P < 0.05$) between the moisture content recorded for the various samples. The reduced amount of moisture recorded for the egg powders were expected since drying is found to reduce moisture content to appreciable level (Abbasi et al., 2009). Freeze dried egg powder had a significant ($P < 0.05$) reduction in moisture compared to solar dried, and this may be due to differences in the moisture removal efficiency of the different drying methods. Freeze drying is noted for efficient removal of moisture compared to solar dryer (Bhatta et al., 2020), and hence the observed variation. The rate of moisture removal of food product which influence the intensity of changes in quality attributes during different drying methods depends on the nature of material, pretreatment, drying process, type and parameters affecting color, shape, volume, density, texture, flavor, nutrients, water activity and rehydration ability. The moisture content of the freeze and solar dried egg powders were within acceptable levels (below 8.79%) for longer shelf-life stability and microbiological safety of commercial egg powders (Chávez et al., 2007; Olayemi et al., 2017; Nasir et al., 2003). Åkesson et al. (2016) established that proper storage is necessary to prevent biological activity through adequate drying to less than 10% moisture. This shows that both the freeze and solar dried egg powders if given safe or appropriate storage condition, the storage life can be extended for a long time.

The ash content recorded was 1.54% for the raw egg, 4.58% for freeze dried egg powder and 4.14% for solar dried egg powder. Although both freeze and solar dried egg powders had a significant increase in ash content compared to the raw egg, freeze dried egg powder recorded the highest. The differences in ash content could be attributed to the different drying mechanisms (Hosseinizand et al., 2018). Liu (2019) stated that, both dry temperature and duration affect ash contents measurement in products. Again, Asgar et al. (2022) revealed that longer time and higher drying temperature increases the ash content, because higher moisture loss from food sample results in concentration of minerals. The slight variation in the ash content of the dried samples may be due to uneven spread of minerals (Tolera & Abera, 2017). The ash values reported in this present study are in line with the ash content (4.81%) reported by Vaclavik et al. (2008) for egg powder. The high ash content of the egg powders is indicative of high mineral content since high ash content of food samples is associated with high amount of minerals.

The fiber content ranged from 0.09 to 0.18% for the raw egg and the egg powders (Table 3). There were no significant differences ($P > 0.05$) in the fiber content of the samples, indicating that freeze and solar drying have no effect on the fiber content of egg powder. Asghar and Abbas (2015) reported a fiber value of 1.01 which is higher compared to what was reported in this present study. Drying methods and origin of eggs could account for the disparities among the compared values.

Table 3. Proximate composition of raw egg, freeze and solar dried egg powders

Samples / Parameters (%)	Raw egg	Freeze dried egg	Solar dried egg
Moisture	75.98 ± 0.09^{a}	2.32 ± 0.03^{b}	6.70 ± 0.06^{c}
Ash	1.54 ± 0.055^{a}	4.58 ± 0.03^{b}	4.14 ± 0.02^{c}
Fiber	0.09 ± 0.01^{a}	0.18 ± 0.01^{a}	0.12 ± 0.01^{a}
Protein	10.62 ± 0.11^{a}	55.93 ± 0.11^{b}	54.40 ± 0.11^{c}
Fat	8.32 ± 0.62^{a}	29.49 ± 0.31^{b}	27.75 ± 0.21^{c}
Carbohydrate	2.21 ± 0.89^{a}	7.69 ± 0.02^{b}	7.03 ± 0.17^{c}
Energy	130.56 ± 2.30^{a}	519.83 ± 1.63^{b}	485.41 ± 0.75^{c}

Note: each value is presented as mean ± standard deviation. Means within a row with different superscripts are significantly different ($P < 0.05$).

The protein content of the samples was in the range of 10.62 to 55.93% (Table 3). Freeze dried egg powder recorded the highest protein value of 55.93%, followed by solar dried egg powder (54.40%) and fresh egg (10.62%). The protein content of raw egg in this study was lower than the 12.80–13.4% reported for whole egg by Sharif et al. (2018). The protein content of the freeze-dried egg powder was significantly ($P < 0.05$) higher than that of the solar dried egg powder, owing to the fact that, the side chain groups buried deep inside the protein molecules were exposed by freeze drying. The molecular flexibility was enhanced, and the unfolding and morphological change of the protein molecules at the interface was easier (Ulrichs et al., 2015). Maurya et al. (2018) stated that, protein content is influence by drying due to its heat prone properties, enzymatic degradation, and microbial metabolism that occurred during the drying process. The increase in protein content of the dried eggs compare to the raw egg could be as a result of protein homodimerization (Gao et al., 2012). Though proteins are usually susceptible to the processing conditions, it depends on the material species, variety, age, amino acid type, process method, the analyzed material, heat transfer mechanism and the material under treatment (Boye et al., 2012; Sun & Xia, 2010). With regards to the marketing and quality control of egg products, UNICEF requires that the minimum protein value of dried egg should be around 45%, which is in line with the protein content reported for the dried egg samples in this present study. The protein values reported in this current study, were higher than 44.30% and 45.10% reported for spray and the oven drying methods, respectively, by Cotterill et al. (1977). The variation could be attributed to the egg type and drying methods used. The amount of protein in the freeze and solar egg powders meet the UNICEF minimum requirement (45%) for commercial egg powders, which present market opportunity for these drying methods especially solar drying considering its cost effectiveness.

There was a significant ($P < 0.05$) increase in the fat content of the egg powders from 8.32% (raw egg) to 29.49% and 27.75% for freeze and solar dried egg powder, respectively. The difference in fat content of the powders and the raw egg could be ascribed to the drying process involved. Drying helps to remove moisture and cause porous structure in the food, which enhances fat extraction (Xiao et al., 2013). The disparity in the fat content of the freeze and solar dried egg powders can be owed to enhanced ability of the freeze drying technique in causing high cell disruption and disintegration which facilitate the release of fat for extraction and quantification as compared to the solar dryer (Show et al., 2021). The total fat recorded in this study did not exceed the 37.62% recommended by FAO/WHO (2016). The result obtained in this study was below 38.7 reported by Pirkwieser et al. (2022) and 36g/100 g and 39g/100g by Abreha et al. (2021). The cause of the differences could be associated with the type of feeding given to the chickens, type of breed, as well as the fat extraction method used (Cotterill et al., 1977).

The amount of carbohydrate ranged from 2.21 to 7.69% for the various samples (Table 3). Freeze dried egg powder had a slightly higher (7.69%) carbohydrate than the solar dried egg powder (7.03%), but both varied greatly from the raw egg (2.21%). Dehnad et al. (2016) revealed that higher drying temperatures decrease the swelling capacity of carbohydrates and increase their susceptibility to breakdown during hydrothermal processes. Malumbe et al. (2010) also stated that that temperatures deployed during drying process affect rigidity of carbohydrate granules which contributes to its breakdown. The difference in carbohydrate content in the dried egg sample could be attributed to the drying method and it effect on carbohydrate metabolism.

The energy content of raw egg, freeze and solar dried egg powder was found to be 130.56, 519.83 and 485.41 kcal, respectively. The variability in energy content of the various egg powders might result from the varying effect of the drying mechanisms on the parameters like carbohydrate, protein and fat which contribute large to energy content. Freeze dried egg powder had higher protein, fat and carbohydrate contents than the solar dried sample, hence the reason for the observed variation. The gross energy content of the freeze-dried sample was comparable to that of exotic egg powder (565 kcal) (spray dried) and local egg powder (579 kcal) produced using spray drying (Abreha et al., 2021).

3.4 Effect of different drying methods on mineral content of egg powder

The mineral contents in both dried egg powders were consistently higher than that in the raw egg (Table 4). While potassium (29.98 mg/kg), calcium (15.20 mg/kg), and magnesium (5.97 mg/kg) contents in the freeze dried egg were higher, iron (226.12 mg/kg), zinc (40.75 mg/kg), and phosphorus (1360 mg/kg) contents were however higher in the solar dried egg. There were observed significant differences (P < 0.05) among all samples when compared.

Table 4. Mineral compositions of raw egg, freeze and solar dried egg powders

Samples/ parameters (mg/kg)	Raw egg	Freeze dried egg	Solar dried egg
Potassium	0.59 ± 0.01[a]	29.98 ± 0.59[b]	27.25 ± 0.43[c]
Calcium	2.44 ± 0.63[a]	15.20 ± 0.20[b]	12.60 ± 0.10[c]
Magnesium	0.48 ± 0.32[a]	5.97 ± 0.19[b]	4.77 ± 0.15[c]
Iron	6.9 2± 0.20[a]	199.17 ± 20.82[b]	226.12 ± 20.96[c]
Zinc	1.42 ± 0.31[a]	35.33 ± 0.82[b]	40.75 ± 0.45[c]
Phosphorus	192.58 ± 0.18[a]	2465.70 ± 27.76[b]	1360.00 ± 19.72[c]

Note: each value is presented as mean ± standard deviation. Means within a row with different superscripts are significantly different (P < 0.05).

The potassium content observed in this study was higher than 834.00 mg/100g and 818.00 mg/100g reported by Abreha et al. (2021) for local and exotic egg powders respectively in Ethiopia, attributing the value obtained to the type, rearing system, and feeding habit of the layer chickens (Cotterill et al., 1977). The increase in the calcium content noted in this study could be as a result of the rupture of cells caused by the thermal process. The freeze dried egg reserved the highest amount of calcium because of the use of sublimation principle in drying the egg, a method known to best retain the minerals. Magnesium content obtained in this study was lower than 121.00 mg/kg and 42.60 mg/kg reported by Cotterill et al. (1977) for spray dried egg and oven dried egg, respectively. Nonetheless, the recorded values for magnesium in this study is sufficient enough to improve the immunity of both young and adult individuals. Again, the general iron content obtained in this study was higher than the 17 mg/kg and 7.80 mg/kg reported by Cotterill et al. (1977) for spray dried egg and oven dried egg, correspondingly. According to Daramola (2018), the reported values for the dried eggs in the present study is sufficient to improve the immune system of the body. The destruction of mineral cells due to thermal process can be attributed to general increase in zinc content observed in this study. The zinc content obtained in the study is adequate to aid in wound healing and immune system development (Daramola, 2018). Raw egg sample on the other hand had undergone no thermal process to cause a destruction to its cell structure, hence the observed low zinc content. Lastly, the general increase in phosphorus content in both freeze dried and solar dried eggs could be attributed to the heat application process such as the dryer design, drying temperature and time. The phosphorus content observed in this study nonetheless was higher than the 240.00 mg/kg reported by Abreha et al. (2021) using spray dryer, and the variability may be due to the drying method employed.

4. Conclusion

The different drying methods had a remarkable effect on nutritional and physico-chemical properties of the egg powder. In terms of physico-chemical properties, both freeze and solar drying methods had no effect on TTA, but freeze drying contributed significantly to an increase in TSS of the egg powder. All the drying methods caused a reduction in the color characteristics of the egg powder, however, freeze drying proved to have more color conservation effect than the solar dryer. The two drying methods recorded significant increases in protein, fat, carbohydrate and energy contents of the egg powders, though they were paramount in the freeze drying method. Both freeze and solar dried egg powders had comparable concentrations of K, Ca, Fe, Zn and Mg, indicating equal effects of freeze and solar drying methods on mineral composition. The freeze drying was more efficient in moisture removal, color preservation and maintaining high nutritional profile of the egg powder, and therefore has potential for commercial production of egg powder to promote food and nutrition security. Further studies should be conducted to determine the shelf-life, microbial stability, peroxide value, vitamin contents and functional properties of egg powders produced using freeze and solar drying methods.

Data availability

Data is available upon reasonable request from the corresponding author.

Conflict of interest

The authors have declared no conflicts of interest for this article.

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