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EFFECT OF CITRUS POMACE AND CHICKPEA ON PHYSICOCHEMICAL, BIO-FUNCTIONAL AND ORGANOLEPTIC PROPERTIES OF CORN EXTRUDATES

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Abstract

Ready-to-eat snacks are more popular among the consumers. They are energy-dense but lack of protein and micronutrients. Therefore, this study was planned to develop the corn extrudates with the simultaneous addition of citrus pomace and chickpea (0-20%). Results showed that dietary fiber and protein contents of supplemented extrudates were increased by 4.04 and 1.04 times, respectively than the control samples. Moreover, bulk density, water absorption and water solubility index were increased by 14.42%, 25.99% and 47.77%, respectively compared to non-supplemented samples. However, the expansion ratio and porosity were decreased by 0.85 and 0.58 times, than the control sample. Likewise, the bio-functional characteristics of extrudates i.e. total phenolic contents (TPC) and ABTS were increased by 1.28 and 3.52 times, respectively. Furthermore, organoleptic properties results revealed that corn extrudates of up to 5% citrus and chickpea in each addition were best among the treatments. Therefore, citrus pomace and chickpeas can be employed to develop healthy and appetizing extrudates, contributing to food waste management, and mitigating malnutrition.

Keywords: Extrudates, Citrus, Chickpea, Antioxidant, Ready to Eat

1. INTRODUCTION

The market progress of extruded products is constantly growing in the context of modern consumer habits, driven by sensory characteristics such as taste, texture, palatability and acceptance [1]. The extruded products market is projected to reach an estimated 333.12 USD billion by 2027. The global market of extruded products demonstrated a 7.9% increase in 2023 as compared to 2022 (Market Research Report, 2023).

Extruded products are very popular among consumers of all age groups due to their wide availability, taste and acceptability. These products are prepared by extrusion process of starchy ingredients such as rice, corn or wheat [2]. The extrusion process involves the cooking of material at high temperatures for a short time, along with mixing and shaping to produce a variety of products [3]. It is a versatile, low-cost, energy-efficient and environment-friendly processing technique for developing cereal-based puffed snacks with consumer appeal [4]. The quality of extruded products depends upon the feed composition, barrel temperature, feed moisture, screw speed etc [4-6].

Extrusion offers different advantages such as anti-nutritional factors, attainment of specific physical structure, enhanced shelf stability, and increased palatability and digestibility of nutrients in the extrudate [7, 8].

These extruded products are mainly prepared from corn grits, rice starch or wheat starch. They possess all the desirable characteristics for the production of extrusion-based products with high acceptability. However, these products are nutritionally poor due to the lower content of essential nutrients such as protein (essential amino acid), mineral, polyphenol and dietary fiber [9].

Thus, there is a need to add these macro and micro nutrients to increase the nutritional profile of extrudates. Among various solutions, value addition of fruits and vegetables by-products is considered. These by-products are abundant sources of fiber, minerals and antioxidants and may include the pomace of citrus, apple, and grapes.

Among them, citrus pomace is a rich source of fiber and is underutilized in Pakistan. It contains different bioactive compounds such as flavones (hesperidin, naringenin), phenols (coumaric, ferulic and caffeic) and essential oils (monoterpenes and triterpenoids) [10, 11]. Citrus pomace is a by-product of citrus juice production and has dietary fiber contents (54.82-82.22 g/100g) including soluble dietary fibers (13.42-25.17g/100g) and insoluble dietary fibers (29.65-68.80 g/100g) [12, 13]. It also contains carotenoids such as lutein, beta-caroteone, zeaxanthin, alpha-carotene and beta-cryptoxanthin [14, 15]. These compounds make it suitable for use in the development of nutrient-dense food products.

Legumes are 2nd most vital human food source after cereals. They are sources of protein (20-40%), dietary fiber, minerals, vitamins and polyphenols [16]. Chickpea is the most vital legume of the sub-continent. It contains, protein (20-22%), dietary fiber (29.26%) and minerals such as Fe 5mg/100g, Zn 4.1mg/100g, Mg 138mg/100g and Ca 160mg/100g [17]. The protein quality of chickpeas is superior to that of other legumes *i.e.,* green gram, pigeon pea and black gram [18].

It can be used for the preparation of protein-enriched extrusion- products [9]. The combined effect of citrus pomace and chickpea to replace the corn grits during extrusion has not been reported in the literature, to the best of our knowledge. Therefore, the current study was designed to develop fiber and protein-enriched corn extrudates. Additionally, the effect of citrus pomace and chickpea incorporation on physiochemical, antioxidant and organoleptic properties attributes were assessed.

2. MATERIALS AND METHODS

2.1 Procurement of raw material

Citrus pomace was collected from local processors in Faisalabad, Pakistan. Chickpeas (*Cicer arietinum*) were purchased from Ayub Agriculture Research Institute, Faisalabad, Pakistan. Chemicals and reagents of analytical grade were used (Merck and Sigma Aldrich, Germany).

2.2 Preparation of raw material

Citrus pomace was dried in a hot air dryer at 80 ℃ for 48 hours and ground to a fine powder using an electric grinder. Chickpeas were cleaned and ground to obtain powder. Subsequently, the powders were passed through sieves to achieve a uniform particle size (<300µm).

2.3 Extrusion process

Fiber and protein-enriched extrudates were prepared using a twin-screw extruder LT70 (L/D = 28) with a barrel diameter of 50 mm. The screw consisted of two equal sections with a flight of 60 mm and 24 mm, maintaining a uniform channel depth (15 mm) and pitch angle (10°). The corn-based extrudates were enriched with varying levels of protein (chickpea) and fiber (citrus pomace) to increase the nutritional profile (Table 1). Initial trials were conducted to optimize the operational parameters of the extruder. The extruder was operated at a feed rate of 30 Kg/h, screw speed (110rpm) and barrel temperature (150°C). A 5 mm die was used, and extrudates were cut by a rotating knife [12]. The extrudates were collected on the trays and packed in polythene bags, then placed at room temperature for further study.

Table 1: Preparation of fiber and Protein enriched corn extrudates

Treatments	Corn grits (%)	Citrus pomace powder (%)	Chickpea powder (%)
T_0	100	0	0
T_1	90	5	5
T_2	80	10	10
T_3	70	15	15
T_4	60	20	20

2.4 Chemical composition of extrudates

The chemical composition of extrudates was measured using the prescribed method with slight modifications [12]. Moisture contents were calculated after drying extrudate samples in a hot air oven at 105℃ for 24 hours. Fat contents were measured using Soxhlet extraction with n-hexane. Similarly, the Kjeldahl apparatus was employed for the determination of crude protein after digesting the samples in sulfuric acid. Ash contents were measured using a muffle furnace at 600℃ for 5 h.

2.5 Techno-functional properties

2.5.1 Bulk Density (BD)

BD of extrudates was measured using 10 random measurements of length (L in cm) and diameter (D in cm) through Vernier calliper (Mitutoyo, Japan), while the mass of extrudates was measured (m in g) by analytical balance (Ohaus Corporation, USA). Subsequently, BD was calculated by the following equation,

$$\mathrm{BD} = \frac{4\mathrm{m}}{\pi \mathrm{D}^2 \mathrm{L}} \quad (1)$$

2.5.2 Expansion ratio

Extrudate diameter was determined using a Vernier calliper (Mitutoyo, Japan) and repeated 5 times for each treatment. Finally, the mean expansion ratio of the sample was obtained by following equation [19].

$$\text{Expansion Ratio} = \frac{\text{Diameter of extrudates}}{\text{Diameter of die}} \quad (2)$$

2.5.3 Porosity

Porosity of extrudates was determined using given equation

$$\text{Porosity} = \frac{\text{Bulk volume} - \text{apparent volume}}{\text{Bulk volume}} \quad (3)$$

Likewise, bulk and apparent volume were determined using the suggested method [12].

2.5.4 Water Absorption Index (WAI) and Water Solubility Index (WSI)

The extrudate sample (1g) and 10 mL of distilled water were added to centrifuge tubes at room temperature. Then, centrifugation was carried out at 3000 rpm for 15 minute. The supernatants layer was transferred into a china dish. The weight of sediment after the removal of supernatant per unit weight of dry solid is called the water absorption index [20]. The WSI was determined using given equation 5.

$$WAI(g/g) = \frac{Weight\ of\ sediment}{weight\ of\ dry\ solid} \quad (4)$$

$$WSI\ (\%) = \frac{weight\ of\ dissolved\ solid\ in\ supernatant}{weight\ of\ dry\ solid} \times 100 \quad (5)$$

2.6 Biofunctional characteristics

2.6.1 Preparation of extract

Extracts for total phenolic contents, total flavonoid contents and antioxidant activity were prepared at room temperature (25℃) by mixing extrudates with 80% methanol (2 mL) for 2h using an orbital shaker at 200 rpm and centrifuged at 7000 rpm for 10 mints. Supernatants were collected and centrifuged through Whatman Filter No. 2 to remove insoluble particles [9].

2.6.2 Total phenolic contents (TPC)

The TPC of extrudates was measured using the Folin-Ciocalteu (FC) method with a slight modification [21]. 0.4 mL of extract and FC reagent was mixed followed by the addition of $NaHCO_3$ (1:1). Furthermore, the solution was placed at room temperature for 90 min. The absorbance was measured at 725nm using a Spectrophotometer. The standard curve of gallic acid was used as a reference, and sample values were presented in terms of mg GAE/100g.

2.6.3 Total flavonoid contents (TFC)

TFC extrudates were calculated by adopting the $AlCl_3$ colorimetric procedure according to the suggested method [22]. In this method, 1 mL of extrudate extract was added to a 3 mL solution of methanol containing $AlCl_3$ and potassium acetate. Afterwards, distilled water (5.6 mL) was added to dilute the solution, and it was placed at room temperature for half an hour. Then, the sample absorbance was measured at 415 nm wavelength using the spectrophotometer 752D (UV Visible, China). Quercetin curve was used as reference and the results are presented in terms of mg QE/100g.

2.6.4 ABTS radical scavenging activity

The free radical scavenging activity of extrudate extract was determined using ABTS (2,2-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) method reported by [23]. In this method, the ABTS radical cation (ABTS+) was generated through the reaction of 7mM ABTS and 2.45mM potassium persulfate (1:1 v/v). After that, mixture was kept in dark place place for 12-14 hours. The ABTS+ solution was diluted with ethanol until an absorbance of 0.7 at 734nm was achieved. This ABTS+ solution (3 mL) was added with 0.02 mL of the extract or Trolox standard. The mixture was kept at room temperature for 10 minutes, and the absorbance was noted at 734 nm.

2.7 Dietary fiber

The dietary fiber contents of fiber and protein-enriched corn extrudates were determined using suggested methods with minor changes [12]. A 1g sample of extrudates was put in a flask and immersed in 40 mL of MES/TRIS solution (pH 8.2) at 24 °C and then digested by heat stable α-amylase (50µL) for fifteen minutes in boiling a water bath. Protease and amyloglucosidase (200 µL) were added, and the mixture were held for half an hour at 60°C. After filtration, recovery of insoluble dietary fiber from enzyme digestate, followed the drying in a hot air oven at 105°C and weighed. Precipitation of soluble dietary fiber with ethanol (4 mL of 95%) in the filtrate then filtration was carried out. The precipitate was then dried in a hot air oven at 105°C and weighed. Residues were also evaluated for protein and ash (described in section 2.4). The sum of soluble and insoluble fiber is referred as total dietary fiber.

$$\text{Dietary Fiber } (\%) = \frac{\text{Residue weight} - \text{protein} - \text{ash} - \text{blank}}{\text{weight of sample}} \times 100 \qquad (6)$$

2.8 Color analysis

Color analysis of extrudates were measured according to the suggested method [24] using High quality Colorimeter (ST-CP60, Stalwart, USA). The L*, a*, and b* were taken at various parts of the extrudates in triplicates. Change in color (ΔE), chroma (C*) and whiteness indexes (WI) were calculated using the following equations,

$$\Delta E = \sqrt{(L^* - L^*_{std})^2 + (a^* - a^*_{std})^2 + (b^* - b^*_{std})^2} \quad (7)$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (8)$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad (9)$$

2.9 Organoleptic properties

The extrudates, enriched with fiber and protein were evaluated for organoleptic properties (color, taste, texture, and overall acceptance) by semi-trained panelists at National Institute of Food Science and Technology, University of Agriculture, Faisalabad. The panelists comprised of 30 members of faculty and postgraduate students. An unbiased assessment was conducted using a 9-point hedonic scale to evaluate the organoleptic properties of extrudates. The sample were labelled with codes and presented in separate booths equipped with white fluorescent light. Consequently, the actual composition of extrudates was not disclosed to the panelists for their impartial judgment about each sample. The extrudates were offered to panelists on coded plates at room temperature (25℃). Plain water was provided to panelists before each evaluation to rinse their mouths and neutralize their taste buds [12, 25].

2.10 Statistical analysis

All analysis were performed in triplicates and statistical analysis was employed using a complete randomized design followed by Tukey test at 5% level of significance. The results are presented as mean values along standard deviation. Various letters indicate significant ($p<0.05$) difference among the treatments.

3. RESULTS AND DISCUSSION

3.1 Chemical composition of extrudates

The chemical composition of newly developed extrudates is presented in Figure 1. The results reveal that the composition of extrudates has a significant effect with the addition of citrus pomace and chickpea. It is evident that moisture content in extrudates does not significantly change with increasing concentration of citrus pomace and chickpea. Additionally, fat content varied among the treatments, ranging from 1.25 to 4.96 g/100g. The increase in fat content was linear increased with the incorporation of citrus pomace and chickpea. Similarly, ash content varied from 1.15 to 2.52 g/100g and increase about 2.19 times compared to the control sample. Likewise, protein contents in extrudates varied 7.05 to 9.98 g/100g among the treatments. The 5% incorporation of chickpea and pomace increased the protein by 10.21% compared to control sample. The increasing the concentration (10 and 15%) of pomace and chickpea, protein contents significantly increased ($p<0.05$) by 21.27 and 31.48%, respectively. Similarly, the maximum protein contents (9.98 g/100g) were observed in $T_{4,}$ which contained the highest (20%) concentration of pomace and chickpea. Therefore, supplementation of extrudate linearly increased the protein contents. This is attributed to the incorporation of chickpea which is a rich source of protein content [26]. These findings are in line with the literature findings [27], who studied the effect of the extrusion process on the functional and antioxidant properties of germinated chickpea-enriched corn extrudates.

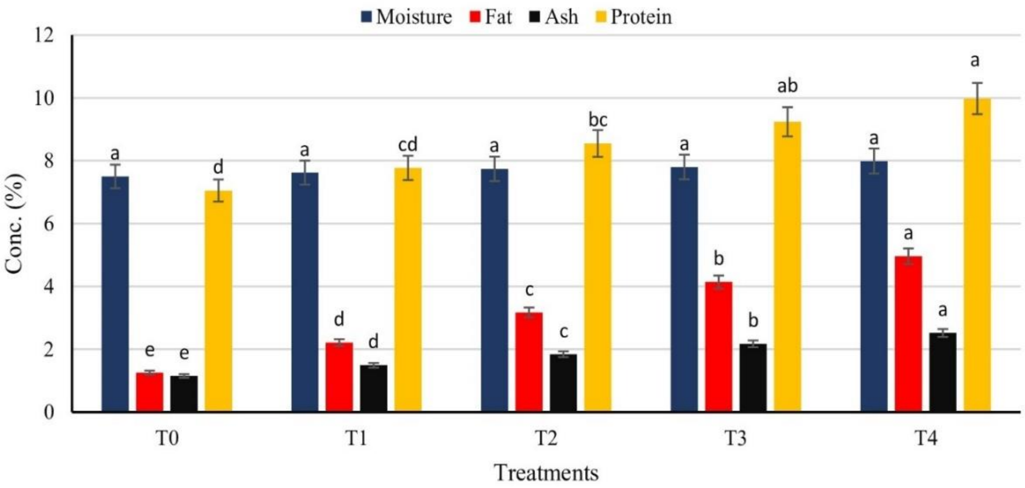


Figure 1: A graphical representation of the chemical composition of extrudates

3.2 Bulk density

Bulk density (BD) serves as an indicator of the extent of puffing, constituting a crucial physical characteristic for extrusion-based food products. The BD of extrudates was measured, and the results are represented in Table 2. The findings revealed a significant impact ($p<0.05$) on the BD of extrudates by pomace and chickpea. The BD in extrudates varied among the treatments, ranging from 0.104 to 0.119 g/cm^3. The elevation in BD in extrudates may be attributed to the increasing concentration of fiber and protein in the blend. The incorporation of fiber and protein influences the gelatinization of starch and the rheological properties of melted material. Fiber, a non-starch polysaccharide, retains water more effectively during extrusion compared to protein and starch, inhibiting water loss at the die [28]. Numerous studies have demonstrated that the inclusion of various by-products results in an increased bulk density of snacks [29, 30].

3.3 Expansion ratio & porosity

The expansion ratio (ER) of extrudates was determined, and the results are shown in Table 2. These results revealed that pomace and chickpea had a significant ($p<0.05$) impact on the ER values. The ER values of extrudate are in the range of 1.49-1.75. The expansion of snacks depends on the food materials and process parameters. Starch plays a vital role in the expansion, other ingredients (protein and lipids) act as diluents.

Results indicated that the expansion ratio significantly ($p<0.05$) decreased. High fiber and protein contents lead to a reduced expansion ratio. The decrease in the expansion ratio observed in the present study can be attributed to the fact that pomace and chickpea contain fiber and protein. Fiber solubility also affects the expansion. Insoluble fiber holds water in the food matrix during extrusion cooking, hindering the generation of steam [31]. Protein influences the distribution of water in the matrix and macromolecular structure which affects the extensional characteristics of extruded melt [32]. These outcomes are correlated with previous literature [33], who studied the incorporation of whey protein concentrate and isolate in corn and rice snacks and reported that higher inclusion of protein decreases the expansion. Extrusion cooking not only causes the expansion of product but also causes structural modifications [34].

Air cells were produced during extrusion which gives expansion to the products. The porous and sponge-like structure produce inside the extrudates due to the generation of tiny steam bubbles by the quick release of pressure after exiting the die (Rathod and Annapure, 2016). Porosity in extrudates was significantly ($p<0.05$) decreased as the pomace and chickpea concentration increased (Table 2). It may be attributed that the dilution of starch with the incorporation of fiber and protein source for expansion. Reduction in porosity is also due to degradation in the melted starch structure [32]. The results indicated that BD has inverse corealtion with porosity which is an indication of compact structure. These results are in line with the works of other researchers [28] who studied the physical and functional characteristics of extruded snacks prepared from food by-products.

Table 2: Effect of varying concentrations of citrus pomace and chickpea on the bulk density, expansion ratio and porosity of extrudates

Treatment	*Bulk density* (g/cm^3)	*Expansion ratio* (-)	*Porosity* (-)
T_0	0.104 ± 0.01^{b}	1.75 ± 0.03^{a}	0.50 ± 0.01^{a}
T_1	0.109 ± 0.05^{ab}	1.68 ± 0.02^{ab}	0.45 ± 0.06^{b}
T_2	0.112 ± 0.02^{ab}	1.60 ± 0.04^{bc}	0.37 ± 0.04^{c}
T_3	0.115 ± 0.03^{a}	1.55 ± 0.03^{bc}	0.32 ± 0.07^{d}
T_4	0.119 ± 004^{a}	1.49 ± 0.05^{c}	0.29 ± 0.02^{d}

3.4 Water absorption index (WAI) and Water solubility index (WSI)

WAI of the extrudates was determined and results are presented in Figure 2. Results revealed that citrus pomace and chickpea had a significant effect on the WAI of corn extrudates. In this study, WAI values of extrudates as a function of pomace and chickpea (5, 10, 15 and 20% each) were found 6.93, 7.42, 7.79 and 7.90 g/g, respectively. The increase in WAI is due to the presence of a high amount of fiber and protein in the raw materials compared to the non-supplemented sample. The extrusion process also had a significant effect on the WAI due to the denaturation of protein, gelatinization of starch and swelling of crude fiber [35]. These findings are correlated with prior literature[36] they studied the influence of spelt flour addition on the properties of extruded products. In this study, WAI was positively correlated with bulk density ($p<0.05$), but negatively correlated with porosity ($p<0.05$).

WSI indicates the degradation of starch granules and the presence of a higher content of molecules with lower molecular weight [37]. These results indicated that WSI significantly increased with the addition of pomace and chickpea (Figure 2). This may be due to the presence of a high amount of fibers in the pomace and chickpea compared to the corn sample. The inclusion of 5 and 10% each of pomace and chickpea increased the WSI by 10.09 and 14.81%, respectively. A further increase in the concentration of pomace and chickpea in the extrudates significantly ($p<0.05$) increases the WSI. The highest WSI (22.24%) was observed in the extrudates with the highest pomace and chickpea contents (20% each). The increase in WSI at 20% inclusion of pomace and chickpea was 47.77% compared to the control sample. It may be attributed that the disintegration of starch granules in extrusion due to shear forces, allows the rapid water molecules to enter into the granule interior, thereby accelerating and increasing the gelatinization and depolymerization of starch molecules, increasing the WSI [38, 39]. These findings are consistent with previous literature findings [36, 40] they studied the effect of brewer spent grain and spelt flour incorporation in corn extrudates. In the present study, WSI was positively correlated with bulk density ($P<0.05$) but had a negative correlation with porosity ($p<0.05$).

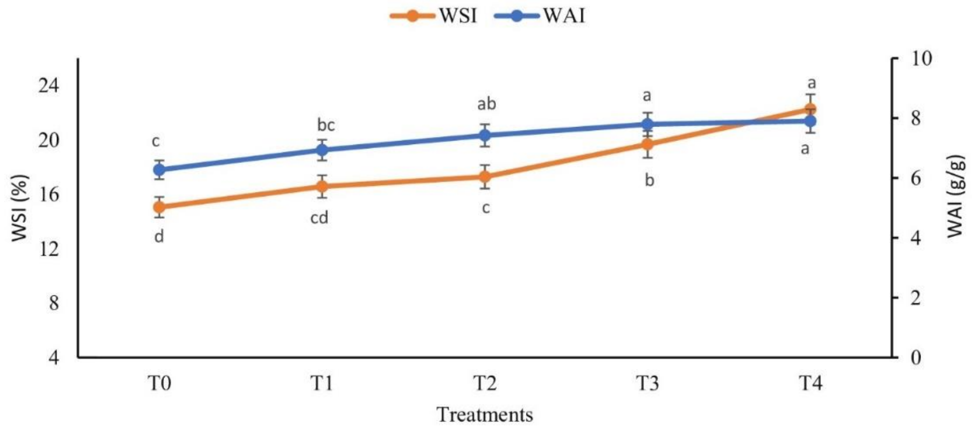


Figure 2: Effect of varying concentrations of pomace and chickpea on the WAI and WSI of corn extrudates

3.5 Dietary fiber

Dietary fiber (DF) contents extrudates were determined and presented in Figure 3. Results revealed that DF significantly increased with the supplementation of raw materials (pomace and chickpea) in the corn extrudates. The 5% inclusion of each pomace and chickpea, increased the DF by 75.98% than the control sample. A further increase of pomace and chickpea (10 and 15%), DF was increased 2.52 and 3.25 times, respectively. The highest DF was observed in T_4 (11.29%), which is 4 times greater than the control sample. Thus, DF contents of supplemented extrudates increased linearly ($R^2 = 0.99$) correlated with the supplementation of citrus pomace and chickpea. The increase in fiber contents may be due to the formation of complexes among the polysaccharides, proteins and phenolic compounds which significantly increased the DF [14]. These outcomes are in line with a previous study [41], which studied the effect of extrusion processing to increase the dietary fiber contents in gluten-free products.

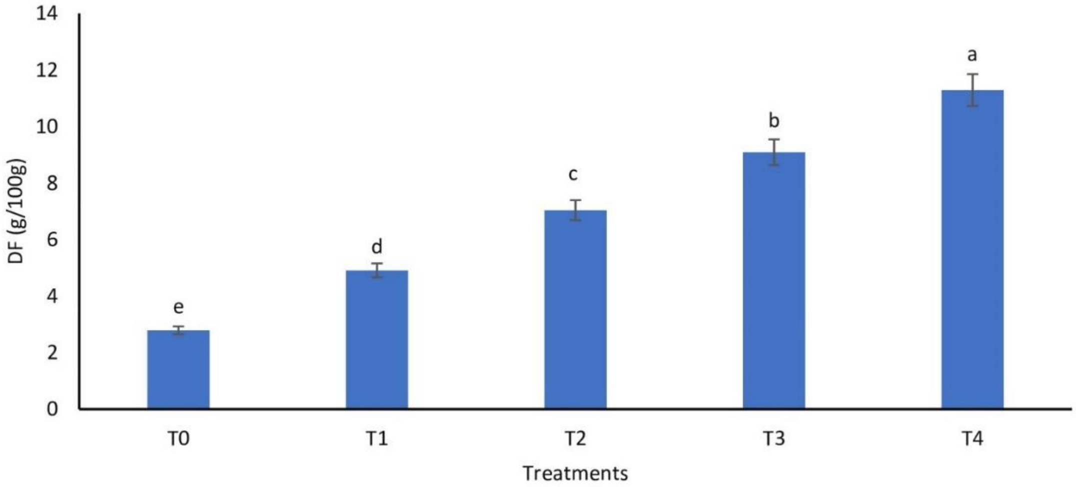


Figure 3: Graphical representation of dietary fiber content of fiber and protein-enriched corn extrudates

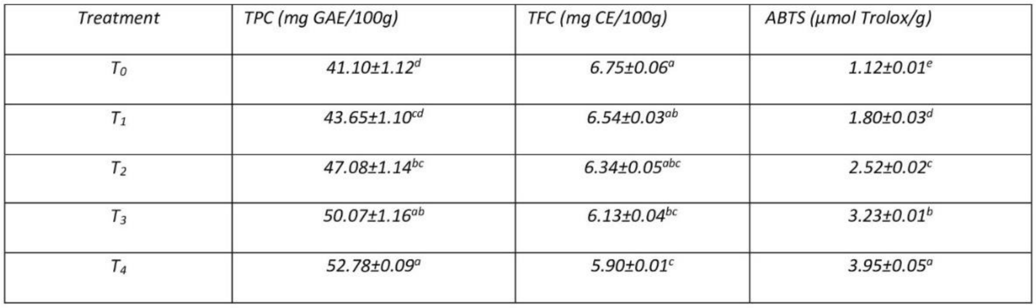
3.6 Bio-functional properties

The incorporation of citrus pomace and chickpea in corn extrudates significantly effect ($P<0.05$) on the bio-functional characteristics. Total phenolic (TPC) contents in extrudates were assessed and results are shown in Table 3. Results indicated that pomace and chickpea had a significant ($p<0.05$) increase in the TPC of extrudates. The incorporation of 5% of each pomace and chickpea increased the TPC by 6.20% than the control sample. With a further increase in chickpea and citrus pomace (10 and 15%), TPC increased by 14.54 and 21.82%, respectively. The maximum TPC was observed in T_4 (52.79 mg GAE/100 g). The increase in TPC at 20% inclusion of each pomace and chickpea was 28.44% compared to the non-supplemented sample. The increase in TPC is due to the incorporation of citrus pomace and chickpea and high temperatures during extrusion [42]. High temperature during extrusion change the molecular structure of phenolic compounds and increase the chemical reactivity [43]. Antioxidant compounds and antioxidant changes in the extruded products are due to the release of phenolic compounds from cell walls, protein interaction with phenolics, and generation of Maillard products at high temperatures during extrusion [44, 45]. These findings are by the literature [46], who studied the characterization of vegetable-enriched corn extrudates.

Total flavonoid contents (TFC) have attracted attention by their various beneficial effects on the health of humans. The majority of them have antioxidant characteristics. Results indicated that TFC significantly ($p<0.05$) decreased as shown in Table 3. This reduction might be due to damage caused by the heat during the extrusion process because flavonoids are sensitive to high temperatures [47, 48]. These results are in line with [49] and [50] for sweet potato and buckwheat, respectively, upon heating.

The antioxidant activity of fiber and protein-enriched extrudates was estimated through ABTS radical scavenging (RS) activity and results are presented in Table 3. These findings indicated that the RS activity of the extrudates significantly increased ($p<0.05$). The inclusion of 5% pomace and chickpea increased the antioxidant activity by 60.71% as compared to the control sample. A further increase in pomace and chickpea concentrations (10 and 15% each) increased the antioxidant activity 2.24 and 2.88 times, respectively. The maximum antioxidant activity of extrudates was observed in T_4 (3.95 µmol Trolox/g). The increase of antioxidants at 20% supplementation of pomace and chickpea each was 3.52 times greater than the non-supplemented sample. The upsurge in antioxidant activity may be due to the presence of Maillard reaction products created during extrusion [51]. Thermal processing can produce brown-coloured complex polymeric compounds called melanoidin, which increases antioxidant capacity, such as hydroxymethyl furfural [52]. These outcomes correlated with the literature findings [53] who studied the effect of cashew pomace incorporation in cereal-based extrudates.

Table 3: Effect of varying concentrations of pomace and chickpea on TPC, TFC and ABTS of corn extrudates



Treatment	*TPC (mg GAE/100g)*	*TFC (mg CE/100g)*	*ABTS (µmol Trolox/g)*
T_0	41.10 ± 1.12^{d}	6.75 ± 0.06^{a}	1.12 ± 0.01^{e}
T_1	43.65 ± 1.10^{cd}	6.54 ± 0.03^{ab}	1.80 ± 0.03^{d}
T_2	47.08 ± 1.14^{bc}	6.34 ± 0.05^{abc}	2.52 ± 0.02^{c}
T_3	50.07 ± 1.16^{ab}	6.13 ± 0.04^{bc}	3.23 ± 0.01^{b}
T_4	52.78 ± 0.09^{a}	5.90 ± 0.01^{c}	3.95 ± 0.05^{a}

3.7 Color analysis

Color is a critical quality characteristic of food products, which affects consumer perception of the product. The color of extrudates was carried out in terms of L*, a* and b* values that were used to determine the change in color (ΔE), chroma (C*) and whiteness index (WI) as shown in Figure 4. ΔE can be observed as a physical indicator of the intensity of the extrusion process and can be associated with chemical changes occurring in food. Results revealed that the change in color significantly ($p<0.05$) increased with the incorporation of pomace and chickpea. ΔE of the extrudates were increased by 3.13, 4.77, 11.24 and 22.06 in T_1, T_2, T_3, and T_4, respectively, than the control sample, which indicates a significant change. This may be due to the Maillard reaction, caramelization, hydrolysis, and non-enzymatic reactions [30, 54, 55].

Chroma values indicate saturation and are directly proportional to the color intensity. Results showed that chroma values significantly decreased with increasing inclusion of pomace and chickpea. It may be attributed that the increase in the 'a' value of color obtained from the instrumental process is due to the Maillard reaction products (melanoidins) which are responsible for the browinng of extrudates [56]. WI of extrudates decreased significantly ($P<0.05$) with increasing the concentration of pomace and chickpea. The maximum WI value (47.28) was observed in the control sample. Increasing pomace and chickpea inclusion decreased the WI values by 1.90, 3.21, 14.14 and 32.63% in T_1, T_2, T_3 and T_4, respectively as compared to the non-supplemented samples (control).

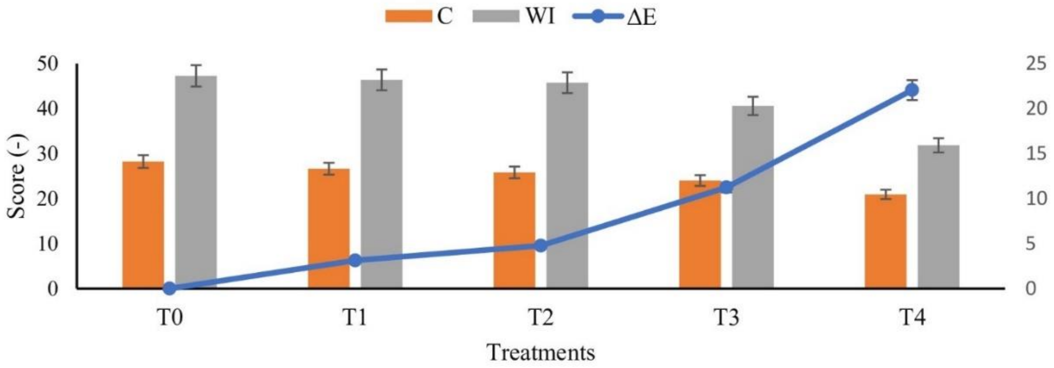


Figure 4: A graphical representation of change in color, chroma and whiteness index of corn extrudates

3.8 Organoleptic properties

Organoleptic properties of extrudates were assessed based on color, taste, texture, and overall acceptability and results are presented in Figure 5. It is evidenced from the results that extrudates containing 5% pomace and chickpea showed better scores among the treatments. Extrudates containing greater than 5% citrus pomace and chickpea showed bitter tastes and received lower scores of taste and overall acceptability. It may be due to the citrus pomace which contains flavanone-7-O-neohesperidoside and limonene [57]. Likewise, extrudates containing more than 5% pomace and chickpea received lower scores. It may be due to the Maillard & caramelization reactions and degradation of food pigments [55, 58].

Increasing concentration of pomace and chickpea the texture of extrudates became harder. These results have co-similarity with previous literature [59], where it has been described that the addition of fiber increased the hardness of extruded snacks. It may be attributed that soluble dietary fiber is present in the raw materials which would make more water available for texturization [55]. The taste of the extrudates significantly decreased

($P<0.05$) with the inclusion of pomace and chickpea. Thus, it may be concluded from the results that citrus pomace and chickpea had a significant effect on the organoleptic properties of extrudates.

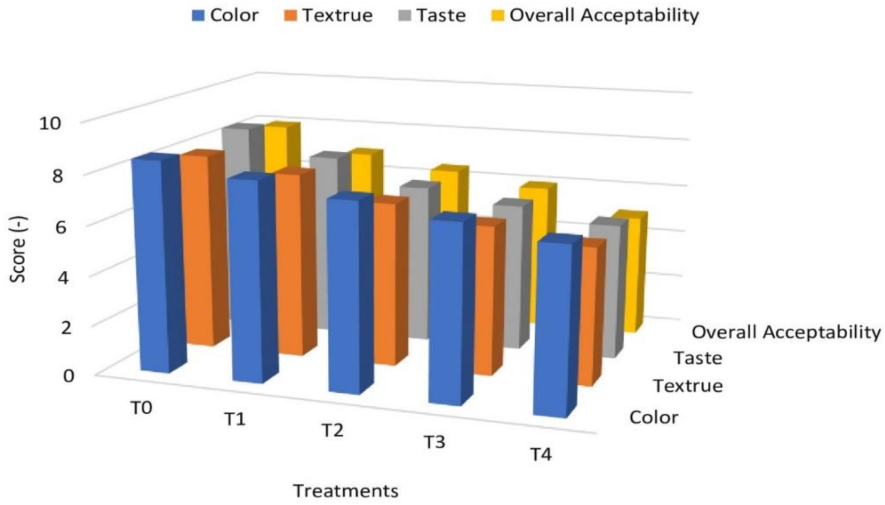


Figure 5: Graphical representation of organoleptic properties of fiber and protein-enriched corn extrudates

4. CONCLUSION

The aim of the present research was the development of healthy snacks with the inclusion of citrus pomace and chickpea in corn grits to enhance the fiber and protein content of extrudates. Results indicated that the inclusion of pomace and chickpea significantly increased the dietary fiber (2.79-11.29g/100g) and protein (7.05-9.98%). Moreover, citrus pomace and chickpea addition improved the technological parameters such as bulk density (0.104-0.119g/cm^3), water absorption index (6.27-7.90g/g) and water solubility index (15.05-22.25%). These Extrudates showed better health-promoting functional characteristics as TPC (41.10-52.78 mg GAE/100g), TFC (6.75-5.09 mg CE/100g) and ABTS (1.12-3.95 µmol Trolox/g). Furthermore, organoleptic properties (color, texture, crispiness, taste and overall acceptance) of novel supplemented extrudates revealed that T_1 is the best among the treatments. Therefore, citrus pomace and chickpeas can be used to develop healthy and appetizing extrudates along with food waste management and helpful to mitigate malnutrition.

Authors contribution

Muhammad Asif: Writing original draft, data collection and statistical analysis; Muhammad Kashif Iqbal Khan: Conceptualization, editing and review of draft; Muhammad Issa Khan: review of draft and improve the draft; Abid Aslam Maan: Review of draft

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Conflict of Interest

All the authors declare no conflict of interest.

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