Optimal formulation of a product containing black wheat granules

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ABSTRACT
This study describes the development process of a healthy nutritional product containing black wheat granules (BWGP), which was based on Xinjiang characteristics of miscellaneous grains and nuts. BWGP was designed and developed as a local characteristic of nutritious food, which is produced from wheat, black sesame seeds, flour, corn flour, chickpeas, walnuts, peanuts, melon seeds, red dates, and brown sugar. The product was then underwent sterilization process followed by the inflated or vacuum quantitative packing as an instant ready-to-eat food. The best formula (%) was determined as follows: black wheat 30, corn flour 20, flour 15, chickpeas 15, black beans 2, peanuts 3, melon seeds 3, walnut 3, black sesame seeds 4, red date powder 15, sugar powder 15, maltodextrin 15, and sunflower oil 20. BWGP has several advantages, which include: a regional characteristic, simple production methods, and rich flavors. Overall, our study focused on the nutritional, flavor, and compositional effects and how a food product can be made healthier, more sustainable or more acceptable to the consumer.

ARTICLE HISTORY
Received 3 June 2018
Accepted 19 August 2018

KEYWORDS
Black wheat; nutrition; granule; product development

Introduction
In the 21st century, consumers are no longer simply satisfied with the daily food\textsuperscript{[1]}, but start to focus on eating well and healthy.\textsuperscript{[2]} Therefore, consumers have begun to bring food together in a comprehensive, diverse, and borderless manner.\textsuperscript{[3]} A “food and nutrition, eating healthy” food revolution is quietly beginning all over the world.\textsuperscript{[4]}

There is a growing understanding of the relationship between food ingredients, diet, and health among consumers who are aware of the effect of specific food ingredients on health and physiological functions.\textsuperscript{[5,6]} Currently, there are many kinds of powdered foods that are readily available on the market,\textsuperscript{[7]} such as black sesame paste, walnut powder, and lily powder. However, most of these instant granules use only a small amount of the main ingredients, and many of these products are similar to each other. In the Xinjiang Uygur Autonomous Region, China, there are some characteristic food ingredients that can be used to develop a healthy nutritional granulated product.\textsuperscript{[8]}

One of the food ingredients used in the design of Xinjiang characteristic granulated product is black wheat (triticale), which is rich in protein and antioxidant. Black wheat also contains high-quality proteins and essential amino acids, particularly the content linoleic and linolenic acids are 30%-50% higher than normal wheat. Its consumption is associated with several health benefits such as protecting endothelial cells, preventing heart and cardiovascular diseases (CVD) and as anticancer agents.\textsuperscript{[9,10]} In addition, it also contains anthocyanins and procyanidins. These bioactive

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compounds are associated with a reduced risk of the pathogenesis of chronic diseases such as diabetes, obesity, cancer, and cardiovascular disease.\textsuperscript{[11,12]}

Other ingredients such as sunflower oil are in the design of Xinjiang characteristic granulated product. The oil content of sunflower oil is generally between 30%-70\% \textsuperscript{[13]}, in which linoleic acid content is usually around 65%-73\%.\textsuperscript{[14]} Since the linoleic acid content is high, it is associated with some health benefits such as a reduction of blood pressure and serum cholesterol.\textsuperscript{[15]} Moreover, sunflower oil is also rich in vitamin A, D, and E.\textsuperscript{[16,17]} Therefore, regular consumption of sunflower oil is associated with a reduced risk of atherosclerosis, hypertension, and coronary heart disease.

Chickpeas (\textit{Cicer arietinum L.}) are also used in the design of Xinjiang characteristic granulated products. Chickpeas are one of the traditional sources of protein intake in humans. They are usually fermented or fried, especially in India, Spain, and some Mediterranean countries. Chickpeas have become the world’s third most important food legumes after dry beans and dried peas because the global consumption of chickpeas has increased steadily in recent years.\textsuperscript{[18]} Chickpeas are rich in potassium and phosphorus.\textsuperscript{[19]} For those who are lactose-intolerance, chickpeas can account for a large proportion of calcium required. Chickpeas are a good source of B vitamins, vitamin C, A, E, and K. Chickpea protein content ranges from 18\% to 28\%.\textsuperscript{[20,21]} Its protein digestibility, biological value, net protein utilization, and protein efficiency are higher than soybeans.\textsuperscript{[22,23]} Even with different methods of processing chickpea, this does not affect the composition of its amino acids.\textsuperscript{[24]} This can greatly improve the diet of malnourished people. The protein digestibility of chickpeas ranges from 48\% to 89.01\% \textsuperscript{[25]}, higher than that of soybeans and peas.\textsuperscript{[26]} Chickpeas can also lower cholesterol level because of the composition of its fatty acids. Chickpeas have 35\% oleic acid and 63\% linoleic acid.\textsuperscript{[27,28]}

Other food ingredients such as black sesame and jujube (Chinese date) are also used in the design of Xinjiang characteristic granulated products. Black sesame is rich in vitamin E content\textsuperscript{[29,30]} and its consumption has been associated with health benefits such as protective against CVD and hypertension.\textsuperscript{[31,32]} Jujube is high in sugar content.\textsuperscript{[33]} It is rich in various proteins, amino acids, carotenoids, vitamin C, vitamin B\textsubscript{2}, calcium, iron, and phosphorus.\textsuperscript{[34]} Therefore, the aim of the study was to develop a healthy nutritional product containing black wheat granules (BWGP), which was based on Xinjiang characteristics of miscellaneous grains and nuts.

\textbf{Materials and methods}

\textbf{Materials and reagents}

Black wheat, black beans, black sesame, chickpeas, corn flour, flour, peanuts, melon seeds, walnuts, red dates, and brown sugar powder were bought from Urumqi Home Supermarket Co., Ltd. (China). Additives including maltodextrin, calcium carbonate, calcium gluconate, vitamin C, TBHQ, BHT, and D-VC sodium were provided by the manufacturers and complied with the Chinese National Standards.

\textbf{Instruments and equipment}

DHG-9140A electric blower drying box (Shanghai YiHeng Scientific Instrument Co., Ltd., China); ATO-M4016AB ACA electric oven (North America Electrical Appliance (Zhuhai) Co., Ltd., China); TCH-60 automatic stir baking machine (Qufu Tianyang Machinery Manufacturing Co., Ltd., China); FW-100 high-speed universal crusher (Beijing Yong Guangming Medical Instrument Co., Ltd., China); C21-SDHCB15 induction cooker (Zhejiang SUPOR Share Ltd., China); 20–160 target standard sampling sieve (Zhejiang Shangyu Gauze Sieving Factory, China); PL2002 electronic balance (Mettler Toledo instruments (Shanghai) Co., Ltd., China); DLH-50L small mixer (Shanghai Deyue Powder Machinery Co., Ltd., China); DZ-260 vacuum packing machine (Wenzhou Xingye Machinery Equipment Co., Ltd., China).
**Process flow**

Figure 1 shows the technological process of the production of BWGP. As seen in Fig. 1, after the screening of raw materials and food ingredients, they were processed and mixed. After the semi-finished product was produced, it was tested and packaged as a finished product (i.e. BWGP).

**Operation points**

Black wheat, flour, and corn flour were roasted in a sealed pot at 80–100°C for 10–15 min in order to remove excess moisture from cereals. Then, the mixture was heated up to 150–160°C for 15 min in order to produce starch paste and flavors.

**Roasting of black wheat, flour, and corn flour**

The aroma of the mixture gradually appeared with increasing roasting time. Different roasting times were applied on black wheat, flour, and corn flour. When the roasting time was increased, the color of black wheat, flour, and corn flour changed gradually from white to yellow and finally to brownish. The wheat flavor was also increased with time.

**Baking of black wheat, flour, and corn flour**

Using 80–100 mesh sieve of fine powder as raw materials, the mixture was baked using an oven.

**Pre-treatment of black beans**

Fresh black beans were smashed using a universal crusher with 80–120 mesh sieve. Before adding to the mixture, black bean powder was stir-fried to increase its aroma.

**Black sesame treatment process**

High-quality black sesame seeds were soaked in the water to remove the soil and sediment. Then, black sesame seeds were blast dried to remove excess moisture on the surface of black sesame seeds. Black sesame seeds were baked on an ACA oven. After black sesame seeds were stir-fried using a flat pan at 160–180°C for 10–15 min, they were quickly cooled down for the esterification reaction to take place.

Figure 1. Shows the production process flow of BWGP from raw materials screening, processing, mixing, semi-finished products, testing, packaging, finished product sales, and other links.
Pretreatment of chickpeas
After fresh chickpeas were roasted using an oven, the chickpeas were smashed by a universal crusher with 80–120 mesh sieve.

Pretreatment of red dates
Red dates were graded according to their quality red dates before they were washed to remove the impurities. After removing pits from red dates, they were cut into small pieces for roasting at 60°C for 12 h to reduce the water content to <4%. Then, they were smashed using a universal crusher with 80 mesh sieve.

Results and discussion
Effects of baking condition on sensory evaluation of wheat flour
In Fig. 2, when baking at 140°C for 40 min and at 160°C for 30 min, the color of wheat flour gradually changed from white to dark yellow and then brown; and the aroma was also richer; the taste also had also changed from raw flour flavor into a slightly sweet cooked flour flavor, and there was a little bit of clumping. In addition, the color, taste, and aroma were good in all aspects. Since a longer baking time can have a certain impact on the equipment and increase the cost of production, it is better to choose the baking temperature of 160°C and the baking time of 30 min.

Effects of baking conditions on sensory evaluation of flour
In Fig. 3, when baking at 160°C for 40 min and 180°C for 5–10 min, the color of flour gradually changed from white to yellowish, and the aroma was also richer. The initial raw flour flavor gradually turned into a slightly sweet pasta flavor. Also, flour also caused agglomeration because of an increase in water loss. Although the color, taste, and aroma of flour were better in all aspects at 160°C for 40 min, a shorter baking time is preferable when taking into consideration both the food production and processing processes. Therefore, it is advisable to choose the baking temperature of 180°C and baking time of 15–20 min.

Figure 2. Effects of baking condition on sensory evaluation of Wheat flour (1 means “Not edible state (inedible)”; 2 means “During heating”; 3 means “Less cooked”; 4 means “Half-cooked state”; 5 means “Cooked edible state”). Temperature (from top to bottom) for each level is 10, 20, 30, and 40 min, respectively (The illustrations of Figures 2 to 6 are the same).
Effects of baking conditions on sensory evaluation of corn flour

In Fig. 4, when baking 160°C for 30–40 min and 180°C for 5–10 min, the color of corn flour gradually changed from light yellow to yellow-brown; the aroma of corn was obvious; the taste of cornflour gradually turned into a slightly sweet taste of cooked corn. Corn flour was different than flour, even when there was a large water loss, and basically, no agglomeration was observed and sensually as soft as fine sand. Although corn flour was better in color, taste, and aroma at 160°C for 30–40 min, the baking time was too long and it was not efficient for the cost of food production and processing processes. Therefore, it is advisable to choose the baking temperature of 180°C and baking time of 5–10 min.

Effects of baking conditions on sensory evaluation of black beans

When an excessive amount of black bean powder was added, this would give a more intense smell of black beans and will dilute the aroma of sesame and red dates. In Fig. 5, when baking at 140°C for 25–30 min, it gave the unique aroma of black beans. However, when the temperature was too high or baking time was too long time, black beans gave a sense of burnt and this would greatly affect the taste of the product, Therefore, it is advisable to choose the baking temperature of 140°C and baking time of 25–30 min.
Selection of roasting, baking conditions and content of black sesame seeds

Black sesame seeds were baked before crushing in order to remove the bitter taste of black sesame outer layering and increase the aroma of black sesame seeds. Stir-frying black sesame seeds gave an outstanding aroma fragrance and if followed by crushing (more than 40–60 mesh), the aroma would be particularly prominent. However, it is not recommended to grind them too fine because this would affect the overall taste. In addition, once the black sesame seeds are cooked, they should be used as soon as possible. Their storage time should not be too long because the unique aroma of the black sesame seeds would gradually dissipate.

Effect of baking conditions on sensory evaluation of black sesame seeds (Fig. 6). In Fig. 6, a too high baking temperature would make the black sesame seeds to produce a char smell. At the same time, the color of black sesame also turned from black to gray, and this would greatly affect the taste and color of products. Therefore, the most suitable condition was determined to be 160°C for 20 min.

Effects of added black sesame on the sensory quality of BWGP

In Table 1, the color, aroma, and taste of the BWGP increased with the addition of black sesame. However, when the dosage was more than 5%, the aroma of black sesame concealed the aroma and taste.

Figure 5. Effects of baking condition on sensory evaluation of black beans. The annotation in Figure 5 is the same as Figure 2.

Figure 6. Effects of baking condition on sensory evaluation of black sesame seeds. The annotation in Figure 6 is the same as Figure 2.
of other materials, which was similar to that of black sesame paste. When the dosage was less than 3%, the black sesame aroma was lacking and this caused the fragrance not sufficient. Therefore, after considering the distinction between the ubiquitous black sesame pastes available in the market, the product’s fragrance, the characteristics of Xinjiang foods, product sale costs and practical application of operations, the addition of 3%-5% black sesame seeds was considered to be appropriate.

Effects of roasted chickpeas on the sensory quality of BWGP

Chickpeas were baked by an ACA oven, but the effect was not better than frying. This is because frying can heat the chickpeas more evenly and quickly while avoiding chickpeas get burnt. The temperature of frying was 140–160°C for 20 min. Cooked chickpeas basically had no bean flavor. Therefore, an additional amount of chickpeas could be added as appropriate. However, considering that the poor water retention of chickpeas and the homogeneity of products, the amount of chickpeas added was determined to be 20%.

Effects of red dates on the sensory quality of BWGP

Adding a certain amount of red date powder to BWGP not only improved the sweetness of the product in synergy with brown sugar; but also made the product rich in aroma due to the special thick aroma of red dates. In Table 2, the sweetness, aroma, and taste of BWGP increased with the addition of the amount of red dates. With increasing amount of red dates added, the flavor of red dates was stronger, while the sunflower, sesame, peanut, and other fragrance were diluted. The flavor of red dates was too strong, vaguely accompanied by bitterness. Therefore, it was more appropriate to add 15% of red dates.

Effects of brown sugar on the sensory quality of BWGP

As shown in Table 3, when the amount of brown sugar was 5%, the sweetness was obviously insufficient. When it was added to 20%, there was a sweet feeling (except for those who had sweet tooth). When the

| Table 1. Effects of black sesame seeds on the sensory quality of BWGP. |
|---------------------------------------------------------------|
| Evaluation index                                   | Additions of black sesame seeds (%) |
|---------------------------------------------------------------|
| Color                                              | 1 | 3 | 5 | 8 |
| Aroma and taste                                    | Lighter color, brownish gray | Black appears | Brownish black, black sesame in the mixed material has obvious | Was brown, black |
| Aroma and taste                                    | Smell lighter, sesam specific aroma | Aroma is better, sesame specific aroma | Sesame unique aroma, flavor and fragrance are more appropriate head | Sesame aroma too thick, covering the aroma of dates and so on |
| Taste                                              | Insufficient sense of taste | No sesame exclusive taste, peanuts, red dates are good taste | Strong sense of taste | Strong sense of taste |

| Table 2. Effects of the addition of red dates on the sensory quality of BWGP. |
|---------------------------------------------------------------|
| Evaluation index                                   | 5 | 10 | 15 | 20 |
| Sweetness                                          | Lighter taste, no sweetness | Taste is still not obvious, Aroma appropriate | Slightly sweet, suitable for the general population, Aroma suitable, a little thick | More sweet, a small number of people prefer sweet food, Aroma, cover up part of the sesame, peanut aroma |
| Aroma and taste                                    | Basically do not highlight the aroma of red dates | Taste slightly, not prominent | Appropriate taste, synergy with sugar better | Jujube taste is too strong, a little bitter taste |
| Taste                                              | Basically no jujube flavor | Basically no jujube flavor | Basically no jujube flavor | Basically no jujube flavor |
amount of sugar was about 15%, moderate sweetness, in line with popular preferences, the comprehensive evaluation of the selection of brown sugar to add about 15% was appropriate.

**Sensory assessment**

Before products are released into the market, a sensory assessment is needed to be performed. However, the sensory assessment is easily to be affected by the external environment and human subjective factors which will result in a lack of certain objectivity and biased results.\(^{37}\) Therefore, the experiments are based on fuzzy mathematics theory in order to optimize the sensory test, quantify the ambiguity, the external environment, and subjective factors.\(^{38,39}\) This is a more scientific and accurate method to do the sensory evaluation.\(^{38,39}\) It also provides a theoretical basis for the industrial application using rational formulas.\(^{38,39}\)

**Determination of domain assessment**

The assessment domain related to the scopes of the study was determined in the form of a collection (a factor in which a branch of a domain is interconnected and has some relevance). In the sensory evaluation, the assessment domain is usually used as a general set of indicators that best reflect the quality of the food. Generally, this is referred as: \(U, U = \{u_1, u_2, u_3, \ldots, u_n\}\); where \(u_i\) represents the corresponding evaluation index of the \(i\)-th item, denoted as “\(i = 1,2,3, \ldots, n\)”.

The organizational structure, color and luster, aroma and taste, impulse stability and taste were the important sensory indicators of BWGP, which provide a more comprehensive reflection of the BWGP sensory quality. Therefore, these five indicators were selected as the evaluation objects and sensory evaluation was carried out by the method shown in Table 1. For example, \(u_1\) was set to represent the organizational structure, \(u_2\) was the color and luster; \(u_3\) was the aroma and taste, \(u_4\) was the impulse stability, and \(u_5\) indicates the taste. The final output for BWGP was calculated as \(U = \{u_1, u_2, u_3, u_4, u_5\}\).

For the sensory evaluation, a total of 10 participants were selected based on criteria including taste-sensitive in the research direction of agricultural product processing. According to the sensory evaluation criteria, the five indicators of BWGP were evaluated and the scores were recorded by participants.

**Determination of the commentary domain scores**

The comment domain refers to the set of feedback information about the evaluation index of a certain kind of food. Comments can be given in the form of text and used to represent a certain value or level. Usually, the commentary of the sensory test is denoted as: \(V, V = \{v_1, v_2, v_3, \ldots, v_n\}\); where \(v_i\) represents the evaluation level or score of the corresponding item \(i\). Remember: \(i = 1, 2, 3, \ldots, m\). According to the quality rating criteria shown in Table 1, the comment on the Black Wheat nutrition granules was calculated as: \(V = \{v_1, v_2, v_3, v_4\}\), Namely: \(V = \{\text{excellent, preferably, general, unqualified}\}\).
**Determination of the weight vector**

Due to the different degree of influence of the indicators on quality, a weight vector can be determined according to the weight value of each index. The weighting factors are: \( A = (a_1, a_2, a_3, \ldots, a_n), 0 \leq a_i \leq 1, \sum a_i = 1 \), where \( A \) is a fuzzy subset of \( U \); \( A \) and \( U \) are corresponding to each other, and \( A \) is a subset of \( U \). The weight vector related to triticale BWGP is obtained according to the weight values of the indexes in Table 4.

**Establishment of the quality factor weight set**

User survey method was adopted in the study.\(^{[40]}\) A ratio of 1:5 or 1:6 above 80°C hot water was added to 35–45 g BWGP samples, which were given to the 10 participants who did the sensory evaluation based on the five indicators.\(^{[41]}\) The weight of each quality factor, \( K \) was determined for the five indicators. The results were as follows: organizational structure (0.215), color and luster (0.195), aroma and taste (0.19), impulse stability (0.20) and taste (0.20), which gave \( K = (0.215, 0.195, 0.19, 0.20, 0.20) \) and the sum of weight values was 1 (Table 5).

**Establishment and results of fuzzy judgment matrix**

Table 5 shows the results of 10 participants according to the BWGP sensory evaluation criteria. The 5 indicators of the sample were determined by the 8 groups of samples (i.e., 8 sets of samples were different in the formulation adjustment) and the distribution of votes for each factor in each level was determined (Table 6). Fuzzy matrix 1–8 samples are as follows:

| State description       | Evaluation level                      |
|------------------------|---------------------------------------|
|                        | \( \psi_1: \text{excellent} \) | \( \psi_2: \text{preferably} \) | \( \psi_3: \text{general} \) | \( \psi_4: \text{unqualified} \) |
| Organizational structure | Loose powder without agglomeration, no visible foreign impurities, no fat precipitation | Loose powder slightly caking, a little fat precipitation | Slight caking, fat precipitation | Caking phenomenon, a little impurities, a large amount of fat precipitation |
| Color and lustre        | Color, texture is more uniform, showing gray-black | Gray-black, more uniform | Light gray or dark black, uniform | Gray and uneven |
| Aroma and taste         | Fragrant aroma, no burnt or other odor | With sesame and noodles flavor, no other smell | Slight fragrance, with a little burnt taste | No fragrance, burnt or other smell |
| Impulse stability       | With a proper amount of boiling water above 80 degrees, no obvious agglomeration, no layered phenomenon, moderate viscosity, uniform paste, and better fluidity | With a proper amount of boiling water above 80 degrees, no obvious agglomeration, moderate viscosity, fluidity after mixing better | After boiling water, knot groups, stratification phenomenon, the fluidity after mixing somewhat less | Too thick or too thin, more agglomeration or poor mobility, it is difficult to form homogeneous after mixing |
| Taste                   | Mellow taste fine, sweet entrance, and there is no astringent taste which is difficult to swallow | Taste more mellow, slightly sweet entrance, no significant astringent taste | Some astringent taste, sweet taste or sweet taste is not obvious | Rough taste, uneven sweetness, poor overall taste |
Table 5. The weight distribution statistics of BWGP quality factors (Fuzzy Judgment Matrix).

| Sensory evaluator number | Organizational structure | Color and lustre | Aroma and taste | Impulse stability | Taste |
|--------------------------|--------------------------|------------------|-----------------|------------------|-------|
| 1                        | 18.3                     | 19               | 20              | 20.5             | 22    |
| 2                        | 22                       | 21.5             | 18.5            | 18.5             | 19.5  |
| 3                        | 19                       | 21               | 19              | 22               | 19    |
| 4                        | 21.5                     | 19.5             | 20              | 19               | 20    |
| 5                        | 20.5                     | 19               | 22              | 19               | 20.5  |
| 6                        | 19.5                     | 20.5             | 18              | 22               | 20    |
| 7                        | 21                       | 19.5             | 19              | 20.5             | 20    |
| 8                        | 26                       | 16.5             | 20              | 16               | 21.5  |
| 9                        | 23.5                     | 19.5             | 18              | 17.5             | 21.5  |
| 10                       | 22                       | 18.5             | 17.5            | 23.5             | 18.5  |
| Mean value               | 21.5                     | 19.5             | 19              | 20               | 20    |
| Weight value             | 0.215                    | 0.195            | 0.19            | 0.20             | 0.20  |

Table 6. BWGPs for sensory evaluation of the distribution of votes (Fuzzy Judgment Matrix).

| Sensory evaluator number | Organizational structure | Color and lustre | Aroma and taste | Impulse stability | Taste |
|--------------------------|--------------------------|------------------|-----------------|------------------|-------|
| v₁; excellent; v₂; preferably; v₃; general; v₄; unqualified. |

\[
A_1 = \begin{bmatrix} 0.2 & 0.6 & 0 & 0.2 \\ 0.3 & 0.3 & 0.2 & 0.2 \\ 0.1 & 0.4 & 0.3 & 0.2 \\ 0.1 & 0.4 & 0.3 & 0.2 \\ 0.1 & 0.4 & 0.2 & 0.3 \\ 0.3 & 0.3 & 0.4 & 0 \\ 0.1 & 0.3 & 0.4 & 0.2 \\ 0.3 & 0.3 & 0.4 & 0 \end{bmatrix},
A_2 = \begin{bmatrix} 0.2 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.4 & 0.1 & 0.2 \\ 0.2 & 0.4 & 0.2 & 0.2 \\ 0.1 & 0.5 & 0.2 & 0.2 \\ 0.2 & 0.3 & 0.4 & 0.1 \\ 0.3 & 0.5 & 0.1 & 0.1 \\ 0.2 & 0.6 & 0.2 & 0 \\ 0.2 & 0.5 & 0.3 & 0 \end{bmatrix},
A_3 = \begin{bmatrix} 0.3 & 0.3 & 0.4 & 0 \\ 0.4 & 0.3 & 0.4 & 0 \\ 0.2 & 0.6 & 0.2 & 0 \\ 0.1 & 0.6 & 0.3 & 0 \\ 0.3 & 0.2 & 0.4 & 0.1 \end{bmatrix},
A_4 = \begin{bmatrix} 0.3 & 0.3 & 0.4 & 0 \\ 0.1 & 0.3 & 0.4 & 0.2 \\ 0.3 & 0.3 & 0.4 & 0 \\ 0.5 & 0.1 & 0.3 & 0.1 \\ 0.3 & 0.5 & 0.2 & 0 \end{bmatrix},
A_5 = \begin{bmatrix} 0.2 & 0.5 & 0.3 & 0 \\ 0.2 & 0.8 & 0 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \end{bmatrix},
A_6 = \begin{bmatrix} 0.3 & 0.3 & 0.4 & 0 \\ 0.4 & 0.2 & 0.4 & 0 \\ 0.2 & 0.3 & 0.5 & 0 \\ 0.4 & 0.2 & 0.4 & 0 \\ 0.3 & 0.4 & 0.3 & 0 \end{bmatrix},
A_7 = \begin{bmatrix} 0.3 & 0.4 & 0.3 & 0 \\ 0.2 & 0.3 & 0.3 & 0.2 \\ 0.1 & 0.6 & 0.3 & 0 \\ 0.2 & 0.4 & 0.2 & 0.2 \\ 0.2 & 0.4 & 0.3 & 0.1 \end{bmatrix},
A_8 = \begin{bmatrix} 0.4 & 0.2 & 0.4 & 0 \\ 0.3 & 0.4 & 0.3 & 0 \\ 0.4 & 0.1 & 0.5 & 0 \end{bmatrix}.

Fuzzy transformation and a comprehensive score

The weight K was multiplied by the fuzzy relation matrix Aₖ, namely: Rₖ = K × Aₖ. For example, corresponding to j sample, the evaluation result was Rᵢ, which reflected the excellent, preferably, general or unqualified approval rate of sensory evaluation for sample j. Taking the first group of samples as an example, the results of comprehensive evaluation of the samples were as follows:
The results showed that, under the condition that the content ratio was adjusted in different formulations, all participants reported that the treatment of BWGP under this condition was well. This indicated that the sample no. 8 had a favorable rating of 34.1%; 23.95% considered it as better; 41.95% considered it as normal and none considered this as failed. Similarly, the results of the comprehensive score of samples no. 2–8 were as follows:

\[
R_2 = (0.1995, 0.4215, 0.2205, 0.1585);
R_3 = (0.0835, 0.4195, 0.4590, 0.0380);
R_4 = (0.3010, 0.3000, 0.3400, 0.0590);
R_5 = (0.2815, 0.5595, 0.1375, 0.2150);
R_6 = (0.1635, 0.3960, 0.4005, 0.0400);
R_7 = (0.2025, 0.4185, 0.2800, 0.0990);
R_8 = (0.2025, 0.4185, 0.2800, 0.0990);
\]

Combined with the sensory evaluation of fuzzy mathematics, 8 samples were evaluated and evaluated by 10 participants in order to establish a comprehensive score. By comprehensive score:

The unqualified rates of 1st, 2nd, 5th, and 7th samples were between 10% and 22%, suggesting a relatively high product failure. While the 3rd and 6th samples had a positive rate of 8.35% and 16.35%, respectively. The sample no. 8 had a qualified rate of 100%, and the unqualified rate was 0. Meanwhile, the sample no. 4 also came after group 8th with higher scores and a relatively lower 5.9% rejection rate.

Using the formula, samples with the best ratio (i.e., the best quality of BWGP) were considered as the highest quality of the fuzzy sensory scores. Therefore, sample no. 8 had the most favorable ratio, reaching 34.1%, and the sum of ratios in favor reached 58.05%. Also, none think that the quality of the sample No. 8 was failed. Therefore, according to the BWGP fuzzy mathematical sensory comprehensive score, the sample no. 8 was corresponded to the processing conditions that indicated the best formula match.

**Conclusion**

From the selection of the various ingredients in the BWGP to the two methods of baking and frying the raw materials, the fuzzy evaluation of BWGP was carried out by the fuzzy mathematics sensory evaluation method. The best formula weight was set up, and the best formula weight set was \( K = (\text{organizational structure 0.215, color and luster 0.195, aroma and taste 0.190, impulse stability 0.20 and taste 0.20}) \). Therefore, sample no.8 was the best BWGP formula. The best formula (%) was determined as follows: black wheat 30, corn flour 20, flour 15, chickpeas 15, black beans 2, peanuts 3, melon seeds 3, walnut 3, black sesame seeds 4, red date powder 15, sugar powder 15, maltodextrin 15, and sunflower oil 20. Therefore, the development of BWGP will promote the use of some characteristic food ingredients in Xinjiang Uygur Autonomous Region, China because the expanded utilization of BWGP will increase its production. This will result in the social development of the region by creating job opportunities and opening new markets. Since the success of this study showed that BWGP is nutritious and easy to be prepared, future study should determine if BWGP can be used to provide food security, nutrition, and sustainability in populations.

**Acknowledgments**

The authors would like to thank the Key Technology Research and Development Program of Xinjiang Uygur Autonomous Region, China (2017B01003-3) for funding this project. All authors declare no conflict of interest.
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