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Full Length Research Article

PROXIMATE COMPOSITION AND SENSORY PROPERTIES OF WHOLE-WHEAT FLOUR AND CHICKEN EGG-BASED EXTRUDED SNACKS

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ABSTRACT
This paper aims to evaluate the proximate content and sensory quality of the extrudates from whole-wheat flour and chicken egg. The whole-wheat flour (WWF) and raw whole egg, WWF and raw egg yolk, WWF and raw egg albumen were mixed separately, extrusion of the samples was done in a twin-screw extruder. The samples were evaluated for proximate composition and sensory acceptance. Data analysis was carried out using one-way analysis of variance. Results indicated no statistically significant differences in overall acceptability among the egg-based products ($p > 0.05$). However, snacks containing egg yolk were generally more preferred, with acceptability further enhanced at 20% yolk substitution, while albumen reduced acceptability. The addition of chicken egg increased protein content (14.52–16.72%), decreased carbohydrate content (71.55–67.64%), and maintained low levels of fat (1.87–4.02%), ash (1.77–2.34%), and crude fibre (1.69–1.93%). These findings demonstrate that incorporating chicken egg into wheat-based extrudates improves protein density and yields a nutritious, sensory-acceptable snack.

Keywords: Sensory properties, lipids, cereals, proteins, chicken egg

INTRODUCTION

Snacks have become an important component of the human diet due to their widespread consumption worldwide (Adegunwa *et al*., 2017). However, the rising prevalence of diet-related diseases such as obesity, diabetes, and cardiovascular conditions has increased demand for more nutritious snack alternatives. Extrusion cooking has been widely applied in snack production because it allows for product flexibility, high efficiency, and the incorporation of functional ingredients (Uzun *et al*., 2025).

Snacking is nearly universal, particularly among children, but concerns have been raised about its contribution to excessive energy intake (Tugault-Lafleur & Polsky, 2024). The global snack food industry continues to expand, with puffed-extruded snacks valued at USD 51.59 billion in 2019 and projected to grow at 4% annually until 2026 due to evolving consumer habits and demand for ready-to-eat foods (Antwi *et al*., 2024). The United States remains the largest consumer of snack foods, followed by England, Germany, and France (Saldivar, 2016). Given this high consumption, improving the nutritional quality of snacks is crucial, particularly for populations that increasingly replace conventional meals with snack products. Many common snacks are high in fats, sugar, and refined carbohydrates, yet low in protein, fibre, and micronutrients, making them nutritionally inadequate (Tumuluru, 2016). Cereal-based snacks can be nutritionally enhanced by incorporating complementary protein sources. Although legumes are often used, eggs provide an excellent alternative as they are rich in first-class proteins and bioactive compounds. Eggs contain high-quality proteins in the albumen and antioxidant compounds in the yolk, and their inclusion in food products has been shown to improve both nutritional value and functional properties (Lesnierowski & Stangierski, 2018). Egg-based formulations are therefore considered functional foods (Patrignani et al., 2013).

Despite studies on wheat–egg-based extrudates (Singh *et al*., 2007; Stojceska *et al*., 2008; Zardetto & Rosa, 2009; Peng *et al*., 2022), there remains limited information on extruded snacks produced from whole-wheat flour enriched with fresh chicken egg. Developing such products may provide affordable, protein-rich, and acceptable snacks suitable for diverse population groups, including children, the elderly, pregnant women, and nursing mothers.

This study therefore aimed to evaluate the proximate composition and sensory quality of extruded snacks produced from whole-wheat flour supplemented with chicken egg, in order to determine their potential as nutritious alternatives to conventional cereal-based snacks.

MATERIALS

Four bags of 50 kg each of whole-wheat flour were purchased from Supreme Flour Mills, 6, President Burgers Street, Pretoria West 0183, Pretoria, South Africa. Thirty-two crates of thirty eggs each of freshly laid eggs were purchased from Northwest University farm, Mmabatho Unit 5, Mafikeng 2790, Mafikeng, South Africa.

METHODS

Egg whites were separated from the egg yolk for samples requiring either egg yolk or egg white using an egg separator. The whole-wheat flour and raw whole egg or raw egg yolk or raw egg white were mixed using a 50-litre paddle mixer constructed by Centre for Advanced Manufacturing (CFAM), Potchefstroom, South Africa, in different proportions (Table 1**)**. After mixing, extrusion of the samples was done in TX-32 Laboratory Scale (300 kg/h maximum) twin screw extruder made by CFAM. The extrusion was done in a batch size of 20 kg (using a Platform Scale, Model: Micro A12E in CFAM) per run for each of the samples and the extrusion parameters were constant for all the samples at a screw speed of 700 rpm, feed rate of 53.6 – 78.9 kg/h (50 – 60 %) driven by a 6 – 9.7 kW motor, 20.8 – 24.1 AMP, 50 – 55 % Torque, temperature of 139 – 153 ^{o}C and 20 % feed moisture content. Each run lasted 14.22 – 15.02 minutes. A spaghetti die of 1.8 mm (2 rings) with a 40 – 60 % cutter was used in each run. The samples were evaluated for proximate composition (AOAC 2010), using standard methods and sensory acceptance using fifteen man semi-trained

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panel members made up of staff and students of the Department of Food Science and Technology. The evaluation was by assessing the degree of preference of the different samples in terms of colour, texture, appearance, flavour, taste and overall acceptability using a 9-point Hedonic scale where 9 represented like extremely and 1 represented dislike extremely (Iwe 2002).

Data Analysis

Data analysis was carried out using one-way analysis of variance (ANOVA) in a completely randomized design (CRD); mean separation was by Duncan's New Multiple Range Test (Steel and Torrie 1980). Significance was accepted at $p<0.05$.

Table 1: Ingredient combinations for products

Sample	Ratio (whole wheat flour to chicken egg)	whole wheat flour (kg)	Chicken egg (kg)	Total quantity (kg)
RI (Whole wheat flour)	100:0	20	0 (no egg)	20
R2 (Whole wheat flour and raw whole egg)	85:15	17	3 (60 whole eggs)	20
R3 (Whole wheat flour and raw whole egg)	80:20	16	4 (80 whole eggs)	20
R4 (Whole wheat flour and raw egg yolk)	85:15	17	3 (187.5 egg yolks)	20
R5 (Whole wheat flour and raw egg yolk)	80:20	16	4 (250 egg yolks)	20
R6 (Whole wheat flour and raw egg white)	85:15	17	3 (81 egg whites)	20
R7 (Whole wheat flour and raw egg white)	80:20	16	4 (108 egg whites)	20

Calculation used above: One whole egg = 50g, one egg white = 37g, one egg yolk =16g

RESULTS

Table 2: Proximate composition (%) of egg-based wheat snacks

Samples	Moisture	Protein	Fat	Ash	Crude fibre	Carbohydrate
WWF	$8.00^{a}\pm0.00$	$15.10^{d}\pm0.07$	$1.99^{c}\pm0.03$	$1.77^{f}\pm0.02$	$1.69^{a}\pm0.01$	$71.46^{a}\pm0.13$
R1	$8.50^{a}\pm0.71$	$15.12^{d}\pm0.02$	$1.93^{c}\pm0.09$	$2.02^{c}\pm0.04$	$1.67^{a}\pm0.04$	$70.78^{a}\pm0.64$
R2	$8.50^{a}\pm0.71$	$16.63^{b}\pm0.02$	$3.08^{b}\pm0.04$	$2.24^{b}\pm0.04$	$1.72^{a}\pm0.01$	$67.85^{b}\pm0.77$
R3	$8.50^{a}\pm0.71$	$16.72^{a}\pm0.01$	$2.94^{b}\pm0.07$	$2.34^{a}\pm0.01$	$1.68^{a}\pm0.01$	$67.83^{b}\pm0.64$
R4	$8.50^{a}\pm0.71$	$16.21^{c}\pm0.01$	$4.02^{a}\pm0.18$	$1.94^{de}\pm0.06$	$1.68^{a}\pm0.03$	$67.66^{b}\pm0.91$
R5	$8.50^{a}\pm0.71$	$16.24^{c}\pm0.04$	$3.95^{a}\pm0.24$	$1.99^{cd}\pm0.01$	$1.67^{a}\pm0.01$	$67.64^{b}\pm0.42$
R6	$8.50^{a}\pm0.71$	$14.52^{e}\pm0.01$	$1.93^{c}\pm0.08$	$1.82^{f}\pm0.01$	$1.69^{a}\pm0.04$	$71.55^{a}\pm0.61$
R7	$9.00^{a}\pm0.00$	$14.56^{e}\pm0.02$	$1.87^{c}\pm0.14$	$1.90^{e}\pm0.02$	$1.71^{a}\pm0.03$	$70.97^{a}\pm0.11$

Results are means of three replicates. Means with the same superscript in the same column are not significantly different ($p>0.05$). WWF=whole wheat flour, R1 - (100 % WWF), R2 - (85 % WWF and 15 % raw whole egg), R3 - (80 % WWF and 20 % raw whole egg), R4 - (85 % WWF and 15 % raw egg yolk), R5 - (80 % WWF and 20 % raw egg yolk), R6 - (85 % WWF and 15 % raw egg white), R7- (80 % WWF and 20 % raw egg white)

Table 3: Sensory scores of extrudates

Sample	Colour	Taste	Appearance	Mouthfeel	Texture	Overall acceptability
R 1	$4.8^{a} \pm 1.66$	$4.6^{a} \pm 1.59$	$4.87^{a} \pm 1.46$	$3.93^{ab} \pm 1.10$	$4.80^{a} \pm 1.47$	$5.00^{a} \pm 1.07$
R 2	$6.13^{b} \pm 1.06$	$4.6^{a} \pm 1.40$	$5.73^{a} \pm 1.28$	$4.53^{b} \pm 1.25$	$5.40^{a} \pm 1.50$	$5.20^{a} \pm 0.77$
R 3	$5.73^{ab} \pm 1.28$	$4.47^{a} \pm 1.13$	$5.60^{a} \pm 1.24$	$4.20^{ab} \pm 0.86$	$5.00^{a} \pm 1.65$	$4.93^{a} \pm 1.10$
R 4	$6.13^{b} \pm 1.25$	$4.67^{a} \pm 1.76$	$6.13^{a} \pm 1.13$	$4.53^{b} \pm 1.46$	$5.40^{a} \pm 1.45$	$5.53^{a} \pm 1.19$
R 5	$6.07^{b} \pm 1.39$	$4.80^{a} \pm 1.78$	$6.07^{a} \pm 1.79$	$5.00^{b} \pm 2.00$	$5.87^{a} \pm 1.46$	$5.67^{a} \pm 1.35$
R 6	$6.00^{b} \pm 1.07$	$4.53^{a} \pm 1.25$	$6.00^{a} \pm 1.36$	$4.33^{b} \pm 0.90$	$4.87^{a} \pm 1.55$	$5.20^{a} \pm 1.37$
R 7	$6.07^{b} \pm 1.53$	$3.73^{a} \pm 1.91$	$5.60^{a} \pm 2.20$	$3.20^{ab} \pm 1.74$	$4.73^{a} \pm 2.34$	$4.87^{a} \pm 1.60$

Means with the same superscript in the same column have no significant difference ($p>0.05$). WWF=whole wheat flour, R1 - (100 % WWF), R2 - (85 % WWF and 15 % raw whole egg), R3 - (80 % WWF and 20 % raw whole egg), R4 - (85 % WWF and 15 % raw egg yolk), R5 - (80 % WWF and 20 % raw egg yolk), R6 - (85 % WWF and 15 % raw egg white), R7- (80 % WWF and 20 % raw egg white)

DISCUSSION

The protein content of extruded egg-based wheat snacks

Table 2 shows the protein content of the extruded egg-based wheat snacks. Whole-wheat flour has been shown to contain about 15 % protein. This is in agreement with the 15 % protein reported by Cornell (2012) and 14.7 % reported by Ocheme *et al*. (2018). When extruded (R1) the protein content was still shown to be about 15.12 ± 0.02 %. The similarity in protein contents seems to be due to the similarity in moisture content (Table 2) which did not change on extrusion. Substitution of whole-wheat flour with various levels of raw egg increased the protein contents on extrusion. This is in agreement with the report of Surai and Sparks (2001) that the

nutritive value of an egg is high such that it enhances the nutritive value of foods in which it is incorporated. Thus, the extrusion of whole-wheat flour substituted with 15 % raw whole egg led to increasing of the protein content to 16.63 %. Similar increases were observed with the substitution of whole-wheat flour with 20 % raw whole egg, 15 % and 20 % raw egg yolk. Also, the higher the egg content, the higher the protein content in the extruded products (16.63 % in products containing raw whole egg and 16.72 % in product containing 20 % raw whole egg). However, substitution with raw egg white appeared to reduce the protein content in the extruded products. For example, compared with R1 (which contained no egg and which had 15.12 ± 0.02 % crude protein, R6 (which contained 15 % raw egg white) had a protein content of 14.52 ± 0.01 % while R7 (which contained 20 % egg white) had protein content of 14.56 ± 0.02 %. The dilution effect is attributed partly to the fact that raw egg white contains proportionately lower protein compared to raw whole egg and raw egg yolk. It is known that raw chicken egg contains about 12 % protein while egg yolk contains 50 % of this 12 %, and egg white contains about 40 % (Zhu *et al*., 2018).

The fat content of extruded egg-based wheat snacks

The fat content of the extruded egg-based wheat snacks is shown in Table 2. Significant ($p<0.05$) differences were observed between the products. The fat content of WWF (1.99 %), R1 (1.93 %), R6 (1.93 %) and R7 (1.87 %) was not significantly ($p>0.05$) different from one another. The similarity between these in fat content is attributed to the fact that egg white (used in substituting whole-wheat flour) does not contain fat; therefore, the fat contained in R6 and R7 was from whole-wheat flour.

These values for fat content are similar to the value (2.10 %) reported by Ocheme *et al*. (2018). The addition of whole egg or egg yolk increased the fat content of R2 to R5. However, R4 (4.02 %) and R5 (3.95 %) contained higher fat content compared to R2 (3.08 %) and R3 (2.94 %). This may be attributed to the high-fat content in egg yolk compared with whole egg. The fat content of raw whole egg and raw egg yolk amount to 11.0 and 32.5 % (Vaclavik and Christian 2008) respectively in the whole chicken egg. R2 and R4 contained 15 % of whole egg and egg yolk respectively while R3 and R5 contain 20 % of whole egg and egg yolk, respectively.

The ash content of extruded egg-based wheat snacks

The ash contents of the extruded egg-based wheat snacks are shown in Table 2. The ash content of whole-wheat flour was shown to be 1.77 ± 0.02 %. On extrusion, the ash content significantly ($p<0.05$) increased (2.02 ± 0.04 %). The incorporation of whole egg and egg yolk further increased the ash content in the extruded snacks. The values obtained are similar to 2.10 % reported by Ocheme *et al*. (2018). Substitution of the whole-wheat flour with 15 % and 20 % egg white diluted ash content in the extruded products significantly ($p<0.05$). This dilution effect is attributed partly to the higher moisture content of egg white and partly to the fact that egg white contains less ash compared to egg yolk and whole egg. The ash content of the whole egg, egg white and yolk amount to 11.0, 0.2 and 2.0 % (Vaclavik and Christian 2008), respectively in the raw chicken egg.

The crude fibre content of extruded egg-based wheat snacks

The crude fibre content of the extruded egg-based wheat snacks is shown in Table 2. The crude fibre of the whole-wheat flour has been shown to be 1.69 ± 0.14 %. This is similar to the crude fibre content of 1.86 ± 0.92 % to 1.94 ± 0.87 % (Bashir *et al*., 2017). On extrusion, the crude fibre slightly reduced to 1.67 ± 0.04 % due to, presumably thermally induced hydrolysis. The values obtained from the extruded products did not significantly ($p>0.05$) differ from each other. Substitution of whole-wheat flour with raw whole egg, raw egg yolk and raw egg white did not appear to influence the crude fibre content of the extruded snacks probably because the egg does not contain crude fibre; therefore, the crude fibre values in the products were contributed entirely by the whole-wheat flour. The importance of fibre in the diet and human nutrition cannot be overemphasized as it is known to be beneficial to bowel movement in addition to other benefits. Whole-wheat is much sought after because of its fibre content.

The carbohydrate content of extruded egg-based wheat snacks

The carbohydrate content of the extruded egg-based snack products is shown in Table 2. The whole-wheat flour contained 71.46 ± 0.13 % carbohydrates. Ocheme *et al*. (2018) reported a higher (78.73 %) carbohydrate content in whole-wheat flour. There were no significant ($p>0.05$) differences in the carbohydrate contents of the extruded egg-based snacks. Substitution of whole-wheat flour with raw egg products reduced the carbohydrate contents of the products presumably due to heat-induced oxidation of sugars. Also, the addition of raw whole egg, raw egg yolk and raw egg white did not appear to influence the carbohydrate contents of the extruded products because the egg does not contain an appreciable quantity of sugars. Therefore, carbohydrate contents obtained in this study were supplied entirely by wheat. Carbohydrate is important in the diet and human nutrition. It is the main supplier of energy for the growth and maintenance of the human body.

Sensory scores of the extruded egg-based whole-wheat snacks

Table 3 shows the sensory score of the extruded egg-based wheat snacks. The colour scores of the products show that the extruded egg-based whole-wheat snacks containing whole-wheat only (R1) had significantly ($p<0.05$) the least desirable colour (4.8 ± 1.16). Substitution of whole-wheat with egg improved the colour desirability of all subsequent products (R2 - R7). The colour desirability improved due to the protein and lipid contents of whole egg and egg yolk which were involved in the Maillard browning reactions leading to the development of desirable brown colour. However, the differences in colour of the products containing various proportions of eggs were not significant ($p>0.05$).

Products containing higher proportions (20 %) of egg (R3, R5 and R7) scored slightly lower in colour compared to the corresponding products containing lower (15 %) quantities of egg (R2, R4 and R6) due to the darker brown colour in samples containing more egg. A product containing 15 % egg yolk (R4) scored the highest in colour. The colour of a food is very important as an eating quality parameter. It is the first and instant indicator of quality. Consumers expect a food of certain colour to possess an expected quality characteristic. This is why it seemed that the colour of the extruded products influenced other sensory parameters of the products because as shown in Table 3, R4 and R5 which contained egg yolk substitutes and which scored highest in colour also ranked highest in other sensory parameters as well as overall acceptability.

The trend in colour scores is also similar to that of appearance

(Table 3) which showed that the product containing 15 % of egg yolk (R4) had the most desirable appearance (6.13 ± 1.13) while the product containing whole-wheat alone (R1) had the least desirable appearance (4.87 ± 1.46). Colour and appearance have a significant ($p<0.05$) correlation ($r = 0.894$) showing that both are evaluating similar sensory phenomenon of how the eyes evaluate/ see a product. It also shows that an increase in the desirability of colour would be expected to lead to increasing in the desirability of appearance.

The scores for taste (as shown in Table 3) indicate that the differences in the tastes between products were not significant ($p>0.05$). Although no significant differences in taste could be established between products, the products containing egg white (R6 and R7) were least in scores, apparently because lipids which enhance taste/ flavour of food is absent in egg white and the higher quantity of egg white in the products, the lower the desirable taste due to dilution from egg white. This is why R1 products containing whole-wheat alone (with 1.93 % lipid in the whole-wheat) scored higher in taste (4.6 ± 1.4) compared to R6 products containing 15 % egg white (with 0 % lipid in the raw egg white) scoring 4.5 ± 1.25 and the product containing 20 % egg white (R7) diluting the taste further to 3.73 ± 1.9. The presence of egg yolk caused the development of a more desirable taste (R2 - R5) and the more egg yolk in the products, the better the score. This is why R5 containing 20 % egg yolk substitute had the highest colour scores (4.80 ± 1.78) followed by R4 (containing 15 % egg yolk substitute) with a score of 4.67 ± 1.76.

Table 3 shows the scores for the mouthfeel of the extruded egg-based whole-wheat snacks samples containing whole-wheat alone (R1), which had a score of 3.93 ± 1.11. Although, there were no significant differences ($p>0.05$) in the mouthfeel of the products, the inclusion of egg in the mix increased the mouthfeel desirability because products containing egg scored slightly higher than R1 which had whole-wheat only. Snack products containing egg yolk (R4 and R5) showed higher scores than products containing egg white (R6 and R7) or whole egg (R2 and R3) because the lipid components of the yolk would have increased the creaminess and flavour of the product. Furthermore, products containing 15 % egg had slightly more desirable mouthfeel than corresponding products containing 20 % egg (except for products containing egg yolk (R4 and R5) where products containing 20 % egg yolk (R5) had a more desirable mouthfeel compared to that which contains 15 % yolk (R4). This has been attributed to higher lipid content for products containing yolk which made the products creamier and flavourful. Mouthfeel had a significant ($p<0.05$) correlation ($r = 0.908$) with taste showing that an increase in desirable mouthfeel should be expected to increase the taste to the same degree.

The texture scores of the extruded egg-based wheat snacks shown in Table 3 did not indicate significant differences ($p>0.05$) in texture between products. However, products containing eggs were slightly higher in texture desirability compared to those containing whole-wheat only (the exception are products containing egg white which were lower than those containing only whole-wheat). Furthermore, products containing 15 % whole egg and egg white had higher texture desirability than those containing 20 % whole egg and egg white. On the contrary, those containing 20 % egg yolk (R5) had a higher desirable texture probably because of the larger amount of lipid in egg yolk that would have acted as a shortening and emulsifying agent all of which could have impacted on texture. Products containing whole eggs were next in desirability because of the presence of yolk in a whole egg which also contained a reasonable amount of lipids. The lower desirability of products containing 20 % egg white could be attributed to the absence of yolk (and its lipids). Hence, in terms of desirability, products containing 20 % egg white performed worse than R1 containing no egg. The texture is significantly ($p<0.05$) correlated with mouthfeel ($r = 0.858$) and taste ($r = 0.650$) suggesting that both are controlled by the same factors which are likely to be the amount of lipid in the products. It also showed that as the desirability of one parameter increases, the desirability of others also increases.

Table 3 shows that the differences in the overall acceptability of the egg-based wheat products were not significant ($p>0.05$). However, products containing egg yolk were more acceptable than others. An increase in egg to 20 % substitution (R5) increased further the overall acceptability. The lower score of 4.87 for R7 (containing 20 % egg white) suggests that egg white reduced the overall acceptability of products. Overall acceptability was significantly ($p<0.05$) correlated with appearance ($r = 0.689$), mouthfeel ($r = 0.841$) and texture ($r = 0.883$) suggesting that these three parameters influenced overall acceptability and as they increase in desirability overall acceptability is also expected to increase.

Conclusion

The incorporation of chicken egg into whole-wheat flour significantly improved the nutritional quality of the extruded snacks, particularly by enhancing protein content and increasing ash levels. While egg substitution did not markedly affect crude fibre or carbohydrate levels, egg yolk contributed higher fat and protein values than whole egg or albumen. Sensory evaluation revealed that the inclusion of egg, especially yolk, enhanced colour, appearance, taste, and overall acceptability. Overall acceptability was strongly associated with appearance, mouthfeel, and texture, indicating that these attributes drive consumer preference.

In conclusion, extruded snacks formulated from whole-wheat flour and chicken egg offer a nutritious and acceptable product with potential application as a high-protein, egg-based cereal snack. It is strongly encouraged that chicken egg is added to whole-wheat flour extrudates which will enhance the nutritive value and sensory attributes.

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REFERENCES

Adegunwa, M. O., Omolaja, N. O., Adebowale, A. A. and Bakare, H. A. (2017). Quality Evaluation of Snacks Produced from Blends of Unripe Plantain, Bambara Groundnut and Turmeric Flour. *Journal of Food Processing and Preservation*, 41(1). John Wiley & Sons, Ltd (10.1111): 12760. DOI: 10.1111/jfpp.12760.

Antwi, C. K., Rosa-Sibakov, N. and Emmambux, M. N. (2024). Impact of added enzyme-treated bran on the techno-functional properties of puffed-extruded sorghum snack. *Journal of Cereal Science*, 120: 104051. https://doi.org/https://doi.org/10.1016/j.jcs.2024.104051.

Anyika, J. U., Obizoba, I. C. and Nwamarah, J. U. (2009). Effect of Processing on the Protein Quality of African Yambean and Bambara Groundnut Supplemented with Sorghum or Crayfish in Rats. *Pakistan Journal of Nutrition*, 8(10): 1623–1628. DOI: 10.3923/pjn.2009.1623.1628.

AOAC (2010). Official methods of analysis of the association of official analytical chemists. 18th Edition. Gaithersburg.

Bashir, K., Swer, T. L., Prakash, K. S. and Aggarwal, M. (2017). Physico-chemical and functional properties of gamma irradiated whole wheat flour and starch. *LWT - Food Science and Technology*, 76: 131–139. http://dx.doi.org/10.1016/j.lwt.2016.10.050

Bawa, A. S. and Sidhu, J. S. (2003). Snack foods: Range on the Market. In: Caballero B (ed.) Encyclopedia of Food Sciences and Nutrition (Second Edition). Oxford: Academic Press, pp. 5322–5332. DOI: https://doi.org/10.1016/B0-12-227055-X/01096-8.

Cornell, H. J. (2012). The chemistry and biochemistry of wheat. In: S. P. Cauvain (Ed.), Breadmaking: Improving quality (2nd edition) pp. 35–76. http://dx.doi.org/10.1533/9780857095695.1.35.

De Vlieger, N. M., Collins, C. and Bucher, T. (2017). What is a nutritious snack? Level of processing and macronutrient content influences young adults' perceptions. Appetite 114. Elsevier Ltd: 55–63. DOI: 10.1016/j.appet.2017.03.021.

Hess, J. M. and Slavin, J. L. (2018). The benefits of defining "snacks". Physiology and Behavior 193. Elsevier Inc: 284–287. DOI: 10.1016/j.physbeh.2018.04.019.

Iwe, M. O. (2002). Handbook of Sensory Methods and Analysis. Rojoint Communication Services Ltd. Enugu.

Lesnierowski, G. and Stangierski, J. (2018). What's new in chicken egg research and technology for human health promotion? - A review. *Trends in Food Science and Technology*, 71: 46–51. DOI: 10.1016/j.tifs.2017.10.022.

Ocheme, O. B., Adedeji, O. E., Chinma, C. E., Yakubu, C. M. and Ajibo, U. H. (2018). Proximate composition, functional, and pasting properties of wheat and groundnut protein concentrate flour blends. *Food Science and Nutrition*, 6: 1173–1178. DOI: 10.1002/fsn3.670.

Patrignani, F., Vannini, L., Kamdem, S. L. S., Hernando, I., Marco-Molés, R., Guerzoni, M. E. and Lanciotti, R. (2013). High pressure homogenization vs heat treatment: Safety and functional properties of liquid whole egg. Food Microbiology 36(1): 63–69. DOI: https://doi.org/10.1016/j.fm.2013.04.004.

Peng, J., Zhu, K-X., Guo, X-N. and Zhou, H-M. (2022). Egg white protein addition induces protein aggregation and fibrous structure formation of textured wheat gluten. Food Chemistry 371: 131102, https://doi.org/10.1016/j.foodchem.2021.131102.

Saha, T., Singh, M. K., Rai, D. C. and Kumar, A. (2025). HR-MS-based bioactive profiling of green Banana flour and millets-based Murukku snack. *Food and Humanity*, 100511. https://doi.org/https://doi.org/10.1016/j.foohum.2025.100511.

Saldivar, S. O. S. (2016). Snack Foods: Types and Composition. In: Reference Module in Food Science: Encyclopedia of Food and Health. Elsevier Ltd., pp. 13–18. DOI: 10.1016/B978-0-12-384947-2.00633-4.

Singh, S., Wakeling, L. and Gamlath, S. (2007). Retention of essential amino acids during extrusion of protein and reducing sugars. *Journal of Agricultural and Food Chemistry*, 55(21): 8779–8786, DOI: 10.1021/jf071769z

Steel, G. D. and Torrie, J. H. (1980). Principles and Procedures of Statistics: A Biometrical Approach 2nd Edition. McGraw-Hill Book Company Inc. New York.

Stojceska, V., Ainsworth, P., Plunkett, A., Ibanoğlu, E. and Ibanoğlu, Ş. (2008). Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. *Journal of Food Engineering*, 87(4): 554–563, DOI: 10.1016/j.jfoodeng.2008.01.009

Surai, P. F. and Sparks, N. H. C. (2001). Designer eggs: from improvement of egg composition to functional food. *Trends in Food Science and Technology*, 12(1): 7–16. https://doi.org/10.1016/S0924-2244(01)00048-6.

Tugault-Lafleur, C. N. and Polsky, J. Y. (2024). Temporal snacking patterns among Canadian children and adolescents. *Applied Physiology Nutrition and Metabolism*, 49(10): 1353–1362. https://doi.org/https://doi.org/10.1139/apnm-2024-0059.

Tumuluru, J. S. (2016). Snack Foods: Role in Diet. In: Reference Module in Food Science: Encyclopedia of Food and Health. Elsevier Ltd, pp. 6–12. DOI: 10.1016/B978-0-12-384947-2.00632-2.

Uzun, D. E., Nemli, E., Apak, R., Bener, M., Tomas, M., Yağcı, S. and Capanoglu, E. (2025). Starch-based composite formulation of chickpea flour and black carrot (Daucus carota l.) pomace in extruded snacks: In vitro gastrointestinal behavior and stability of bioactive compounds. *International Journal of Biological Macromolecules*, 293: 139075. https://doi.org/https://doi.org/10.1016/j.ijbiomac.2024.139075.

Vaclavik, V. A. and Christian, E. W. (2008). Essentials of food science. (3rd edition) In: Springer, Springer Science+Business Media, LLC., 233 Spring Street, New York, NY 10013, USA. ISBN: 9780387699394.

Valverde, D., Laca, A., Estrada, L. N., Paredes, B., Rendueles, M. and Díaz, M. (2016). Egg yolk fractions as basic ingredient in the development of new snack products. *International Journal of Gastronomy and Food Science*, 3: 23 – 29, DOI: 10.1016/j.ijgfs.2016.02.002

Wadhera, D. and Wilkie, L. M. (2018). College-aged men view more foods as snacks than women do. *Food Quality and Preference*, 69: 53–56. DOI: 10.1016/j.foodqual.2018.05.008.

Zardetto, S. and Rosa, M. D. (2009). Effect of extrusion process on properties of cooked, fresh egg pasta. *Journal of Food Engineering*, 92(1): 70–77. DOI: 10.1016/j.jfoodeng.2008.10.027

Zhu, Y., Vanga, S. K., Wang, J. and Raghavan, V. (2018). Impact of food processing on the structural and allergenic properties of egg white. *Trends in Food Science and Technology*, 78: 188–196. https://doi.org/10.1016/j.tifs.2018.06.005.