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Physico-Chemical and Nutritional Evaluation of Flour Made from an Under-Utilized Food Crop Buckwheat

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Buckwheat (*Fagopyrum esculentum Moench*) is widely regarded as a pseudo-cereal among economically significant yet underutilized crops. Nutritionally, it is comparable to or even superior to major cereals such as rice, wheat, and maize, particularly in terms of protective nutrients. Buckwheat is a gluten-free pseudo-cereal known for its high nutritional content and numerous scientifically proven health benefits. Its nutritional appeal lies in its high lysine content, absence of gluten due to lack of prolamin, and substantial protein levels. For processing buckwheat, seeds from a local variety were sourced from Roing, located in the Dibang Valley district of Arunachal Pradesh (Latitude: 28.17194, Longitude: 95.82454). The physico-chemical properties of the seeds

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were analyzed by measuring parameters such as length, width, bulk density, thousand kernel weight, moisture, crude protein, total fat, total ash, crude fiber, and in vitro protein digestibility. The study reported that buckwheat is an excellent source of protein, fiber, dietary fiber, and minerals. The nutritional content of buckwheat flour was determined as follows: moisture, 12.08%; ash, 2.33%; fat, 0.89%; protein, 12.84%; carbohydrates, 66.54%; energy content, 325.53 Kcal/100g; crude fiber, 5.38 g/100g; dietary fiber, 18.28 g/100g; protein digestibility, 74.38%; and carbohydrate digestibility, found to be low. The sodium and potassium contents were 3.7 mg/kg and 66.2 mg/kg, respectively. These findings highlight the nutritional benefits of buckwheat, showcasing its potential as a valuable food source, especially for those needing a gluten-free diet and seeking high-protein, high-fiber alternatives to traditional cereals.

Keywords: Protein; protein digestibility; carbohydrate digestibility; physical parameters; buckwheat.

1. INTRODUCTION

Increasing the intake of plant-based foods offers an effective strategy for addressing global issues of undernutrition and overnutrition, along with their impacts on public health and environmental sustainability. Reliance on cereal-based diets, such as those primarily based on wheat and maize, is considered a contributing factor to malnutrition in low- and middle-income countries due to their comparatively low levels of essential amino acids. Moreover, the Western diet, characterized by highly processed and refined foods, a lack of whole grains, and high levels of sugar, salt, and fat, as well as protein sourced from red meat, contributes to metabolic disorders and obesity-related diseases. Dietary macronutrient diversification, including the incorporation of plant-based protein sources, can promote agricultural diversity, help achieve climate goals, and improve health outcomes [1].

Under-utilized food crops are traditional crops that are agronomically well-suited to rainfed areas, including marginal lands. These crops thrive under a wide range of environmental and soil health conditions and are often nutritionally comparable to or even superior to major cereals like rice, wheat, and maize, especially concerning protective nutrients. Given the rapidly growing population and the need for alternative food crops to ensure nutritional security, it is essential to expand our food basket. Buckwheat (*Fagopyrum esculentum* Moench) is widely recognized as a pseudocereal among economically important underutilized crop plants. It belongs to the family Polygonaceae and the genus Fagopyrum. In India, buckwheat is cultivated in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, where it is gaining popularity due to the suitable climate [2].

In addition to Sikkim and Arunachal Pradesh, states in North East India, buckwheat is also commonly cultivated in the North Eastern states of Manipur, Nagaland, Meghalaya (West Khasi Hills), and in some regions of the Assam plains [3]. The crop is referred to in Assam by many different local names, including "*Dhemchi*" and "*Phaphar*." Although it has been cultivated in a few areas of Assam, the acreage and production numbers are not available since the crop is referred to as "coarse cereals"

Buckwheat is a gluten-free pseudo-cereal with high nutritional content and scientifically proven health benefits. Buckwheat flour is used in various products to create gluten-free foods suitable for individuals with gluten intolerance. Combined with health-promoting ingredients like phenolic compounds, sterols, and antioxidants, buckwheat is gaining popularity as a potential functional food [4]. It is well known for its rich content of nutritionally important proteins, lipids, dietary fiber, and minerals. Buckwheat proteins are noted for their high biological value and their content of thiamine, riboflavin, and pyridoxine. Nutritionally, buckwheat surpasses cereal grains in fatty acid composition, containing 80% unsaturated fatty acids, with more than 40% being essential linoleic acid [5]. Due to its very low prolamin content, buckwheat is particularly suitable for celiac patients, as it has a minimal amount of α-gliadin [6].

Foods with lower carbohydrate digestibility, such as buckwheat, typically have a lower glycemic index, resulting in a slower release of glucose into the bloodstream. This slow release helps manage blood sugar levels, making buckwheat an excellent choice for people with diabetes or those looking to avoid blood sugar spikes. Additionally, the slow digestion of carbohydrates increases satiety, aiding in appetite control and weight management. The high dietary fiber content of buckwheat contributes to its lower carbohydrate digestibility, promoting digestive health by nourishing beneficial gut bacteria and preventing constipation. Furthermore, buckwheat provides a balanced and sustained energy release, helping to maintain steady energy levels throughout the day and reducing the risk of energy crashes. Consuming low-glycemic foods like buckwheat can also reduce the risk of metabolic disorders such as insulin resistance, type 2 diabetes, and cardiovascular diseases. Overall, the lower carbohydrate digestibility in buckwheat enhances its value as a food source for those seeking to manage weight, control blood sugar, and maintain overall health. Given the significance of buckwheat as a functional food with high therapeutic and nutritional value, a study was conducted to analyze its physico-chemical and nutritional properties [7].

2. MATERIALS AND METHODS

2.1 Grain Collection

Buckwheat crop was grown in poor and less fertile land by broadcasting, with a seed rate of 40-45kg/ha. The crop was sown between September and October, and it was harvested 80 to 85 days later. The seeds (local variety) were obtained from Roing (Latitude is *28.17194 and Longitude is 95.82454*), in Dibang Valley district of Arunachal Pradesh. To remove any undesired dust particles, grains were washed carefully manually while soaking in running water. Clean grains were dried for 24 hours at 40 °C in a hot air oven (Oven Universal, hot air oven, NSW India). The remaining grains were ground to flour in a cutting miller (Retsch SM 100) and then sieved (mesh 60 mm), with one fraction of the grains being set aside for physical analysis. For further study, the flour was then stored in airtight jars.

2.2 Estimation of Physico Chemical Properties

2.2.1 Length and width

The physical characteristics (width and length) of the grains were measured with a vernier calliper [8] and the crop sample was measured ten times in a row.

2.2.2 Bulk density

The bulk density (gcm^{-3}) of the samples was determined using the volumetric displacement method [9].

2.2.3 Thousand kernel weight

A crop of one thousand seeds was chosen at random, and weights were recorded using an electronic digital scale. There were ten test weight replicates used.

2.2.4 Moisture

Using a hot air oven, the moisture content of grains was determined. Samples were placed in moisture dishes that had already been weighed and heated to 105°C ± 5 for one hour in a hot air oven. After removing the moisture dishes from the hot air oven and letting them cool in a desiccator, their weight was determined. Until a steady weight was reached, this process was repeated. The following formula was used to determine the moisture content: Moisture (%) = loss in weight (g)/weight of sample (g) × 100 [10].

2.2.5 Crude protein

The Kjeldahl method was utilised to assess the protein content. Samples were processed using a two-gram digestion mixture (potassium and copper sulphates) and 10 millilitres of 96% sulfuric acid on a heated plate in a Kjeldahl flask. After cooling and filtering via Whatman filter paper, the digested sample was poured into a 100 ml volumetric flask. A distillation flask containing 5 millilitres of the digested samples and 10 millilitres of 40% sodium hydroxide was used to capture the ammonium borate that had been freed. The boric acid solution (4%) contained two to three drops of indicator (methyl red and bromocresol green). 0.1 M HCl was used to titrate the distillate that was produced.

The following formula was used to calculate the nitrogen content: nitrogen (%) = sample weight × 100/titration value × M of HCl × 14 × 100, and the protein content using the following formula: Protein crude (%) equals nitrogen (%) × 6.25 [11].

2.2.6 Total fat

Using the Soxhlet extraction procedure, the total fat content was found. Weighed samples were placed in a thimble and extracted for eighteen hours using petroleum ether in a Soxhlet system. After that, the fat extract was put via a funnel in a beaker that had been previously weighed. After that, petroleum ether was evaporated, and the proportion of fat was measured by weighing the beaker [12].

2.2.7 Total ash

Ash content was determined using a muffle furnace for incineration, the content of ash was ascertained. First, weighted samples were burned on a hot plate in a pre-weighed silica crucible. After that, the crucible was heated to 550°C 5 for four hours in a muffle furnace. The crucible was then allowed to cool in a desiccator before being weighed. The following formula was used to determine the sample's ash content: Ash percentage = ash weight/sample weight × 100 [12].

2.2.8 Crude fiber

Total crude fibre were determined by standard methods of analysis [13]. Sodium and potassium contents were estimated for buckwheat flour using flame photometer method [14]. All the results from the above parameters were statistically analyzed to test the significance of the results using percentages, means, standard deviations [15].

2.3 *In vitro* Protein Digestibility

In vitro digestion of buckwheat protein begins with sample preparation, where a homogenized sample of the food containing the protein is weighed. The sample is then incubated with digestive enzymes, starting with pepsin at a pH of around 2.0 to mimic stomach conditions, followed by pancreatin at a pH of around 7.5 to simulate the small intestine. The sample is incubated at 37°C during these stages. The enzymatic reaction is terminated by adding trichloroacetic acid (TCA) to precipitate undigested proteins, and the mixture is centrifuged to separate the digested proteins in the supernatant from the undigested proteins in the precipitate. The soluble protein content in the supernatant is then analyzed using methods such as the Kjeldahl method. Protein digestibility is calculated by comparing the amount of soluble protein in the supernatant to the total protein content in the original sample, expressed as a percentage. Understanding protein digestibility is crucial for evaluating the nutritional quality of food products, aiding in the formulation of foods that meet specific dietary needs, and ensuring regulatory compliance through standardized testing methods. The AOAC method provides reliable information about the bioavailability of proteins in various foods, including buckwheat, thereby enhancing their nutritional value and health benefits [16].

2.4 *In vitro* Carbohydrate Digestibility

In vitro carbohydrate digestibility process begins with sample preparation, where buck wheat flour containing carbohydrates is accurately weighed and homogenized for uniformity. The sample then undergoes enzymatic digestion, starting with the addition of α-amylase, which breaks down starch into maltose and other oligosaccharides at 37°C for a specified period. Following this, the pH is adjusted to around 4.5 to simulate small intestine conditions, and amyloglucosidase is added to further hydrolyze the oligosaccharides into glucose, with incubation continuing at 37°C for an additional period. The enzymatic reaction is then terminated by heating the mixture to inactivate the enzymes, followed by cooling to room temperature. The mixture is centrifuged to separate the digested carbohydrates from the undigested residue, and the supernatant containing the soluble carbohydrates is collected. The glucose concentration in the supernatant is measured using a glucose assay kit or suitable analytical methods such as HPLC or spectrophotometry. Carbohydrate digestibility is calculated as a percentage of the total carbohydrate content in the original sample, providing valuable insights into the glycemic response and overall nutritional quality of the food [10].

3. RESULTS AND DISCUSSION

3.1 Physical Parameters

Understanding the physical characteristics of seeds is crucial for advancing processing technology. The development of value-added products, along with the design and fabrication of specific equipment and structures used in unit operations such as handling, transport, processing, and storage, requires comprehensive knowledge of the physical, chemical, and nutritional properties of buckwheat. This knowledge is essential because buckwheat undergoes a series of unit operations before reaching the final processing stage [17]. To characterize buckwheat, various physical characteristics were examined, including color, shape, bulk density, length, breadth, 1000-kernel weight, L/B ratio, and bulk density. The results of these investigations are presented in Table 1.

Buckwheat seeds were found to be dark to dark grey in color, with sharp edges forming a triangle shape. Buckwheat is distinguished by the shape of its seeds. According to cultivar and region-specific conditions, buckwheat's colour can range from dark brown to dark grey [18]. It was discovered that the bulk density averaged 0.65 g/ml. The larger bulk densities can be result of the grain's volume and shape.

The grain weight is an important yield contributing trait and therefore, the grain weight of buck wheat was found to be 29.68 g. Sangeeta and Grewal [19] reported higher hundred kernel weight (2.37/100 g) and lower bulk density (0.69 g/ml) for buckwheat varieties. Variation in physical characteristics in buckwheat may be attributed to varietal differences which is influenced by the size of the grains, moisture content etc. [20]. Length, breadth and L/B ratio of buck wheat seeds were 4.15mm, 3.25mm and 1.28. The value of length, breadth and L/B ratios of buck wheat seeds were varying depends on species.

3.2 Proximate Composition of Buckwheat Flour

The proximate composition of buckwheat flour was analysed and presented in Table 2. Data revealed that the moisture, ash, fat, protein, carbohydrate content was found to be 12.08, 2.33, 0.89, 12.84, 66.54%, respectively and the energy content of buckwheat flour was 325.53 K cal/100g.

Bhavsar et al. [21] reported the mean values of moisture, fat, protein, ash, and carbohydrate content in buckwheat flour as 11.35%, 2.20%, 10.41%, 2.67%, and 70.40%, respectively. The lower moisture content of buckwheat flour justifies its suitability for long-term storage without deterioration. Tang [22] evaluated the proximate composition of buckwheat and observed that the moisture, protein, lipid, carbohydrate, and ash content varied from 11.0 to 11.5%, 15.1 to 16.3%, 6.1 to 6.9%, 73.3 to 74.7%, and 3.5 to 3.9% on a dry weight basis. When compared to other common grains, buckwheat flour exhibits several distinctive nutritional properties [23]. For instance, the moisture content of buckwheat flour, as reported by Bhavsar et al. [21] and Tang [22] is slightly lower than that of wheat flour, which typically ranges from 13-14% [24]. This lower moisture content enhances the shelf life of buckwheat flour by reducing the risk of microbial growth and spoilage. Similarly, rice flour generally has a moisture content of 12-14% (Juliano, 1985), while maize flour ranges from 12-13% [25] making buckwheat flour more suitable for long-term storage. In terms of protein content, buckwheat flour, with values ranging from 10.41% to 16.3%, surpasses rice flour (6-8%) and maize flour (7-9%) [26]. Wheat flour's protein content is typically between 10-13% (Shewry, 2009), making buckwheat a comparable or superior source of protein, especially in the higher range reported by Tang [22]. This makes buckwheat flour an excellent option for those seeking higher protein content in their diets, particularly vegetarians and those with gluten intolerance. Regarding fat content, buckwheat flour (2.20% to 6.9%) has a higher fat content compared to wheat flour (1.5-2%) and rice flour (0.5-1%) [23]. Maize flour, with a fat content of 3-4% [25] is more comparable to buckwheat flour, especially in the higher ranges reported by Tang [22]. The higher fat content contributes to the energy density of buckwheat flour and provides essential fatty acids, including a significant proportion of unsaturated fatty acids [5].

The carbohydrate content of buckwheat flour (70.40% to 74.7%) is similar to that of wheat and maize flour, both of which range from 70-75% (FAO, 1991). However, it is lower than rice flour, which typically contains 80-85% carbohydrates [23]. This moderate carbohydrate content, coupled with a lower glycemic index, makes buckwheat flour a beneficial option for managing blood sugar levels and supporting weight management. Lastly, the ash content of buckwheat flour (2.67% to 3.9%) is significantly higher than that of wheat (0.4-0.7%), rice (0.3-0.6%), and maize flour (1.0-1.5%) [26]. This higher ash content indicates a richer mineral profile, enhancing the nutritional value of buckwheat flour and providing essential minerals needed for various bodily functions. In summary, the nutritional composition of buckwheat flour, as reported by Bhavsar et al. [21] and Tang [22] shows that it is a superior and versatile grain, particularly in its protein, fat, and mineral content. This makes it a valuable ingredient for those seeking gluten-free alternatives and nutritionally dense food options.

A wide variation in moisture, crude protein, fat, ash, crude fibre, carbohydrates, were observed in buckwheat flour which ranged from 10.2 to10.9%, 10.1 to 15.2%, 1.6 to2.9%, 1.4 to 2.5, 6.9 to 9.3%, and 61.8 to 67.7% respectively. Comparative performance of common buckwheat revealed the satisfactory presence of crude fibre, ash, carbohydrates and protein content. Buckwheat can be used for value addition of cereals and pulses [2].

Table 1. Physical attributes of buckwheat seeds

Sl. No.	Physical Attributes	Mean value
1.	Colour	Dark grey
2.	Shape	Triangular with sharp edges
3.	1000 Kernel Wt. (g)	29.68±0.41
4.	Bulk Density (g/ml)	0.65±0.02
5.	Length (mm)	4.15±0.85
6.	Breadth (mm)	3.25±0.41
7.	L/B ratio	1.28±0.02

Note: Values are expressed as mean ± standard deviation of three determinations.

Table 2. Proximate composition of buck wheat flour

S. No.	Parameters	Mean values
1.	Moisture (%)	12.08±0.25
2.	Ash (%)	2.33±0.13
3.	Fat (%)	0.89±0.08
4.	Protein (%)	12.84±0.80
5.	Carbohydrates (%)	66.54 ±1.00
6.	Energy (K cal/100g)	325.53 ±1.14

Note: Values are expressed as mean ± standard deviation of three determinations.

3.3 Nutritional Analysis of Buck Wheat Flour

The buckwheat flour (BWF) on the basis of dry weight was analysed for nutritional composition and the data are presented in Table 3. The crude fiber and dietary fiber content was found 5.38 g/100g and 18.28 g/100g. The protein digestibility of buck wheat flour was found to be 74.38%. Sodium and Potassium content of buck wheat flour was 3.7 and 66.2mg/kg, respectively.

3.3.1 Crude fiber

According to Mehta and Kaur [27] crude fiber is the material that remains after food sources undergo rigorous treatment with acidic and alkaline chemicals. Dietary fiber, on the other hand, refers to the plant material in food that resists enzymatic digestion. This includes components such as gums, mucilages, cellulose, hemicellulose, pectic compounds, and lignin. Natural sources of dietary fiber encompass grains, fruits, vegetables, and nuts. Evidence suggests that fiber-rich diets offer significant health benefits [28].

High-dietary-fiber diets help reduce the risk of cardiovascular diseases by lowering LDL and plasma cholesterol levels, although they do not affect HDL or triglyceride concentrations [29]. Table 3 displays the analysis results of the dietary fiber and crude fiber content in buckwheat flour (BWF). The in vitro protein digestibility of BWF was found to be 74.38%. Previous research has shown that the in vitro protein digestibility of raw flour at the intestinal phase ranges from 37.9% for millet to 78.0% for buckwheat, exceeding that of cereal-based diets [30,2,31]. The sodium and potassium contents of BWF were 3.7 mg/kg and 66.2 mg/kg, respectively (Table 3).

3.4 *In vitro* Protein Digestibility (%) of Buck Wheat Flour

The in vitro protein digestibility (IVPD) of buckwheat flour was reported to be 74.38±1.66%. This percentage indicates the amount of protein from buckwheat flour that can be broken down and absorbed during digestion, highlighting its nutritional accessibility. Comparing this finding with other studies reveals that buckwheat flour's protein digestibility is competitive among various grains and pseudocereals. Studies on quinoa and amaranth, for example, have reported IVPD values around 80% and 76%, respectively [32]. These values are slightly higher than that of buckwheat flour, suggesting comparable digestibility among these pseudocereals. In contrast, wheat flour typically demonstrates higher protein digestibility, ranging from 85% to 90% [33] owing to its composition and processing characteristics.

Table 3. Nutritional composition of buckwheat flour

S. No.	Parameters	Mean values
1.	Crude fiber (g/100g)	5.38±0.50
2.	Total dietary fiber (g/100g)	18.28±0.48
3.	In vitro protein digestibility (%)	74.38±1.66
4.	Sodium (mg/kg)	3.7 ±0.16
5.	Potassium (mg/kg)	66.2 ±0.74

Note: Values are expressed as mean ± standard deviation of three determinations

3.5 *In vitro* Carbohydrate Digestibility (%) of Buck Wheat Flour

One of the most important strategies for preventing the consequences of diabetes is blood glucose management. As oral hypoglycemic medications, inhibitors of the enzymes that analyse carbohydrates (α-amylase and α-glucosidase) have proven beneficial in controlling hyperglycemia only in people with type-2 diabetes mellitus [34]. α – amylase is a major enzyme responsible for breakdown of dietary starch into its by-products (oligosaccharide) which can then be broken down into absorbable monosaccharide in the intestine. Therefore, inhibiting this enzyme is seen as an active approach to diabetes treatment [35].

In the present study, the *in vitro* carbohydrate inhibition activities of the buck wheat flour extract was investigated using α- amylase enzyme [36-38]. IC_{50} values were calculated and the results are presented in Table 4 and percent inhibition of α- amylase enzyme activity in *in-vitro* carbohydrate digestibility was given in Fig. 1. IC50 was obtained by interpolation of linear regression analysis from the data obtained at various concentrations. The IC_{50} value of buckwheat flour (BWF) was better than the standard maltose. This implies that consumption of buckwheat flour inhibits α- amylase enzyme activity thereby extending the total carbohydrate digestion time, leading to a decrease in the rate of glucose absorption and therefore reducing the post prandial plasma glucose rise [39-41].

Table 4. Inhibitory activity of BWF against α - amylase

S. No	Parameter	BWF	Maltose
1.	IC_{50}	40.13±0.07	55.32± 0.04
2.	Mean	51.80	47.91
3.	S.E of mean	0.57	7.34
4.	C.D	1.30	1.01
5.	C.V (%)	1.32	1.14

Note: Values are expressed as mean ± standard deviation of three determinations. Means within the same column followed by a common letter do not differ significantly at p≤ 0.05.

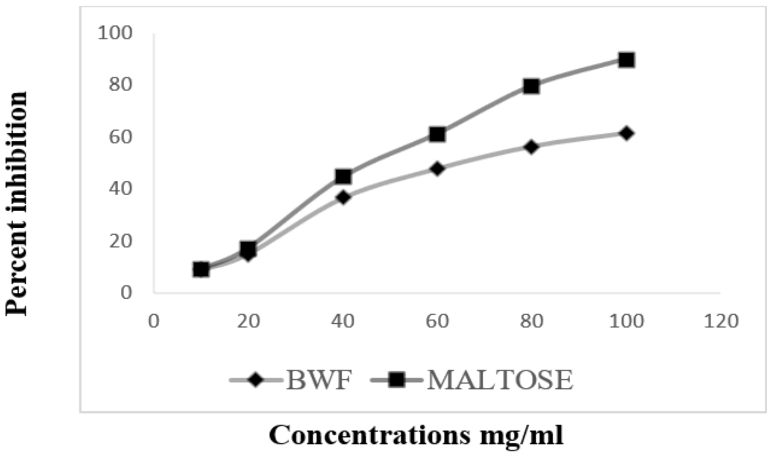

Fig. 1. Percent inhibition of α- amylase enzyme activity in *in-vitro* carbohydrate digestibility

4. CONCLUSION

In conclusion, the chemical and nutritional composition of buckwheat flour (BWF) demonstrates its potential as a valuable food ingredient rich in protein, fiber, dietary fiber, and essential minerals. The low starch digestibility of BWF suggests a beneficial role in managing blood glucose levels, making it a suitable component for foods aimed at improving health and nutrition. Incorporating BWF into various food products can enhance their functional and nutraceutical properties, contributing to a healthier diet. BWF can be used in gluten-free baking, pasta, and snack products, providing a rich source of nutrients while catering to dietary restrictions. The unique flavor profile of buckwheat adds an appealing taste to these products, further increasing their consumer acceptance. To fully leverage the benefits of BWF, further research is necessary to explore its applications across a diverse range of food products, thereby unlocking its full potential as a high-value ingredient in the food industry. Additionally, research on the synergistic effects of combining BWF with other health-promoting ingredients can further enhance its nutraceutical value. With continued exploration and innovation, buckwheat flour has the potential to become a cornerstone ingredient in the development of healthier, functional foods that meet the nutritional needs of a diverse population.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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