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Comprehensive analysis of physicochemical properties, nutritional composition and acrylamide risks of potato chips in Bangladesh

Islam, M.M., Bisshas, S., Rudra, A., Sima, N.J. and *Sultana, A.

Department of Chemistry, University of Dhaka, Dhaka-1000, Bangladesh

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Abstract

Acrylamide is a potentially harmful compound formed during high-temperature processing of carbohydrate-rich foods, raising food safety concerns. This study comprehensively evaluated the quality and safety of commercially available salted potato chips in Bangladesh by analyzing their physicochemical properties, nutritional composition, and acrylamide content. Twenty popular brands were collected from Dhaka and analyzed for moisture, ash, salt, sugar, starch, total fat, fatty acid profile, and acrylamide levels using standardized methods. The results revealed significant variations in key parameters: moisture (1.587-3.308%), ash (2.430-3.532%), salt (0.499-2.640%), sugar (0.183–4.110%), starch (48.750–77.337%), and total fat (16.904–31.468 g/100 g). Fatty acid profiling showed concerning levels of saturated fats (up to 81.734% in PC-4) in some samples, while others contained predominantly monounsaturated fats (83.524–85.182%), reflecting differences in frying oil selection. Acrylamide content ranged from 85.277 to 386.209 $\mu g kg^{-1}$, with one sample (PC-18) exceeding the European Union benchmark (300 $\mu g kg^{-1}$). Dietary exposure assessment indicated potential health risks, with two samples (PC-12 and PC-18) showing margin of exposure (MOE) values below safety thresholds for both neurotoxicity (MOEn <100) and carcinogenicity (MOEc <10,000). The highest-risk sample (PC-18) had a daily acrylamide exposure of 0.552 $\mu g kg^{-1} day^{-1}$, primarily attributed to suboptimal frying conditions. Recommended mitigation strategies include adopting lower-temperature frying, using high-oleic oils, reducing seasoning additives, and implementing rigorous quality control measures. These findings provide essential baseline data for policymakers to develop localized food safety regulations and empower consumers to make informed dietary choices. The study underscores the urgent need for standardization in Bangladesh's growing potato chip industry to ensure product quality and consumer safety.

1. Introduction

Potato chips are one of the most widely consumed snack foods globally, prized for their crispy texture and savory taste (Bhattacharya, 2023). Originating in the 19th century, they have evolved into a multi-billion-dollar industry, with growing demand in both Western and Asian markets (Datta, 2020). In Bangladesh, the consumption of potato chips has surged due to urbanization, changing dietary habits, and the expansion of local and international snack brands. The Bangladesh Potato Chips Market is expected to grow at a strong CAGR of 10% from 2025 to 2031, according to 6Wresearch. This growth is driven by rising urban demand for ready-to-eat snacks, higher disposable incomes, and changing food preferences. Additionally, local raw material availability and innovative marketing strategies are supporting increased market penetration (Bangladesh Potato Chips Market | Size, Share and Volume 2031, 2025). These chips are typically produced through slicing, frying, seasoning (often with salt and spices), and packaging, which directly influences their physicochemical and sensory properties (Pedreschi *et al.,* 2016; Cui *et al.,* 2024). However, variations in processing techniques-such as frying temperature, oil quality, and additives-can significantly affect their nutritional profile and safety (Dangal *et al.,* 2024; Yildiz *et al.,* 2024). Given their popularity, assessing the quality and health implications of potato chips in the Bangladeshi market is essential for consumer awareness and food regulatory standards.

The physicochemical properties of potato chips critically influence their quality and consumer acceptability (BUNGA, 2023; Zhang *et al.,* 2025). Moisture content affects texture and crispiness,

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*Corresponding author.
Email: *abida.chem@gmail.com*

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while also determining shelf-life, as higher moisture promotes microbial growth and rancidity (Pareek and Kitinoja, 2011; Fellows, 2017; Nawaz *et al.,* 2021). Ash content, representing inorganic residues after combustion, serves as an indicator of mineral composition and processing efficiency (Harris and Marshall, 2017; Funk *et al.,* 2020). Excessive ash may suggest contamination or improper frying, whereas optimal levels reflect proper raw material and production control. Analyzing these parameters ensures product consistency, safety, and compliance with food standards, making them essential for evaluating the overall quality of commercially available potato chips (El-Sayed *et al.,* 2023; Khalil *et al.,* 2024). Potato chips are energy-dense snacks whose nutritional profile raises significant health concerns. Total fat content, primarily from frying oils, often constitutes 30-40% of the product, contributing to excessive calorie intake and obesity risks (Pedreschi *et al.,* 2016; Mahmud *et al.,* 2023). The fatty acid composition further influences health outcomes; high levels of saturated fats may elevate cardiovascular disease risk, whereas unsaturated fats (e.g., oleic and linoleic acids) are comparatively beneficial (Briggs *et al.,* 2017; Gaytancıoğlu *et al.,* 2024). Additionally, salt (sodium) content in seasoned chips is a major concern, as excessive intake is linked to hypertension and cardiovascular disorders (Grillo *et al.,* 2019; Vala and Azam, 2024). The total sugar and starch content also contribute to metabolic issues, including insulin resistance, obesity, and type 2 diabetes, particularly with frequent consumption (Aller *et al.,* 2011; Sanders *et al.,* 2020; So *et al.,* 2020). Processing methods significantly alter nutritional quality. Deep-frying at high temperatures not only increases fat absorption but may also degrade heat-sensitive nutrients and generate harmful compounds (Liu *et al.,* 2021; Rani *et al.,* 2023; Ok *et al*., 2025). Seasoning additives enhance flavor but often exacerbate sodium and sugar levels. Understanding these nutritional aspects is crucial for assessing dietary risks and guiding healthier production practices (Kothari *et al.,* 2025). Given the growing consumption of potato chips in Bangladesh, evaluating their nutritional composition is essential for public health awareness and regulatory measures. Acrylamide, a potentially harmful processing contaminant, forms in potato chips through the Maillard reaction when reducing sugars and asparagine react at high temperatures (>120°C) during frying or baking (El-Sayed *et al.,* 2023; Adimas *et al.,* 2024; Govindaraju *et al.,* 2024). Classified as a Group 2A carcinogen by IARC, acrylamide exposure has been linked to increased cancer risk and potential neurotoxic effects in long-term consumers (Edna Hee *et al.,* 2024; Mihalache and Dall'Asta, 2024). The acrylamide content in potato chips varies depending on multiple factors. Raw material composition—particularly sugar content in potatoes—plays a key role, with certain varieties accumulating more precursors (Tajner-Czopek *et al.,* 2021; Adimas *et al.,* 2024). Frying conditions (temperature, duration) significantly influence acrylamide formation, where higher temperatures and longer cooking times elevate levels (Gökmen *et al.,* 2006; Adimas *et al.,* 2024; Ahmed and Mohammed, 2024). Additionally, additives like asparaginase or alternative processing methods (vacuum frying, blanching) may help mitigate acrylamide (Granda *et al.,* 2004; Liyanage *et al.,* 2021; Patial *et al.,* 2022). Given the widespread consumption of fried potato snacks, assessing acrylamide levels in Bangladeshi potato chips is crucial for evaluating consumer exposure and informing food safety guidelines.

Despite the growing popularity of potato chips in Bangladesh, comprehensive studies evaluating their nutritional quality and safety remain scarce. While international research has extensively examined physicochemical properties, nutritional composition, and acrylamide risks in fried snacks, such data are notably lacking for locally produced and consumed potato chips. This gap is particularly concerning given Bangladesh's unique food processing practices, ingredient variations, and consumer exposure patterns. Assessing local market samples is crucial to understand actual consumer exposure to potentially harmful components like excessive fats, sodium, and acrylamide. Furthermore, establishing baseline data is essential for developing evidence-based food safety regulations and improving public awareness about the health implications of frequent chip consumption. This study aims to bridge these knowledge gaps by providing a systematic evaluation of commercially available potato chips in Bangladesh, offering valuable insights for policymakers, manufacturers, and health-conscious consumers alike. This study aims to comprehensively evaluate salted potato chips commonly consumed in Bangladesh through four key objectives. First, it will assess physicochemical properties, including moisture and ash content, to determine product quality and shelf stability. Second, the research will analyze nutritional composition, quantifying total fat, fatty acid profile, salt, sugar, and starch content to evaluate dietary implications. Third, the study will measure acrylamide levels formed during processing and estimate potential health risks associated with regular consumption. Finally, the findings will be compared with international safety standards (e.g., WHO, EFSA) to identify gaps in local product quality. Based on the results, science-based mitigation strategies will be proposed to reduce health risks while maintaining sensory appeal. This multidimensional approach will provide crucial data for policymakers, manufacturers, and consumers to improve food safety

Table 1. Sampling of different potato chips of Dhaka city.

Sample code	Sampling date	Brand name	Area	Date of manufacture	Date of expire
PC-1	10-03-2023	Bombay Sweets Potato Crackers	Nilkhet	18-02-2023	20-06-2023
PC-2	10-03-2023	Bombay Sweets Alooz Spanish Tomato Flavour	Nilkhet	22-01-2023	21-07-2023
PC-3	10-03-2023	Ruchi Potato Crackers	Nilkhet	11-02-2023	10-06-2023
PC-4	21-03-2023	Pusti Happy Time Flakes Potato Chips	Chankharpool	15-02-2023	15-08-2023
PC-5	21-03-2023	Bombay Sweets Mr. Twist Potato Chips	Chankharpool	2-03-2023	2-07-2023
PC-6	21-03-2023	Yokozona Twisty Goodness Crackers	Chankharpool	24-01-2023	24-07-2023
PC-7	08-04-2023	Pasta Chips Shells	Farmgate	11-02-2023	10-08-2023
PC-8	08-04-2023	Sun Chips	Farmgate	3-01-2023	02-06-2023
PC-9	08-04-2023	Cheese Puffs	Mouchak	07-03-2023	06-07-2023
PC-10	08-04-2023	Kurkure Cream and Onion flavours	Nilkhet	19-02-2023	19-06-2023
PC-11	17-04-2023	Bombay Sweets Ring Chips	Puran Dhaka	14-03-2023	14-09-2023
PC-12	17-04-2023	Tornado Crackers	Puran Dhaka	5-03-2023	5-07-2023
PC-13	29-04-2023	Spicy Potato Sticks Crackers	Malibagh	20-04-2023	21-09-2023
PC-14	29-04-2023	Krispy Curl Tomato Flavour	Malibagh	2-04-2023	2-10-2023
PC-15	29-04-2023	Zeros Chips	Malibagh	9-04-2023	9-10-2023
PC-16	3-6-2023	Slanty Potato Fries	Mirpur	29-5-2023	28-11-2023
PC-17	3-6-2023	Pringles Original Potato Chips	Mirpur	13-5-2023	12-11-2023
PC-18	3-6-2023	Ruchi Thai Sweet Chilli Potato Crackers	Mirpur	17-4-2023	16-10-2023
PC-19	11-6-2023	Mister Potato Original Crisps	Mirpur	2-5-2023	1-11-2023
PC-20	14-6-2023	Petra Fleiv Barbecue Potato Chips	Gulshan	21-4-2023	20-10-2023

standards and promote healthier snack choices in Bangladesh.

2. Materials and methods

2.1 Sample collection and preservation

Potato chip samples were systematically collected from various local retail outlets located in key areas of Dhaka, Bangladesh, including Nilkhet, Malibagh, Puran Dhaka, Chankharpool, Farmgate, Mouchak, Mirpur, and Gulshan. The sampling period spanned from February 2023 to June 2023, ensuring a representative collection across different seasons (Table 1). The selection of brands was based on their popularity and highest consumption rates, as determined by their availability and sales in local shops. This approach ensured that the samples reflected the most commonly consumed products in the region (Benkhoud *et al.,* 2022; Ordoñez *et al.,* 2023). Each collected sample was assigned a unique alphanumeric code (e.g., PC-1, PC-2, PC-3, PC-4, PC-5, up to PC-20) to maintain traceability and avoid cross-contamination during handling and analysis. Immediately after collection, the samples were transported to the laboratory under controlled conditions to prevent exposure to environmental factors such as humidity, heat, or light, which could alter their physicochemical properties (Adepu and Ramakrishna, 2021). Upon arrival at the laboratory, the samples were homogenized to ensure a uniform and representative mixture for analysis. This was achieved by thoroughly blending the potato chips into a fine powder using standardized laboratory equipment. The dried and homogenized samples were stored in airtight, sealed containers to prevent contamination and preserve their integrity. For long-term preservation, the samples were stored in a laboratory refrigerator at a temperature of -20°C. This low-temperature storage was critical to maintaining the stability of the samples, particularly for parameters such as moisture content, fat composition, and acrylamide levels, which are sensitive to degradation at higher temperatures (Cao *et al.*, 2021). This systematic approach to sample collection, preparation, and preservation ensured that the analytical data generated were representative of the actual quality and safety of the potato chips available in the Bangladeshi market.

2.2 Chemicals and equipment

Analytical-grade solvents, including extra pure n-hexane, ethyl acetate, methanol (99.5%, w/w, Sigma Aldrich), ethanol (99.8% w/v, Sigma Aldrich), NaOH (BDH, U.K.), and BF_3-CH_3OH complex, were procured from Merck, Germany. Additional reagents such as anhydrous $MgSO_4$, anhydrous Na_2SO_4, NaCl, $AgNO_3$, HNO_3, $KMnO_4$, KSCN (Merck, Germany), potassium bromates (SMART LAB, Indonesia), sulfuric acid (98%, w/w, RCI Labscan Limited, Bangkok, Thailand), phenol (Merck, Mumbai, India), ferric alum, and distilled water were utilized for various analytical procedures. Extra pure D-glucose, purchased from Aldrich Chemical Co. Ltd., was stored at 0°C in a refrigerator to maintain stability. For sample analysis, a range of high-precision equipment were employed, including an analytical balance (model-AL 104, METTLER TOLEDO, US), electric balance (FR-200, NDO-450ND, Japan), muffle furnace (CARBOLITE-GSM 11/8), double-beam UV spectrophotometer (UV-1800, Shimadzu), vortex machine (Cat/Art No 444-1372, Germany), gas chromatograph equipped with an electron capture detector (GC-ECD, Shimadzu-2030), gas chromatograph with a flame ionization detector (GC-FID, Shimadzu-2025), oven (GSM 11/8 Hope Valley, S336RB, England), Carbolite furnace (Japan, capacity 750-1250° C), kitchen blender (Miyako Chopper, Japan), rotary vacuum evaporator (Heidolph, Germany), and centrifuge machine (Hanil Science Industrial Co. Ltd., Model-Combi 514 R, or Heraeus Sepatech, Labofuge A, with rotation up to 4000 rpm). These instruments ensured accurate and reproducible measurements for the comprehensive analysis of the potato chip samples.

2.3 Determination of moisture and ash content

The moisture content of potato chips was determined using the air-oven drying method. Approximately 2.0 g of finely ground samples were placed in pre-weighed porcelain crucibles and dried in an oven at 105°C for 4 hours or until a constant weight was achieved (Onyango *et al.,* 2021). The analysis was conducted in triplicate, and moisture content was calculated using the formula: % moisture = (loss of weight × 100) / weight of the sample. For ash content determination, the dry ashing method was employed. About 2.0 g of each sample was weighed into glass crucibles and ignited in a muffle furnace (CARBOLITE-GSM 11/8) at 700°C for 6-8 hours. After cooling in a desiccator, the residue was weighed, and ash content was calculated as: % ash = (weight of the residue × 100) / weight of the sample (Abong *et al.,* 2009; Haqbeen *et al.,* 2019). Both methods ensured accurate and reproducible quantification of moisture and ash content in the potato chip samples.

2.4 Evaluation of salt content

The salt content in 20 distinct varieties of potato chips was determined in duplicate using the Charpentier-Volhard method (Albuquerque *et al.,* 2012; Mohammadi-Nasrabadi *et al.,* 2021). Approximately 3 g of dried and finely crushed potato chips were mixed with 25 mL of 0.1 M $AgNO_3$, ensuring an excess of $AgNO_3$ to completely bind with all chloride ions present. The mixture was then boiled in a solution containing 15 mL of concentrated nitric acid and 50 mL of distilled water. During boiling, 15 mL of a 5% (w/v) potassium permanganate solution was added in 5 mL increments, resulting in a yellow, transparent solution. After boiling, the solution was filtered into a 200 mL volumetric flask, and the filter paper was thoroughly washed with distilled water at approximately 20°C. The filtrate was diluted to the mark with distilled water. For titration, 100 mL of the clear filtrate was treated with 2 mL of a saturated ferric alum solution as an indicator. The excess silver nitrate in the solution was then titrated with 0.1 M potassium thiocyanate (KSCN) until a reddish-brown endpoint was reached. The salt content was calculated based on the titration results, providing an accurate measurement of sodium chloride (NaCl) in the potato chip samples. This method ensured precise and reproducible quantification of salt content.

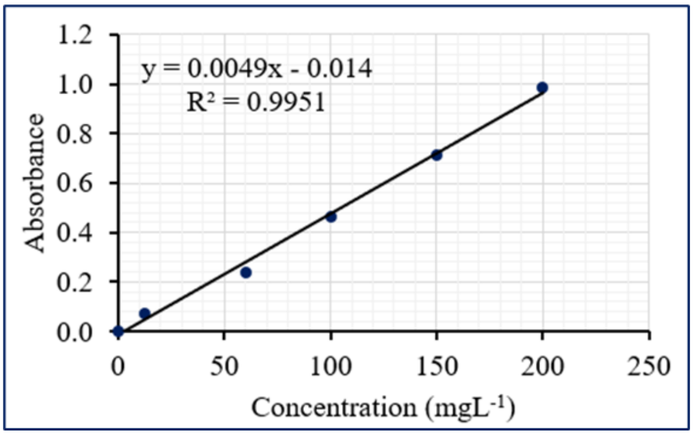

Figure 1. Calibration curve of standard D-Glucose solution.

2.5 Determination of sugar

The sugar content in potato chips was determined using the modified phenol-sulfuric acid method (Yue *et al.,* 2022; Chen *et al.,* 2023; Gao *et al.,* 2024). A standard solution was prepared by vortexing 2.0 mg of D-glucose with 3.0 mL of concentrated H_2SO_4 in a 10.0 mL volumetric flask, which was then diluted to the mark with concentrated H_2SO_4. Serial dilutions of the standard solution were prepared to achieve concentrations of 200, 150, 100, 60, and 12.5 mgL^{-1}. For analysis, 3.0 mL of each dilution was mixed with 50 mL of 80% aqueous phenol in test tubes, vortexed for one minute, and measured for absorbance at 489 nm using a spectrophotometer. A calibration curve (Figure 1) was constructed using the standard D-(+)-Glucose solutions, and the sugar content in the potato chip samples was quantified by comparing their absorbance values to the calibration curve, ensuring accurate and reproducible results.

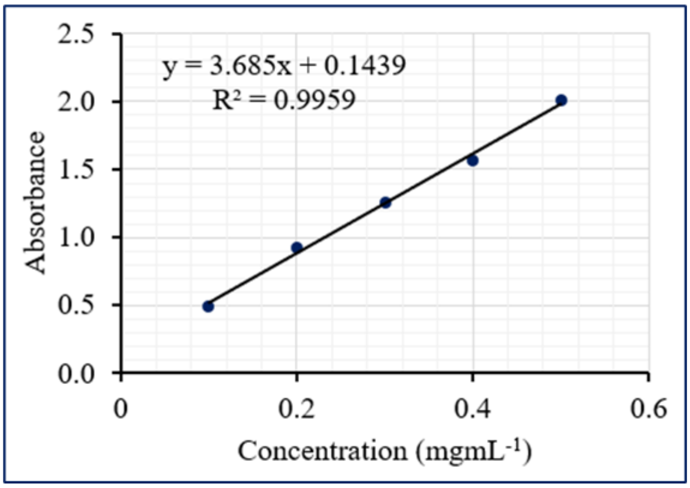

Figure 2. Calibration curve of standard starch solution.

2.6 Determination of soluble starch

UV-visible spectrophotometer was used for the determination of soluble starch in the salted potato chips (Lafont-Mendoza *et al.,* 2018; Ali *et al.,* 2023). A 0.1% standard solution of starch was prepared with soluble starch powder. After weighing 50 mg of soluble starch

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powder, 10 mL of distilled water at room temperature were added. Then the solution was topped up to ~40 mL with warm distilled water. The starch solution was heated to 90°C in order to dissolve the starch. After being cooled to a normal temperature, the solution was transferred to a 50-mL volumetric flask. Finally, distilled water at room temperature was added to fill it up to 50 mL. The concentration of diluted standard solutions were 0.2, 0.3, 0.4, 0.5 and 0.6 $mgmL^{-1}$. The λ_{max} of the working standard solutions were detected at 595 nm (De Caro and Haller, 2015; Bahdanovich *et al*., 2022). Starch content in the potato chips samples was determined by UV-visible spectrophotometer and calibration curve of **s**tandard soluble starch powder (Figure 2). The starch content in samples was quantified by comparing their absorbance to the calibration curve, ensuring accurate and reproducible results. This method provided a reliable measure of starch levels in the potato chips. Potato chips (0.3-0.5 g) were ground with 2 mL distilled water using a mortar and pestle to extract starch. The ground sample was transferred to a 15 mL test tube, diluted to 10 mL with cold water, and centrifuged at 5500 rpm for 10 minutes. The supernatant was discarded, and the pellet containing starch was washed again with cold water and recentrifuged. The starch pellet was then transferred to a 100 mL beaker with 30 mL distilled water, heated while stirring until nearly 100°C, and cooled to 50°C. The hot suspension was filtered into a 50 mL volumetric flask, washed with hot water, and brought to volume with distilled water. The starch solution was diluted 1:10 before measuring absorbance at 595 nm using a UV-visible spectrophotometer.

2.7 Determination of total fat and fatty acid

The total fat and fatty acid composition of potato chips were determined through a detailed extraction and methylation process (Gaytancıoğlu *et al.,* 2024). Initially, samples were finely pulverized, dried at 50°C, and homogenized. Approximately 10 g of the sample was mixed with 30 mL of n-hexane in a 250 mL round-bottom flask and refluxed for 1 hour in a water bath to extract the fat. The solvent was evaporated using a rotary evaporator, and the residual fat was dried at 40-60°C, cooled in a desiccator, and weighed to calculate the total fat percentage. This process was repeated in triplicate for accuracy. For fatty acid analysis, the extracted fat underwent methylation to form fatty acid methyl esters (FAMEs). Briefly, 0.5 g of fat extract was mixed with 10 mL of methanolic NaOH, refluxed for 1 hour, and neutralized with dilute HCl. The mixture was extracted with n-hexane, filtered through anhydrous Na_2SO_4, and dried. Methylation was completed by adding 1.0 mL of BF_3-CH_3OH, refluxing for 15 minutes, and extracting the FAMEs with n-hexane. The final extract was filtered and prepared for gas chromatography (GC) analysis. GC analysis was performed using a flame ionization detector (FID) and an HP-5 capillary column (30 m × 0.25 mm × 0.25 μm). The temperature program started at 105°C, held for 1 minute, increased to 150°C at 5°C/min, held for 1 minute, then raised to 280°C at 2.25°C/min, and held for 7 minutes, with a total run time of 75.78 minutes. The injector and detector temperatures were set at 285°C and 290°C, respectively. Nitrogen served as the carrier gas, while hydrogen and air were used for the flame. Samples were injected in split mode (80:20 ratio) using an auto-injector. This method ensured precise separation, identification, and quantification of individual fatty acids in the potato chip samples.

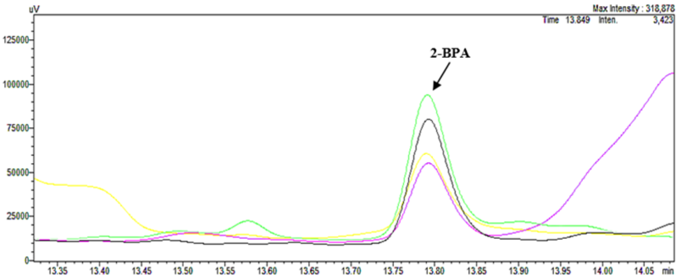

Figure 3. Overlain GC-ECD chromatogram of standard acrylamide solutions.

2.8 Estimation of acrylamide

The amount of acrylamide in potato chip was estimated by a gas chromatograph-electron capture detector (GC-ECD) (Zhang *et al.,* 2006; Zhu *et al.,* 2008). Acrylamide, a polar and nonvolatile compound, requires derivatization to enhance its volatility and improve chromatographic separation. Bromination using potassium bromate ($KBrO_3$) and potassium bromide (KBr) converts into two acrylamide derivatives: 2,3-dibromopropionoamide (2,3-DBPA) and 2-bromopropenamide (2-BPA). The latter, 2-BPA, was selected for quantification due to its significantly higher peak response (20 times greater) and better sensitivity in ECD (Geng *et al.,* 2011; Yang *et al.,* 2011). These derivatives are less polar and soluble ethyl acetate and n-hexane, ensuring sharp peaks and reliable detection. A standard solution of acrylamide (10 μgmL^{-1}) was made into distilled water. Aliquots of 10 μL, 25 μL, 50 μL, 100 μL, and 200 μL were diluted to 10 mL to solutions of 10, 25, 50, 100, and 200 ppb, respectively. Each solution was treated with 0.6 mL of 10% (v/v) sulfuric acid and refrigerated at 4°C for 15 minutes. Derivatization was initiated by adding 1 mL of 0.1 M $KBrO_3$ and 1.5 g of KBr, followed by vortexing and refrigeration for 30 minutes. The reaction was halted with 0.1 mL of 0.1 M sodium thiosulfate ($Na_2S_2O_3$). The derivatives were extracted with ethyl acetate, evaporated to dryness, and reconstituted in n-hexane for GC-ECD analysis. Overlain chromatogram of standard solutions of acrylamide was shown in Figure 3. A calibration curve (Figure 4) was constructed using peak areas at a

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retention time of 13.79 minutes, and the regression equation was derived using the least squares method.

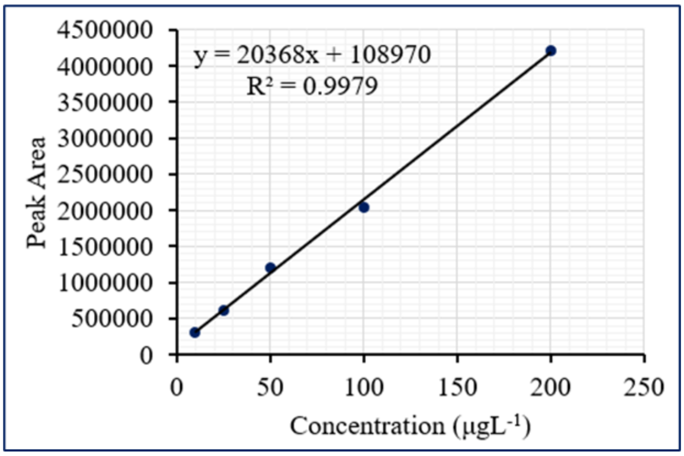

Figure 4. Calibration curve of acrylamide standards solution.

Powdered potato chip samples (1.5 g) were defatted with n-hexane using an ultrasonic shaker. The residue was extracted twice with 7 mL of 2 M sodium chloride (NaCl) to isolate acrylamide. The combined aqueous extracts were treated with 0.6 mL of 10% (v/v) H_2SO_4 and refrigerated. Derivatization was performed as described for the standards, and the derivatives were extracted with ethyl acetate, dried, and reconstituted in n-hexane for analysis. The final extracts were injected (1 µL) into a GC-ECD system equipped with an HP-5 MS capillary column (30 m × 250 µm × 0.25 µm). Nitrogen served as the carrier and makeup gas. The temperature program began at 120°C (hold for 1 minute), increased to 140°C at 12°C/min (hold for 5 minutes), and finally to 240°C at 20°C/min (hold 2 minutes). The injector and detector temperatures were maintained at 240 and 250°C, respectively, with splitless injection mode. Acrylamide residues were identified by comparing sample peaks with standard retention times. A calibration curve was generated from the standard solutions, and acrylamide concentrations in the samples were determined using their corresponding peak areas. This method ensured accurate and reproducible quantification of acrylamide in potato chip samples, providing critical insights into their safety and quality.

2.9 Method validation

Validation of the method was carried out through the analysis of acrylamide calibration curves (10 to 200 µgL^{-1}). A recovery analysis was conducted, which included 3 different chips samples, to confirm the accuracy and precision of the method. To 1.5 g of each chips sample, 500 µL of 1 µgmL^{-1} of acrylamide was added to spike the samples. For 10 min, the matrixes were left to stand. As previously described, acrylamide analysis was done on each sample. The following equation (1) was utilized for the determination of the recovery (R).

$$\% \, R = \frac{A-B}{C} \times 100 \text{ ---------------(1)}$$

where, A= acrylamide concentration in spiked sample, B= acrylamide concentration in unspiked sample, and C= the amount of acrylamide used for spiking.

A calibration curve was obtained with satisfactory linearity with correlation coefficient (R^2) of 0.9979. The sensitivity was studied by means of limits of detection (LOD) and quantification (LOQ). The LOD and LOQ was calculated using the following equations (Equation 2 and 3, respectively).

$$\text{LOD} = \frac{3.3}{b} S \text{ ------------------(2)}$$

$$\text{LOQ} = \frac{10}{b} S \text{ ---------------------(3)}$$

Where, S= SD of intercept of the calibration curve and b= Slope of the calibration curve.

2.10 Dietary acrylamide exposure assessment

This study estimated dietary acrylamide exposure (DAE) from salted potato chips using a standard formula (Equation 4). The calculation took into account the typical consumption of traditional bakery items, the levels of acrylamide in those products, and the average body weight of adults. The formula used is:

$$\text{DAE} = \frac{B \times S}{M} \text{ ---------------(4)}$$

Where, DAE is in µgkg^{-1} body weight per day, B = Amount of potato chips consumed (g or mL per day; 100 gday^{-1} is assumed as standard intake value), S = Concentration of acrylamide (µg/kg), M = Body weight, assumed to be 70 kg for an average adult (Briggs *et al.,* 2017; Benkhoud *et al.,* 2022).

2.11 Risk assessment of acrylamide

To assess health risks related to acrylamide intake, the margin of exposure (MOE) method was applied. This approach evaluates the potential for both neurotoxic and carcinogenic effects by comparing toxicological reference values with the estimated exposure. The neurotoxic risk assessment (MOE_n) value, which reflects the margin of safety for neurotoxic effects, was determined by dividing the no observed adverse effect level (NOAEL) by the estimated acrylamide exposure. The NOAEL for neurotoxicity was defined as 0.2 mgkg^{-1} body weight/day, based on toxicological data (Başaran *et al.,* 2023). The formula used is in equation (5):

$$MOE_n = \frac{\text{NOAEL}}{\text{DAE}} \text{ ---------------(5)}$$

The Margin of exposure for carcinogenicity (MOE_c) for carcinogenic risk assessment was calculated by dividing the Benchmark Dose Lower Confidence Limit for a 10% response ($BMDL_{10}$) by the estimated daily exposure. A $BMDL_{10}$ of 0.31 mg/kg body weight/day (or 310 µg/kg body weight/day) was used to represent the dose linked to a 10% increased cancer risk (Basaran and Faiz, 2022). The formula is in equation (6):

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$$MOE_c = \frac{BMDL_{10}}{DAE} \text{ ---------------(6)}$$

A higher MOE_n value indicates a lower risk of neurotoxic effects. An MOE_n value greater than 100 is generally considered to indicate a low level of concern for neurotoxicity. Similarly, a higher MOEc value suggests a lower risk of carcinogenic effects. An MOEc value greater than 10,000 is typically considered to indicate a low level of concern for carcinogenicity.

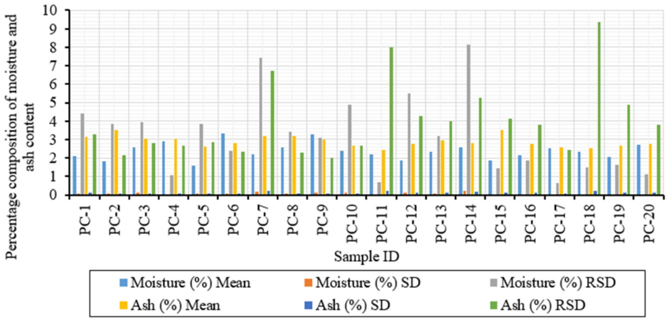

Figure 5. Composition, SD and RSD of moisture and ash content of salted potato chips.

3. Results and discussion

The moisture content of the analyzed potato chip samples exhibited a range of 1.587% (PC-5) to 3.308% (PC-6), with an average of 2.34% across all samples (Figure 5). The lower moisture content in samples like PC-5 (1.587%) and PC-12 (1.863%) suggests optimal frying conditions that achieved sufficient dehydration, which is crucial for achieving the desired crispness and extended shelf life. Conversely, higher moisture levels in PC-6 (3.308%) and PC-9 (3.282%) may indicate either insufficient frying time or inadequate packaging that allowed moisture absorption during storage. The standard deviation (SD) values were generally low (0.015-0.209), indicating good measurement precision, though PC-7 showed higher variability (SD=0.163, RSD=7.453%), potentially due to uneven moisture distribution within the sample batch. The exceptionally low RSD for PC-11 (0.675%) and PC-17 (0.643%) demonstrates excellent sample homogeneity and analytical consistency. Original-cut potato chips available in the Chinese market were found to contain moisture levels ranging from 0.67% to 3.78% (Cui *et al.,* 2024). Another study showed the moisture content for the potato chips varied between 0.92% and 3.67%, indicating that the chips retained relatively low levels of moisture under the different processing conditions. This study is aligned with the present research in Bangladesh (Ahmad Tarmizi and Niranjan, 2013). Proximate analysis of various potato chip varieties by another research revealed moisture content ranging from 1.12% to 1.39%. This variation indicates slight differences in the moisture levels across the different brands (Khalil *et al.,* 2024). Potato chips are packaged with a moisture content of 1.5%, but they turn soft and stale when the moisture level rises to 4% (Saldivar, 2016). The results suggest that most manufacturers in Bangladesh are maintaining proper frying protocols, though some samples (PC-6, PC-7, PC-9) may benefit from process optimization to reduce moisture variability and improve product stability.

Ash content, representing the inorganic mineral residue, varied from 2.430% (PC-11) to 3.532% (PC-2) across the samples, with an average of 2.89% (Figure 5). This variation primarily reflects differences in potato cultivar mineral composition and seasoning additives used during production. The higher ash content in PC-2 (3.532%) and PC-15 (3.502%) likely results from either mineral-rich potato varieties or the addition of salt and other mineral-containing seasonings. In contrast, PC-11's lower ash content (2.430%) suggests minimal use of such additives. The SD values for ash content ranged from 0.059 to 0.235, indicating generally good measurement precision, though PC-18 showed notably higher variability (SD=0.235, RSD=9.346%), possibly due to inconsistent seasoning application or non-uniform mixing during production. The lower RSD values for PC-9 (1.987%) and PC-8 (2.311%) demonstrate excellent process control in these samples. These findings correlate with previous research indicating that ash content in potato chips between 1.38% and 1.90%, indicating relatively consistent mineral composition across different samples (Yadav *et al.,* 2023). The average ash content found in another study varied slightly among the different snack types, with chips samples containing 3.84%, stick samples showing 3.71%, and extruded snacks having the lowest at 3.47% (Gaytancıo *et al.,* 2024). Another study indicated the ash content of potato chips varied between 1.00% and 3.11%, reflecting differences in mineral content (Yaseen *et al.,* 2020). Proximate analysis of different varieties of potato chips by another study showed ash content ranging from 0.93% to 2.13% (Khalil *et al.,* 2024). This variation reflects differences in the mineral composition of the chips. These values indicate minor differences in mineral content, which is aligned with the present study. The results highlight that while most Bangladeshi potato chip manufacturers maintain consistent mineral content, some variability exists, particularly in seasoned products.

The salt content analysis revealed significant variation across samples, ranging from 0.499% (PC-7) to 2.640% (PC-15), with an overall mean of 1.56% (Figure 6). This wide range reflects diverse product formulations targeting different consumer preferences. Samples PC-14 (2.628%) and PC-15 (2.640%) contained somewhat more salt levels. In contrast, PC-7's low salt content (0.499%) suggests it may be marketed as a low-sodium alternative. The standard deviations were generally low (0.007-0.109), indicating good measurement precision, though

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PC-4 (RSD=5.195%) and PC-13 (RSD=8.528%) showed higher variability, likely due to uneven salt distribution during seasoning. The excellent consistency in PC-1 (RSD=1.316%) and PC-16 (RSD=1.289%) demonstrates effective quality control in these products. A study found that 40% of potato chips contained a salt content of more than 2% (Beernaert *et al*., 1984). A study found that typical salt levels in potato chips range from 1.5% to 2.5%. This range reflects the common seasoning practices used by manufacturers to achieve the desired flavor (Riaz, 2004). The results suggest Bangladeshi manufacturers should consider gradual salt reduction strategies, particularly for high-salt products like PC-14 and PC-15, to address public health concerns while maintaining consumer acceptance through flavor optimization.

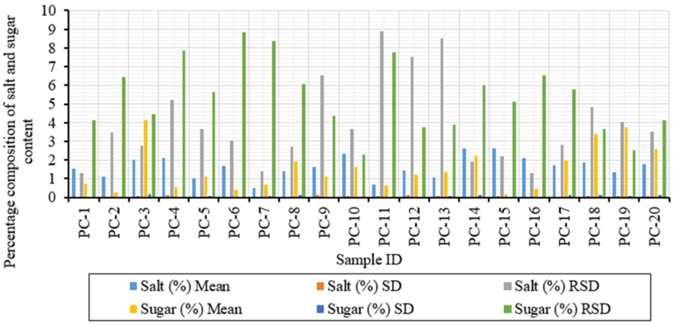

Figure 6. Composition, SD and RSD of salt and sugar content of salted potato chips.

Sugar content varied dramatically from 0.183% (PC-15) to 4.110% (PC-3), reflecting the diversity of product formulations from savory to sweet-flavored chips (Figure 6). The flavored varieties, particularly PC-3 (4.110%) and PC-19 (3.750%), contained significantly higher sugar levels, likely due to added sweeteners in their seasoning blends (Reynolds and Mitri, 2024). In contrast, traditional salted chips like PC-2 (0.263%) and PC-15 (0.183%) maintained minimal sugar content. The analytical precision was generally good (SD: 0.009-0.184), though PC-6 (RSD=8.836%) and PC-7 (RSD=8.355%) showed higher variability, possibly indicating inconsistent seasoning application. PC-10 demonstrated exceptional consistency (RSD=2.310%), suggesting rigorous quality control. These elevated sugar levels in flavored varieties are nutritionally concerning, as they contribute to empty calories and may enhance acrylamide formation during processing (Mesías *et al*., 2024). Another study reported the sugar content of potato chips ranged from 19.80% to 51.79%, indicating a significant variation that may be due to differences in the recipe or seasoning used by different manufacturers (Yaseen *et al*., 2020). Rady and Guyer (2015) reported the maximum sugar levels in potatoes intended for processing into chips typically range from 0.2% to 0.3%. Manufacturers should consider developing reduced-sugar alternatives using non-caloric sweeteners or natural flavor enhancers to address health concerns while maintaining product appeal.

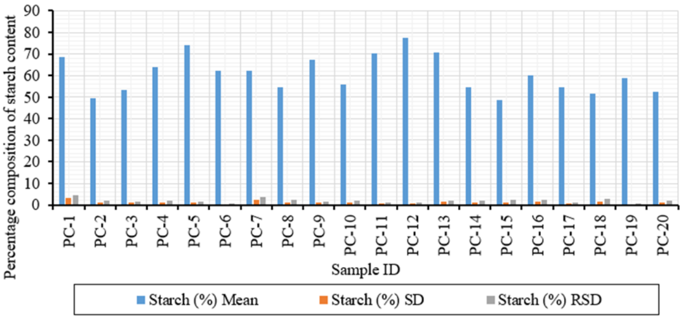

Figure 7. Composition, SD and RSD of starch content of salted potato chips.

The starch content of the analyzed potato chip samples showed considerable variation, ranging from 48.750% (PC-15) to 77.337% (PC-12), with an overall mean of 60.120% (Figure 7). This wide range primarily reflects differences in potato cultivars and processing conditions. Samples PC-12 (77.337%) and PC-5 (74.157%) exhibited exceptionally high starch content, characteristic of certain potato varieties bred for high dry matter content, which typically yield crispier textures after frying (Islam *et al*., 2022). In contrast, lower starch content in PC-2 (49.293%) and PC-15 (48.750%) suggests either the use of different potato varieties or possible starch degradation during processing (Islam *et al*., 2022). A study reported that the starch content in various potato varieties varied significantly, ranging from 26.06% to 21.15% (Islam *et al*., 2022). Another research reported that the starch content in potato chips ranged from 61.49% (Korish *et al.,* 2007). The analytical measurements demonstrated excellent precision, with relatively low standard deviations (0.328–3.055) across all samples. PC-6 showed particularly remarkable consistency (RSD=0.526%), indicating uniform starch distribution, while PC-1 had slightly higher variability (RSD=4.461%), possibly due to uneven frying or raw material heterogeneity. The low RSD values (<3% for most samples) confirm the reliability of the analytical method and suggest good manufacturing consistency. Furthermore, the consistent starch values in most samples (RSD<3%) suggest that Bangladeshi producers maintain good control over raw material selection and processing conditions, though the wide between-sample variation highlights opportunities for standardization to achieve more uniform product quality.

The recovery of acrylamide in spiked samples showed variations across replicates, with PCR1 recovering 77.98% (111.9975 µg/L), PCR2 achieving 84.23% (118.2437 µg/L), and PCR3 yielding 73.67% (107.6874 µg/L) from the 100 µg/L spike. These recovery rates between 73-84% indicate acceptable but slightly inconsistent extraction efficiency, possibly due to matrix effects or methodological variability. The sensitivity was tested by means of LOD = 0.51 μgL^{-1} and LOQ =1.54 μgL^{-1}.

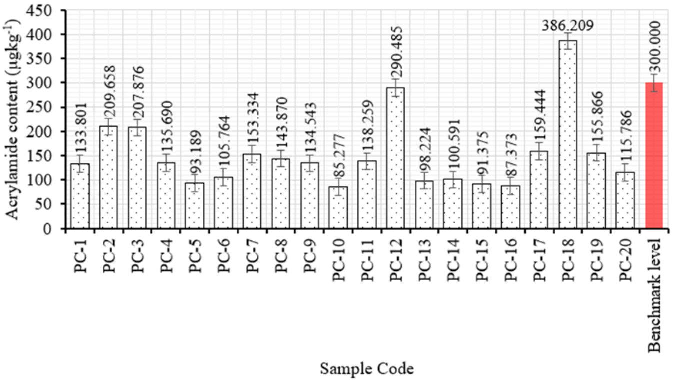

Figure 8. Acrylamide content in different salted potato chips samples.

According to European legislation, the established benchmark level for acrylamide concentration in potato chips is set at 300 μgkg^{-1} (Pogurschi *et al.,* 2021; Regulation - 2017/2158 - EN - EUR-Lex, 2025). The acrylamide content in 20 salted potato chips samples from Bangladesh varied widely (85.277–386.209 μgkg^{-1}), with PC-18 (Ruchi Thai Sweet Chilli) exceeding the European benchmark (300 μgkg^{-1}) by 28.7% (Figure 8). Three other samples (PC-2, PC-3, PC-12) approached this limit (207.876–290.485 μgkg^{-1}), suggesting potential health risks with prolonged consumption. Notably, PC-10 (Kurkure Cream and Onion) and PC-5 (Mr. Twist) had the lowest levels (85.277–93.189 μgkg^{-1}), possibly due to optimized frying conditions or ingredient selection. Regional variations were observed, with Nilkhet and Puran Dhaka samples showing higher acrylamide (133.801–290.485 μgkg^{-1}) compared to Mirpur and Gulshan (87.373–159.444 μgkg^{-1}), possibly linked to differences in processing temperatures or storage practices. These findings align with studies indicating that high-starch foods fried at elevated temperatures accumulate more acrylamide. Mitigation strategies, such as asparaginase treatment or reduced frying times, could help lower acrylamide in high-risk products to meet safety standards (Granda *et al.,* 2004; Liyanage *et al.,* 2021; Patial *et al.,* 2022). A recent study showed the presence of acrylamide in salted potato chips as 1575 μgkg^{-1} (Baharinikoo *et al.,* 2022) which is much higher than this study. A study on potato chips available in the Romanian market reported a highest acrylamide concentration of 266.00 μgkg^{-1} (Pogurschi *et al.,* 2021). Original-cut potato chips available in the Chinese market showed a wide variation in acrylamide levels, ranging from 166700 to 1101780 μgkg^{-1}. This significant fluctuation likely results from differences in frying temperatures, cooking durations, and raw material composition used by different manufacturers (Cui *et al.,* 2024). Significant differences in acrylamide levels observed among various brands producing similar products - primarily stem from variations in production parameters. These include critical processing factors such as cooking temperatures and duration of heat exposure, which are well-established as key determinants in the generation of this potentially harmful substance during food preparation (Jackson and Al-Taher, 2005).

Table 2. Acrylamide exposure risk due to consumption of salted potato chips in Bangladesh.

Sample	DAE (μgkg^{-1}day^{-1})	MOE$_n$	MOEc
PC-1	0.191	1046	1622
PC-2	0.300	668	1035
PC-3	0.297	673	1044
PC-4	0.194	1032	1599
PC-5	0.133	1502	2329
PC-6	0.151	1324	2052
PC-7	0.219	913	1415
PC-8	0.206	973	1508
PC-9	0.192	1041	1613
PC-10	0.122	1642	2545
PC-11	0.198	1013	1570
PC-12	0.415	482	747
PC-13	0.140	1425	2209
PC-14	0.144	1392	2157
PC-15	0.131	1532	2375
PC-16	0.125	1602	2484
PC-17	0.228	878	1361
PC-18	0.552	362	562
PC-19	0.223	898	1392
PC-20	0.165	1209	1874

The risk assessment of acrylamide exposure from salted potato chips in Bangladesh revealed significant variations in potential health impacts across different samples (Table 2). The DAE ranged from 0.122 to 0.552 μgkg^{-1}day^{-1}, with PC-18 showing the highest exposure level. Neurotoxic risk assessment through MOE$_n$ demonstrated that while most samples (MOE$_n$ > 100) posed negligible neurotoxic concerns, PC-12 (MOE$_n$=482) and particularly PC-18 (MOEn=362) fell below the safety threshold, indicating potential risk with chronic consumption. Similarly, carcinogenic risk assessment (MOE$_c$) showed that all samples except PC-12 (MOEc=747) and PC-18 (MOEc=562) exceeded the safety limit of 10,000, suggesting minimal carcinogenic risk for most products. The exceptionally high risk associated with PC-18 (DAE=0.552 μgkg^{-1}day^{-1}) may be attributed to its remarkably high acrylamide content (386.209 μgkg^{-1}), possibly resulting from suboptimal frying conditions or prolonged high-temperature processing. These findings emphasize the need for improved manufacturing practices, particularly for products showing MOE values below safety thresholds, to mitigate potential health risks associated with acrylamide exposure from frequently consumed snack foods in Bangladesh. The variation in risk levels across brands underscores the importance of standardized processing protocols to ensure consumer safety.

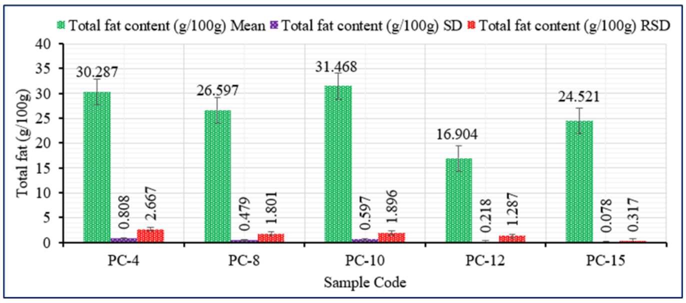

Figure 9. Total fat content in different selected salted potato chips samples.

The total fat content varied significantly among the samples, ranging from 16.904 g/100 g (PC-12) to 31.468 g/100 g (PC-10) (Figure 9). This variation can be attributed to differences in frying conditions, oil absorption rates, and the type of oil used during production (Zhang *et al.,* 2018; Paunović *et al.,* 2021). PC-10 exhibited the highest fat content, suggesting it may have been fried for a longer duration or at a higher temperature, leading to greater oil absorption. In contrast, PC-12 had the lowest fat content, possibly due to optimized frying conditions or the use of oil with lower absorption properties (Liu *et al.,* 2021). The low SD and RSD values across all samples indicate high precision of the analytical method. For instance, PC-15 showed the lowest SD (0.078) and RSD (0.317%), reflecting excellent consistency in measurements. Similarly, PC-12 demonstrated a low RSD (1.287%), further confirming the reliability of the results. The slightly higher RSD for PC-4 (2.667%) may be due to minor inconsistencies in sample homogeneity or extraction efficiency. The fat content in potato chips is a critical parameter for consumer health, as excessive fat intake is associated with various health risks, including obesity and cardiovascular diseases. A recent study reported the fat content in potato chips 28.57-34.58% (Gaytancıoğlu *et al.,* 2024). Similar fat contents were found in vacuum-fried and conventionally fried crisps, measuring 33% and 35%, respectively (Belkova *et al.,* 2018). The total fat content in another study of potato crisps ranged from 20.0 to 42.8% (Albuquerque *et al.,* 2012). Original-cut potato chips sold in the Chinese market exhibited fat contents ranging from 27.91% to 40.16%, reflecting considerable variation (Cui *et al.*, 2024). The results highlight the need for manufacturers to optimize frying processes to reduce fat content without compromising product quality. For example, PC-12, with the lowest fat content, could serve as a benchmark for producing healthier potato chips. The fat content observed in this study aligns with typical values reported for commercially available potato chips, which generally range from 20 to 35 g/100 g (Zhang *et al.,* 2018; Paunović *et al.,* 2021). However, the significant variation among samples underscores the importance of stringent quality control measures during production to ensure consistency and compliance with nutritional guidelines.

The fatty acid composition of selected potato chips (PC-4, PC-8, PC-10, PC-12, PC-15) revealed significant variations (Table 3). Saturated fatty acids (SFAs) were predominant in PC-4 (81.734%), primarily due to high lauric (51.434%) and myristic acid (17.949%) content, whereas other samples contained significantly lower SFAs (10.227-12.236%). Monounsaturated fatty acids (MUFAs) dominated in PC-8 to PC-15 (83.524-85.182%), with palmitoleic (40.862-43.068%) and oleic acids (41.031-43.427%) as major contributors. Polyunsaturated fatty acids (PUFAs) were minor components (3.0228-4.5894%), consisting mainly of linoleic acid (ω-6), while α-linolenic acid (ω-3) was below detection limits. The high MUFA content in most samples suggests the use of oils like palm olein or high-oleic variants, known for oxidative stability (Romano *et al*., 2021; Athanasiadis *et al*., 2024). Conversely, PC-4's high SFA content may indicate coconut or palm kernel oil use, raising health concerns due to potential cardiovascular risks (Arias *et al.,* 2023). These findings highlight the impact of frying oil selection on nutritional profiles.

Table 3. Fatty acids compositions in the selected potato chips samples.

Fatty acids	Types of fatty acids	Relative amount (%)				
		PC-4	PC-8	PC-10	PC-12	PC-15
Caprylic acid (C8:0)	SFA	BDL	BDL	BDL	BDL	BDL
Capric acid (C10:0)	SFA	2.677	BDL	BDL	BDL	BDL
Lauric acid (C12:0)	SFA	51.434	0.768	BDL	0.217	BDL
Myristic acid (C14:0)	SFA	17.949	1.192	1.078	0.965	0.976
Palmitic acid (C16:0)	SFA	BDL	BDL	BDL	BDL	BDL
Stearic acid (C18:0)	SFA	9.674	9.493	11.158	10.867	9.251
Arachidic acid (C20:0)	SFA	BDL	BDL	BDL	BDL	BDL
Behenic acid (C22:0)	SFA	BDL	BDL	BDL	BDL	BDL
	SSFA	81.734	11.453	12.236	12.049	10.227
Palmitoleic acid (C16:1, ω-7)	MUFA	10.065	43.068	40.862	40.777	41.755
Oleic acid (C18:1, ω-9)	MUFA	3.577	41.031	42.662	43.262	43.427
Euric acid (C22:1, ω-9)	MUFA	BDL	BDL	BDL	BDL	BDL
	SMUFA	13.642	84.099	83.524	84.039	85.182
Linoleic acid (C18:2, ω-6)	PUFA	3.0228	4.4471	4.2396	3.9112	4.5894
α-Linolenic acid (C18:3, ω-3)	PUFA	BDL	BDL	BDL	BDL	BDL

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Conclusion

This comprehensive study evaluated the physicochemical properties, nutritional composition, and acrylamide content of commercially available potato chips in Bangladesh, providing critical insights into their quality and safety. The analysis revealed significant variations in moisture, ash, salt, sugar, starch, and total fat across samples, reflecting differences in raw materials, processing techniques, and seasoning formulations. Notably, fatty acid profiling identified distinct oil usage patterns, with some brands containing high saturated fats, posing potential cardiovascular risks. Acrylamide levels exceeded the European benchmark in one sample, while three others approached this limit. Risk assessment indicated potential neurotoxic (MOEn < 100) and carcinogenic (MOEc < 10,000) concerns for two samples due to high dietary acrylamide exposure. The findings underscore the need for standardized frying practices, optimized ingredient selection, and stricter regulatory oversight to mitigate health risks. To enhance product safety, manufacturers should adopt mitigation strategies such as lower frying temperatures (<120°C) and shorter durations to reduce acrylamide and fat absorption; using low-sugar potato varieties and high-oleic oils to improve fatty acid profiles; and reduce salt and sugar content while exploring healthier flavoring alternatives. This study serves as a foundational reference for policymakers to establish localized food safety standards and for consumers to make informed dietary choices. Future research should explore large-scale monitoring and the efficacy of acrylamide-reduction technologies (e.g., asparaginase, vacuum frying) in Bangladesh's snack industry.

Conflict of interest

The authors declare no conflict of interest.

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