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COMPREHENSIVE EVALUATION OF TECHNOLOGICAL PARAMETERS FOR MORINGA POWDER RECONSTITUTION IN THE PRODUCTION OF INSTANT FUNCTIONAL BEVERAGES

The object of research is the recovery of moringa powder in the production of instant functional drinks. Despite the existence of researches on the use of moringa powder in functional products, the relationship between the structural and morphological characteristics of powder particles and the kinetics of its recovery requires in-depth research, which is important for substantiating the technological parameters of the production of instant functional drinks. The microstructure of moringa powder was studied using scanning electron microscopy, and the elemental composition was determined using energy-dispersive X-ray spectroscopy. The powder had a pronounced polydispersity with a predominance of stable cell conglomerates of irregular shape with a size of 5 to 130 μm. The presence of a developed rough surface and regular porous channels (from 5 to 15 μm) provides an increase in the specific area of contact with the liquid. A high protein potential was revealed due to the significant N content (9170 mg/100 g). It was found that consuming 100 g of a drink based on moringa powder provides 17.9% of the daily requirement of K without the risk of excess salt intake (Na covers only 3.3–3.8% of the requirement). Moringa powder is an excellent source of Mg (970 mg/100 g). This confirms its functional ability to contribute to the normalization of the nervous system. In addition, the functional properties of moringa powder and its positive effect on energy metabolism are provided by the high content of P (1100 mg/100 g). Separately, a significant content of Cr (0.36 mg/100 g) was noted, which is an active regulator of carbohydrate metabolism and blood sugar levels. The relationship between the microstructure, mineral composition and hydration behavior of moringa powder has been proven, confirming its use as an ingredient in powdered functional food systems.

Keywords: *Moringa oleifera, microstructural analysis, microelements, macroelements, functional properties, instant drinks.*

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1. Introduction

The main criterion for a product to be classified as functional food is its ability to elicit a noticeable physiological response in the body. The main function of such products is to provide the body with the necessary nutrients.

The functional beverage sector is constantly growing due to the growing desire of people for a healthy lifestyle. Modern consumer trends in the functional products market are formed under the influence of two dominant factors – "convenience" and "health". That is why the most promising form of production of functional beverages is instant drinks [1]. In view of this, the priority task of the industry is the development of dry concentrates of instant drinks.

The work [2] shows that functional foods can be considered foods that contain five minerals (zinc, calcium, iron, copper and magnesium) and twelve vitamins (niacin, pantothenic acid, biotin, A, B1, B2, B6, B9, B12, C, D and E). The results on the features of labeling of functional food products are presented and a detailed analysis of the functional effect on the human body of some of the components included in their composition is carried out. Despite this, the role of such critically important trace elements as chromium and silicon, which actively affect metabolic processes in the body, remained outside the attention of the authors in the mentioned research.

The paper [3] considers modern consumer trends, key bioactive ingredients and technological achievements in the field of functional food products of plant origin. The results shown show that the health-promoting effect of functional food products is largely explained by bioactive compounds such as polyphenols, flavonoids, vitamins, minerals and omega-3 fatty acids. These compounds have antioxidant, anti-inflammatory and cardioprotective properties. In view of this, products of plant origin, which include them, are becoming more popular. However, despite the confirmed high health-promoting potential of phytoraw materials, there is practically no systematic data in the literature on a comprehensive research of the chemical composition and microstructural characteristics of powdered plant systems.

Some researches have been conducted on the analysis of the mineral composition and structure of vegetable powders [4] and their use in the production of fortified milk has been proposed [5]. However, in these researches, the authors' attention was focused mainly on traditional vegetable raw materials. The specifics of the processing of other highly concentrated phytoobjects available for use in the production of functional beverages were not taken into account.

In work [6], the possibility of using wild berries of Viburnum opulus, Sorbus, Hippophae, Sambucus nigra as raw materials for the production of powdered functional food additives was considered. The structure of powdered additives was analyzed, and the content of micro- and macroelements was investigated. Despite a thorough analysis of powdered food additives from wild plant raw materials of regional importance, the results of this research cannot be transferred to other plant raw materials. In particular, highly concentrated leafy raw materials.

In the context of creating functional food additives, green plant raw materials of natural origin with a powerful bioactive potential are of particular scientific and practical interest, in particular spirulina, moringa, chlorella, young barley (barleygrass) and spinach. Moringa olifera is one of many plants that can be used as a functional food product and as a natural food additive [7]. Moringa leaves contain proteins, vitamins, polyphenols, carotenoids, tocopherols and ascorbic acid, which makes them an exceptional ingredient for enriching food products. Moringa leaves are most often used in the form of a powdered functional additive. Analysis of the presented data shows that the efficiency of recovery of powdered plant ingredients is determined by the complex action of their structural and morphological characteristics and technological parameters of the process [8, 9]. The greatest influence is exerted by the size and porosity of the particles, which ensure the intensity of water penetration and the speed of dispersion. At the same time, the temperature regime should be optimal, since excessive heating can negatively affect the functional properties of the components and the consistency of the finished product. Therefore, controlling the microstructure of the powder and the rehydration conditions are the determining prerequisites for obtaining homogeneous, stable, high-quality instant functional drinks. In modern scientific works, considerable attention is paid to the research of the chemical composition of moringa powders and their functional action. However, there are practically no results on the microstructural indicators of their quality. The microstructure of powder additives affects not only the physicochemical and organoleptic properties of enriched products. It determines how easily the body can absorb the biologically active substances present in them.

Worthy of attention is the research devoted to determining the chemical composition and mineral content of the leaves of the *Moringa oleifera* tree [10]. Moringa leaf powder (<0.1 mm) was analyzed. Calcium, iron, zinc, magnesium, sodium, aluminum, manganese, and chromium were found in moringa leaves. However, the structure of the powders was not analyzed. In addition, in the mentioned work, the authors limited themselves to stating only the presence of elements without assessing the degree of ensuring the daily requirement of the human body. Another research [11] showed that the consumption of moringa can cover the daily requirement of the body in Mg, Ca, P, and K. In addition, the bioavailability of the studied minerals was modeled at all stages of digestion in vitro. At the same time, it was found that the mineral composition significantly depends on the conditions of plant cultivation, soil type, vegetation phase, and drying technology [12, 13]. Fluctuations in the concentrations of individual elements in different batches of raw materials can exceed 30–50%, which makes it difficult to ensure stable nutritional value of the finished product. Therefore, when developing food systems using moringa powder, it is important not only to determine the overall mineral composition, but also to assess the safety of individual microelements [12]. However, the problem of technological stabilization of the mineral profile and control of the safety of microelements when used in food systems remains unresolved. It has been shown [14] that the inclusion of moringa powder in beverages improves their nutritional value and antioxidant properties. However, this research was exclusively analytical in nature and does not contain an assessment of the safety of beverages enriched with macro- and microelements.

In [15], attention is focused on the presence of critical gaps, in particular, the lack of unified industrial protocols for the extraction of native substances from moringa powders. Anti-nutritional factors are considered, in particular, the specific earthy-nutty flavor profile of moringa. In the above-mentioned review, the solution of these problems is considered mainly in the context of the creation of liquid emulsion systems. The features of the technological behavior of dry microdispersed powders and the features of their recovery in instant drinks remained beyond the attention of the authors.

The issue of a comprehensive assessment of the elemental profile of moringa powder and determining the exact percentage satisfaction of the daily human need when consuming drinks made on their basis remains unresolved. It is also advisable to study the influence of the microstructure of powder particles on the kinetics of recovery of instant drinks.

The object of research is the recovery of moringa powder in the production of instant functional drinks.

The aim of research is a comprehensive assessment of the technological parameters of moringa powder recovery in the production of functional instant drinks, which will ensure the proper quality of the finished product and the stability of its consumer properties.

To achieve the aim, the following objectives were set:

– to investigate the microstructural composition of moringa powder;
– to investigate the elemental composition of moringa powder and calculate the daily requirement of the body for minerals when consumed;
– to investigate the kinetics of moringa powder dissolution.

2. Materials and Methods

For the research, moringa powder (Moringa oleifera) from the company "Holistic Solutions s.r.o" (Czech Republic) was used.

The microstructural composition of moringa powder was analyzed using a REMMA-102 scanning electron microscope (OJSC "Selmi", Ukraine). A suspension was prepared from moringa powder. For this, the powder was recovered in distilled water at a temperature of 30°C for 20 min. The suspension was applied to the surface of a silicon single crystal KEF (111) and dried in vacuum until the solvent was completely evaporated. Scanning of the sample surface was carried out using an electron beam with a diameter of up to 5 nm with an electron energy of 20 kV. The image multiplicity was 80–800 times, the resolution was 5 nm. The images were obtained in elastically reflected electrons in the SOMRO mode.

Analysis of the elemental composition of moringa powder was carried out using a SEO-SEM Inspect S50-B microscope (OJSC "Selmi", Ukraine) using SEM and EDS detectors. Samples for research were pressed into tablets with a diameter of 2 mm with a polished outer surface. To prevent the accumulation of surface charge in the electron probe experiment, the dielectric samples were covered with a thin layer (30–50 nm) of silver.

The kinetics of hydration and dissolution of moringa powder in water were studied by the conductometric method. This method is based on recording the change in the specific electrical conductivity (x, μS/cm) of a heterogeneous system, increasing due to the diffusion and complete release of free ions of essential minerals (K^+, Mg^{2+}, Ca^{2+}, Na^+, Cl^-) during the dissolution process. A digital conductometer (AZ-86021, China) with automatic temperature compensation was used for the research. The measurement error was ±1%. The true degree of dissolution of dry matter at time (t) was calculated by the formula taking into account the maximum yield of the soluble fraction [16] (72%)

$$\alpha_t = \frac{x_t - x_0}{x_{\max} - x_0} \cdot 72\%, \tag{1}$$

where x_0 – the initial conductivity of distilled water (≈2 μS/cm); x_t – the conductivity at time t; $x_{\max}$ – the maximum stable conductivity after complete dissolution (1062 μS/cm).

Statistical analysis of data was performed by analysis of variance (ANOVA) followed by Fisher's least significant difference (LSD) test for multiple comparisons. Calculations were performed using Statistica 13.1 software (StatSoft, USA). The critical significance level for testing statistical hypotheses was set at $p < 0.05$.

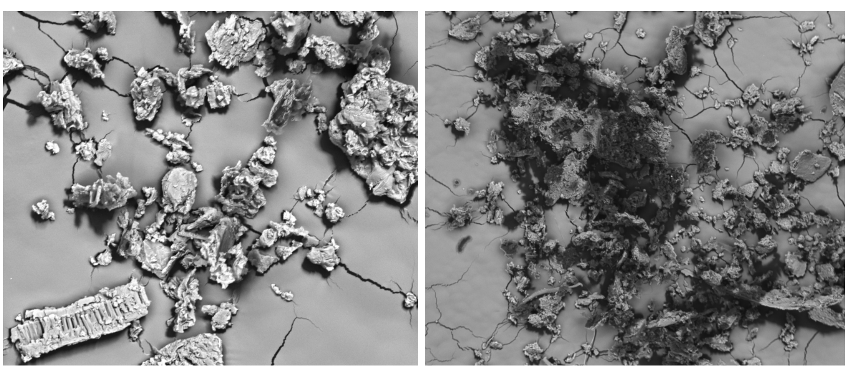
3. Results and Discussion

3.1. Research results of the microstructural composition of moringa powder

The microstructure of moringa powder is presented in Fig. 1.

Microstructural analysis showed that moringa powder is polydisperse with pronounced heterogeneity of geometric shapes and sizes. A mixture of both small fragmentary particles and large conglomerates is observed. The small dispersed fraction is probably represented by fragments of plant tissue cell walls, consisting of insoluble dietary fibers, in particular cellulose. The presence of insoluble dietary fibers in the powder can negatively affect the technological properties of instant drinks (precipitation formation, suspension heterogeneity). However, they play the role of an important biologically active (or prebiotic) component that increases the physiological value of the finished product. The size range of the bulk of the particles is from 5 to 50 μm, with the presence of single fragmentary fractions up to 130 μm. The sample contains anisotropic, angular, scaly structures with high roughness and porosity. This is evidenced by the presence of capillary channels of the conductive tissue.

The formation of fragile conglomerates was observed, in which small fractions (<5 μm) are adsorbed on the surface of large carrier particles (100–130 μm). The presence of individual too bright point inclusions on some fragments may indicate local accumulation of heavier elements (e. g., mineral salts of Fe, Ca or K). For powders obtained by mechanical grinding of dried biomass, an irregular, fragmentary shape is standard [16].



a *b*

Fig. 1. Microstructure of moringa powder: *a* – magnification of 100 μm; *b* – magnification of 500 μm

In general, the texture of moringa powder is characterized by a high specific surface area and a preserved porous structure, which ensures the ability of the powder to further dissolve and extract in beverages.

3.2. Research results of the elemental composition of moringa powder and calculation of the daily requirement of the body in minerals

The daily requirement of minerals was calculated taking into account the previously developed [17, 18] recipe for instant drinks. A portion of an instant drink weighing 100 g contains 25 g of dry concentrate (moringa powder) according to the recipe. The research results of the elemental composition of moringa powder and the daily level of provision are presented in Table 1.

The results showed that moringa powder contains essential macro- and microelements. In particular, Mg (970 mg/100 g) and P (1100 mg/100 g) were detected. Thus, the use of 100 g of a drink with a 25% moringa powder content allows to provide 48.5–60.6% of the daily requirement of the body in Mg and 22.9% in P. This justifies its use for the prevention of magnesium deficiency and stabilization of the nervous system [19]. It is worth noting that according to the results of similar researches [10], the maximum magnesium level in moringa powder was only 97.28 mg/100 g.

Table 1

Elemental composition of moringa powder and the daily requirement of minerals when consuming 25 g

Element	Mass fraction of element in moringa powder, mg/100 g	Daily requirement of the adult population in minerals, mg	Provision of daily requirement in minerals, %
P	1100[a]	1200	22.9
S	1860[a]	1000–3000	15.5–46.5
K	1790[a]	2500–3500	12.8–17.9
Ca	870[a]	1100–1200	18.1–19.8
Fe	32[a]	15–17	47.1–53.3
Cl	1400[a]	800–2300	15.2–43.8
Cr	0.36[a]	0.05	180
N	9170[a]	10000–16000	14.3–22.9
Mg	970[a]	400–500	48.5–60.6
Na	200[a]	1300–1500	3.3–3.8

Notes: *a* – the same letter indices within the lines indicate the absence of statistically significant differences between the studied parallel groups of spectra according to the Fisher least significant difference criterion. The differences between the samples are random and statistically insignificant $F(2, 18) = 0.713$; $p = 0.504$ at the critical significance level $p < 0.05$

Moringa powder was found to have a high level of Ca (870 mg/100 g), which is consistent with the study data [10]. Consumption of 25 g of moringa powder provides 18.1–19.8% of the daily requirement of the body, making moringa powder drink an effective means for preventing calcium deficiency and maintaining bone and tooth strength [20].

In addition, moringa drink may be useful for preventing anemia, as it contains 32 mg/100 g of Fe [21], which provides 47.1–53.3% of the daily requirement of the body. This iron content is more than twice the values (7.7–14.1 mg/100 g) obtained in similar researches [10].

Table 1 shows that the moringa powder drink has a high macronutrient and protein potential. This is evidenced by the high content of N (9170 mg/100 g), which is the main structural component of essential amino acids and plant proteins. When consuming 100 ml of the instant drink containing 25% moringa powder, 14.3–22.9% of the daily nitrogen requirement is provided. Therefore, moringa powder can be considered a valuable food supplement containing a significant amount of plant protein. Also, the studied moringa powder demonstrates an optimal balance [22] of electrolytes K (1790 mg/100 g), Na (200 mg/100 g), Cl (1400 mg/100 g) for the cardiovascular system. Drinking the drink satisfies 12.8–17.9% of the daily requirement for K, without creating the risk of excess salt intake, since Na, present in moringa powder, provides only 3.3–3.8% of the daily requirement.

The studied moringa powder is distinguished by high chromium content – 0.36 mg per 100 g of dry matter. This element directly affects carbohydrate metabolism, helping to maintain optimal glucose concentration in blood plasma [23]. The moringa powder drink can be considered functional, since daily consumption of 100 g provides 180% of the body's daily requirement for Cr. However, it is known [24] that chromium is able to accumulate in tissues, so this level of saturation is close to the optimal upper limit of safe consumption. In order to prevent the accumulation of excess of this element in the body, it is recommended to consume the drink in moderate portions or in periodic courses.

3.3. Research results of the kinetics of dissolution of moringa powder

The research results of the kinetics of dissolution of moringa powder in water are presented in Fig. 2.

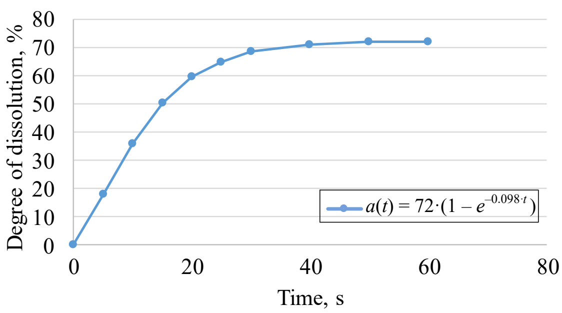


Fig. 2. Kinetics of dissolution of moringa powder in water

Graphical analysis of the obtained dependence showed that during the first 20 s, a phase of intensive mass transfer occurs. This period is characterized by a rapid linear increase in the degree of dissolution of the substance to the level of ≈60%. Such a high dissolution rate is probably due to the microstructural characteristics of the powder. In particular, the high specific surface area of the particles of the 5–50 μm fraction and the presence of a developed system of porous capillaries. Due to the high porosity, water penetrates into the particles, causing their destruction and rapid extraction of mineral salts (K, Mg, Ca).

Starting from the 20th second, a phase of diffusion deceleration and stabilization is recorded. At the same time, the leaching of nutrients from the largest fragmental fractions of plant tissue (130 μm) is completed. A complete thermodynamic plateau at the level of (72%) is reached at the 50–60th second of the research. The obtained results confirm the feasibility and high efficiency of integrating moringa powder into the formulation of dry drinks.

It is worth noting that water with a temperature of 25 ± 0.5°C was used to study the dissolution kinetics, since at this temperature the necessary measurement accuracy of the device is ensured. The use of hot water (90–100°C) significantly intensifies mass transfer. However, it is not recommended to prepare an instant drink based on water with a high temperature, since this will significantly affect its consistency and biological value.

Analysis of the elemental composition of the powder (Table 1) indicates a high content of nitrogen, and therefore proteins, which denature and coagulate at this temperature. Protein flakes can form an additional colloidal precipitate. Insoluble fiber, which is contained in significant quantities in moringa powder, also begins to swell [16]. This will lead to excessive viscosity of the beverage and the formation of insoluble sediment. High temperatures can also lead to the destruction of vitamin C contained in the moringa powder beverage [16]. The recommended water temperature for preparing a functional moringa powder beverage is 50–60°C.

3.4. Limitations and directions of research development

The limitations of this research include the fact that the assessment of the kinetics of powder dissolution was carried out by the conductometric method only at a temperature of 25°C. Although the theoretical justification indicates the feasibility of using water with a temperature of 50–60°C for the preparation of instant drinks, real thermodynamic parameters of mass transfer in this thermal range were not carried out. Such an assumption requires additional experimental confirmation.

The disadvantage of this research is that the analysis of the elemental composition is limited only to the statement of the total content of macro- and microelements in moringa powder. The work does not contain data on the real bioavailability of these nutrients and the degree of their absorption in the human gastrointestinal tract. At the same time, the research of the influence of the established large fragmental particles (up to 130 μm), which are components of the powder, on the sensory and physicochemical properties of instant drinks was ignored. It is appropriate to additionally analyze the technological types of processing of moringa powder, which will contribute to increasing their ability to dissolve.

Thus, further research will be focused on the analysis of the kinetics of dissolution of powders in water of different temperatures and modeling of digestion processes in an in vitro environment.

The results obtained in experimental researches have practical applied value during the implementation of the technology of instant functional drinks based on plant raw materials from dry concentrates. The described dissolution kinetics, which satisfies the obtaining of a stable phase transition in 50–60 seconds, and the reasoned water temperature (50–60°C) allow specifying a clear and precise technological regulation for the preparation of drinks. Compliance with the specified temperature regimes prevents denaturation and coagulation of proteins, given the high nitrogen content – 9170 mg/100 g. Prevents excessive swelling of fiber and destruction of vitamin C. The likelihood of the appearance of undesirable dispersed sediment or an overly viscous finished product is reduced. At the same time, the obtained numerical values of macro- and microelements allow to calculate an acceptable mass fraction of moringa powder in the product composition (25 g per 100 g of drink) to obtain a targeted physiological response.

Consumption of such a portion covers 48.5–60.6% of the daily requirement for magnesium and 47.1–53.3% for iron, which allows the use of raw materials for the prevention of mineral deficiency and anemia. Taking into account the high concentration of chromium (0.36 mg/100 g), the data allow to substantiate recommendations for moderate or regular consumption of the drink for the safe regulation of carbohydrate metabolism. The recorded geometric characteristics (predominance of particles with a size of 5–50 μm, single fractions up to 130 μm and the presence of porous channels from 5 to 15 μm) can serve as reference criteria for incoming quality control of mechanical grinding of dry plant components, since it is this structure that guarantees the intensification of mass exchange and the rapid release of intracellular components into the solution.

4. Conclusions

1. Analysis of the microstructural composition of moringa powder showed a high ability to dissolve and extract. The powder had a pronounced polydispersity with a predominance of stable cell conglomerates of irregular shape with a size of 5 to 130 μm. The presence of a developed rough surface and regular porous channels (from 5 to 15 μm) provides an increase in the specific area of contact with the liquid. This contributes to the intensification of mass transfer, hydration of the powder and the release of intracellular nutrients into the solution. The presence of insoluble dietary fiber limits the technological properties of classical soluble systems due to the risk of sediment formation and suspension heterogeneity. At the same time, these components play the role of valuable prebiotics, which allows positioning moringa powder

as a promising raw material for the production of functional instant drinks. The established features of the microstructure of moringa powder can be used to select the conditions of its technological processing and predict the behavior of raw materials during recovery in the composition of instant functional drinks.

2. Analysis of the elemental composition confirmed the high nutritional and functional value of moringa powder as a source of essential macro- and microelements. The powerful protein potential of the powder was shown, due to the significant content of total nitrogen (9170 mg/100 g). Moringa powder was characterized by a balanced mineral profile with pronounced cardioprotective properties. Consumption of 100 g of a drink based on it covers 17.9% of the daily requirement for K with a minimum sodium load, which eliminates the risk of excess salt intake. Due to the high concentration of Mg (970 mg/100 g) and P (1100 mg/100 g), moringa powder exhibits the ability to normalize the functioning of the nervous system and effectively support cellular energy metabolism. The high Cr content (0.36 mg/100 g) provides additional functional action as an active regulator of carbohydrate metabolism and insulin resistance. The obtained data on the elemental composition of moringa powder are the basis for substantiating its use as a functional ingredient and calculating the content of raw materials in the formulations of beverages with a given nutritional value.

3. Mass transfer kinetics showed the feasibility of using moringa powder for the production of instant beverage concentrates. Due to the microstructural features of the powder, the dissolution time is 50–60 seconds. To preserve the biological value of functional beverages and prevent denaturation and increase in viscosity, it is recommended to use water with a temperature of 50–60°C for their preparation. The established patterns of recovery of moringa powder make it possible to determine the rational parameters of its use in the technology of instant functional beverages, ensuring the proper quality of the finished product and the stability of its consumer properties.

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

Authors' contributions

Nataliia Bolhova: Conceptualization, Investigation, Resources, Writing – reviewing and editing, Supervision, Project administration; ***Vadym Karachov***: Resources, Writing – original draft, Funding acquisition; ***Viktoriia Ivchenko***: Verification, Formal analysis, Funding acquisition; ***Tetyana Yudina***: Methodology, Data curation, Funding acquisition; ***Victoriya Gnitsevych***: Verification, Formal analysis, Funding acquisition; ***Tetiana Pidpala***: Writing – original draft, Visualization, Funding acquisition; ***Marina Nazarenko***: Writing – original draft, Funding acquisition.

All authors have read and agreed to the published version of the article and are jointly responsible for the reliability, accuracy, and integrity of the data and research results presented in the article.

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