APPLICATION OF THE ANALYTIC HIERARCHY METHOD TO OPTIMIZE THE CHOICE OF A GLUTEN-FREE COOKIE FORMULA FORTIFIED WITH BANANA PEEL POWDER

Mohammad Noshad*
Department of Food Science & Technology
Faculty of Animal Science and Food Technology,
Agricultural Sciences and Natural Resources
University of Khuzestan, Mollasani, Iran
Noshad@asnrukh.ac.ir

Sahar Asgharipour
Asghari.pur@gmail.com

ABSTRACT

When considering several factors affecting the quality of gluten-free cookies, choosing the optimal formula based on multi-criteria decision making is complex and not easy. Therefore, in this study the Analytic Hierarchy Process (AHP) method was used to optimize the best formula for a gluten-free cookie containing banana peel powder. For this purpose, physicochemical aspects such as texture, aroma, taste, color and porosity, fiber content, antioxidant activity, phenolic compounds, moisture content and ash content were evaluated to determine the optimal formula for a gluten-free cookie containing banana peel powder. The results showed that the optimal cookie contained 4% banana peel powder with a weight of 0.178. Moreover, the results showed that the rate of inconsistency was 0.77, and since it was less than 0.1 the results are reliable.

Keywords: AHP; gluten- free cookie; banana peel powder

1. Introduction

Celiac disease is an autoimmune disorder in which the patient has a permanent wheat gluten intolerance. When these individuals' intake gluten, the small intestine becomes inflamed causing damage to the intestinal mucosa and problems absorbing nutrients. The only effective treatment for celiac disease is adherence to a gluten-free diet throughout the patient's life (Giuberti, Marti, Fortunati, & Gallo, 2017; Lazaridou, Duta, Papageorgiou, Belc, & Biliaderis, 2007; Molinari et al., 2017). Therefore, paying attention to the production of gluten-free foods is very important for these patients. Currently, in many countries, extensive studies are being conducted in various fields related to this disease. The production of gluten-free products including fiber can play an

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important role in achieving products for celiac patients (Simons & Hall III, 2018; Turabi, Sumnu, & Sahin, 2010). Dietary fibers are carbohydrate polymers with 10 or more monomeric units that are not hydrolyzed by human intestinal enzymes. The fibers have many functions such as reducing cholesterol, blood glucose, and constipation (Lebesi & Tzia, 2011; O'Shea, Arendt, & Gallagher, 2012).

Bananas are one of the most widely used fruits in the world and are grown in almost all tropical countries (Choo & Aziz, 2010; Zhang, Whistler, BeMiller, & Hamaker, 2005). The banana peel makes up about 40% of the weight of a fresh banana and is considered agricultural waste and therefore discarded. The banana skin includes high levels of fiber, starch, pectin and effective chemical compounds. Most of the carotenoids found in the banana skin are xanthophyll (yellow matter), with a small amount of laurate, palmitate or caprate. The banana peel is rich in polymers such as lignin, hemicellulose, and pectin (González-Montelongo, Lobo, & González, 2010; Ortiz et al., 2017; Tibolla, Pelissari, Martins, Vicente, & Menegalli, 2018).

Cookies are a wheat-based food and are an important product of the bakery industry, and are very popular in the daily diet. Cookies have a very long shelf life and are available at almost any time (Jan, Panesar, & Singh, 2018; Popov-Raljić, Mastilović, Laličić-Petronijević, Kevrešan, & Demin, 2013; Simons & Hall III, 2018). Therefore, changes in the composition of cookies to enhance their nutritional or functional properties have attracted the attention of researchers (Molinari et al., 2017). When considering several factors affecting cookie quality, choosing the optimal formula based on multi-criteria decision making is complex and not easy, especially because most of the considered criteria are conflicting so that an increase in the desirability of one can reduce the utility of another. For this reason, multi-criteria decision-making methods have been developed to help solve these problems. In these methods, several options are compared based on several criteria, and the best option or arrangement of the appropriate options is selected. Among the multi-criteria decision-making methods, the Analytic Hierarchy Process (AHP) method is considered effective for considering quantitative and qualitative conditions and variables simultaneously (Ho & Ma, 2017; Saaty, 2008; Sardh et al., 2017).

However, no research has been conducted to date on the use of the AHP method to optimize food formulations. This study aimed to use the AHP method to optimize the best formula for gluten-free cookies containing banana peel powder.

2. Materials and methods

The ingredients that were used in the production of the cookie formulations include rice flour (Shomal Powderineh Co, Iran), sodium bicarbonate (Shahriar, Iran), shortening, sugar powder, dried milk powder (Pegah Co., Iran), xanthan gum (Rhodia Food Company, France), lecithin, sodium chloride and water and these were collected from the local market.

2.1. Preparation of the banana peel powder

After preparing the banana skin and washing it with water, it was placed in a 1% citric acid solution for 10 minutes, then placed in an oven at 40°C for 24 hours. Next, the

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samples were dried until the moisture content was 20%. The dried samples were then milled, and a 35 size mesh sieve was used to make the particle size uniform.

2.2. Cookie preparation

Jacob and Leelavathi (2007) used methods based on the AACC 10-52 standard with some modifications to prepare the cookie dough. The formula of the cookie dough contained 40g rice flour, 24g sugar powder, 12g shortening, 1.2g dried skim milk, 0.32g sodium bicarbonate, 0.18g sodium chloride, 0.18g lecithin, 0.2g xanthan gum, banana peel powder (0-12 g/100g samples of rice flour) and water in the necessary amount. The cookie dough was sectioned into parts with a thickness of 0.5cm × 4cm. The cookies were baked in the oven (SGC5-UD2311N, Snowa, Iran) at 180°C.

2.3. Moisture and ash content

The cookie moisture on a wet weight was measured with the approved method of AACC 44-16, and the cookie ashes were measured with AACC08-01.

2.4. Determination of color

The color of the cakes was determined using the Konica Minolta colorimeter device (CR-400 model, Japan). In this experiment, L* was determined as the criterion of brightness, a* as the criterion of redness, and b* as the criterion of yellowness.

2.5. Texture

The texture of the samples was analyzed using a TA XT2i (Stable Micro Systems, Goldalming, UK) equipped with a 500kg load cell. A full cookie was pressed at a speed of 5 mm/s with a 6 mm cylindrical probe to 50% of the cookie thickness. Through compression, a curve was created with the force greater than the distance. The highest maximum value was recorded because this value showed the first rupture of the cookie at a particular point. This amount of force was considered as the hardness (Cevoli, Balestra, Ragni, & Fabbri, 2013).

2.6. Dietary and non-dietary fiber

The fiber content was calculated according to the standard AOAC-991.43 method. In this test, acidic digestion and then basic digestion were performed, then the samples were dried in the ovens (Garcia-Amezquita, Tejada-Ortigoza, Heredia-Olea, Serna-Saldívar & Welti-Chanes, 2018) .

2.7. Total phenolic content (TPC)

The total phenolic content of the compounds was determined according to Singleton et al. (1999). The sample was defatted with a ratio of v/v 1:1 chlorophyram/petroleum ether. It was then dried in an oven at 40°C. About 1g of the defatted dry extract was mixed with 10ml of water or methanol. The mixture was processed in a centrifuge with 2000g for 15 minutes. Then, 70ml of the solution was separated and mixed with 900ml distilled water, 1ml of folin ciocalteous reagent, and 2ml of 10% sodium carbonate. The absorption was recorded after 60 minutes at a wavelength of 765nm. The total phenolic content as the equivalent of the gallic acid (GAE)/g dry weight sample was calculated from the calibration curve using the standard gallic acid solution (Singleton et al., 1999).

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2.8. DPPH assay

This method is based on the DPPH free-radical recovery by antioxidants in the absence of other free radicals in the environment. This results in coloration in an environment where its intensity can be measured by a spectrophotometer at a wavelength of 517nm. The experiment was carried out according to Benvenuti, Pellati, Melegari and Bertelli (2004).

2.9. Best choice of produced sample

In this research, a hierarchical analysis method was used to prioritize and select the best produced sample. First, the analyzed solutions and criteria obtained through the initial reviews were developed in a hierarchical analysis based on a hierarchical structure (including 4 options and 9 criteria). The data were analyzed using the Expert Choice software. The AHP method used in this study is effective when quantitative and qualitative criteria are present simultaneously, and when the multiple decision-making criteria make selection conditions problematic. The hierarchy determines the importance and priority of the various criteria.

The AHP process was carried out as follows (Saaty, 2008). The Analytic Hierarchy Process begins by identifying and prioritizing decision elements. These elements are comprised of four levels including goal, criteria, sub-criteria and possible options that are used in prioritization. The first level includes determining the goal. In this research, the goal is to achieve the best gluten-free cookie formula. The second level includes determining the criteria. The nine criteria used in this study are texture, flavor, color, moisture, porosity, total fiber content, antioxidant activity, total phenolic content and ash content. The third level includes the solutions, and the four solutions were analyzed, including the produced products to achieve the goal of optimizing the formula of the gluten-free cookie. Figure 1 shows the construction of the Analytic Hierarchy Process (AHP) model.

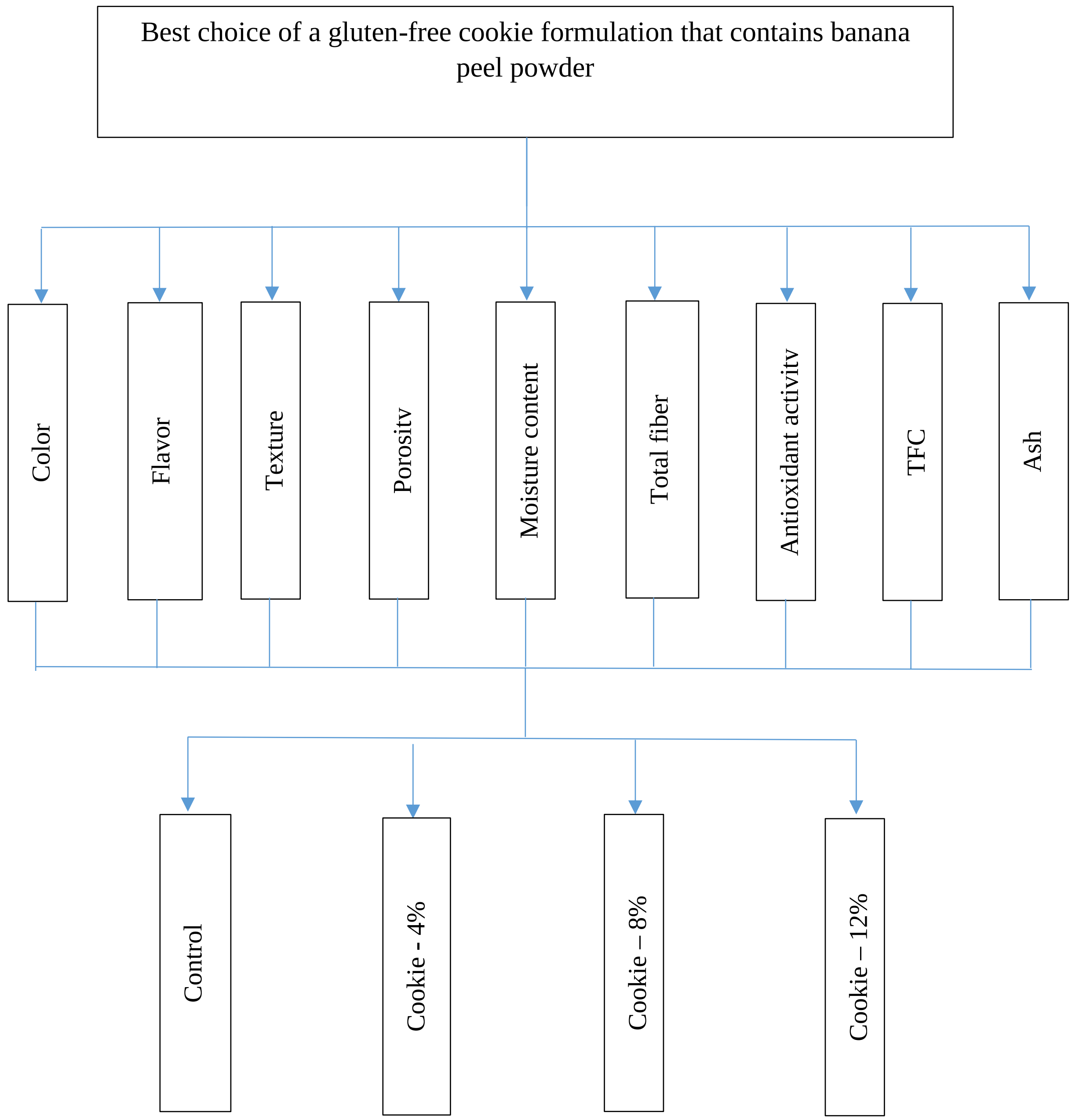

Figure 1 Analytic Hierarchy Process (AHP) model for optimizing the formula of gluten-free cookies

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2.10. Statistical analysis

The data reported in this study are the mean of a minimum of three replicates. All of the data were subjected to an analysis of variance (ANOVA), and later to the Duncan's multiple range test to evaluate the significant differences among the treatments at $p < 0.05$. The statistical analyses were performed using SPSS 23.0 (SPSS Science, Chicago, IL, USA).

3. Results and discussion

3.1. Moisture content

Moisture content is an important factor for evaluating the shelf-life and microbial stability of food products (Lebesi & Tzia, 2011). The results of the analysis of variance of the moisture content showed that there was a significant difference between the control and other samples ($p< 0.05$), however, there was no significant difference between the 4% and 8% samples (Table 1). The results indicate that by increasing the amount of banana peel powder, which is the fiber source, the moisture content of the samples increases significantly (Table 1). The use of dietary fiber increases the absorption and the ability to keep water in the samples, which leads to a delay in the samples becoming stale. This feature (increase in moisture content) is related to the porous structure of the fiber, which is formed by polysaccharide chains, and makes it possible to retain a large amount of water through a hydrogen bond (Kethireddipalli, Hung, Phillips, & McWatters, 2002; Lebesi & Tzia, 2011).

3.2. Color

The results of the analysis of variance showed that the addition of the banana peel powder had a significant effect on the color values (Table 1). The addition of the banana peel powder caused a decrease in L * and b * values. The lowest L* and b *values were for the control sample, and the 12% sample contained the highest values. The addition of the banana peel powder increased the a * value in the samples (Table 1). The reason for the change in the color value during the addition of the banana peel powder to the samples is probably due to the color and pigmentation of the banana that is created during the drying process as a result of the breakdown of pigments and enzymatic and non-enzymatic browning reactions in the sample (Chua, Mujumdar, Hawlader, Chou & Ho, 2001; Prachayawarakorn, Tia, Plyto & Soponronnarit, 2008).

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Table 1
Influence of the banana peel powder on moisture content and color values of the samples

Treatment	Moisture content (%)	b* value	a* value	L* value
Control	2.60±0.12[c]	26.78±0.31[a]	1.51±0.05[c]	71.58±0.13[a]
Cookie- 4%	3.50±0.11[b]	24.85±0.47[b]	3.17±0.48[b]	47.42±0.62[b]
Cookie- 8%	3.86±0.3[b]	22.01±0.53[c]	3.49±0.19[b]	43.49±0.22[c]
Cookie- 12%	4.95±0. 2[a]	20.42±0.13[d]	4.41±0.28[a]	41.48±0.16[d]

The different letters in each column indicate a significant difference ($p<0.05$) between the samples.

3.3. Texture

The hardness is the maximum force required to squeeze the food material between the teeth to achieve a certain deformity (Chaiya & Pongsawatmanit, 2011). The analysis of variance showed that the addition of the 4% banana peel powder did not have a significant effect on the hardness of the samples, while the increase in the amount of banana peel powder (4%-12%) increased the hardness of the samples significantly (Table 2). The increased hardness as a result of the increased banana peel powder is likely due to the connections between the banana peel powder and the corn starch granules, which prevent gelatinization of starch and cell wall fragmentation and thickening of cell walls during bubble formation. This is because the fiber interferes with the formation of air bubbles and increases the thickness of the cell wall. The results of this study were consistent with the results of other researchers regarding the rheological properties of the cake dough with the addition of apple pomace (Sudha, Baskaran & Leelavathi, 2007).

3.4. Ash content

The results of the analysis of variance showed that the addition of the banana peel powder caused a significant increase in the ash content of the samples (Table 2). Since increasing the amount of the banana peel powder, the minerals in the samples also increased, indicating the presence of minerals in the banana peel powder. The results were consistent with the results of other researchers (Choo & Aziz, 2010).

3.5. Total phenolic content (TPC)

Phenolic compounds are one of the most important antioxidant compounds in fruits and vegetables. Epidemiologic studies show that natural phenolic compounds play a major role in human health through antioxidant properties (Baliga, Baliga, Kandathil, Bhat, & Vayalil, 2011). The results (Table 2) showed that adding the banana peel powder had a significant effect ($p< 0.05$) on the TPC of the samples. The sample containing the 12% banana peel powder had the highest TPC among the samples. The increase in TPC in the sample due to the addition of the banana peel powder shows the presence of phenolic compounds in the banana peel powder (González-Montelongo et al., 2010).

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3.6. Antioxidant activity

The results of the DPPH radical inhibitory investigation are shown in Table 2. The results of the study showed that cookies containing the banana peel powder had more radical inhibitory capability when compared to the control sample, and the addition of the banana peel powder had a significant effect ($p < 0.05$) on the amount of radical inhibitory effect of the samples. As the amount of banana peel powder increased, the amount of the radical inhibitory strength of the samples also increased, as a result of the presence of phenolic compounds in the banana powder (Someya, Yoshiki, & Okubo, 2002).

Table 2
Influence of the banana peel powder on texture, ash, TPC, and antioxidant properties of the samples

Treatment	Hardness (N)	DPPH (%)	TPC (mg/g DW)	Ash (%)
Control	2.41 ± 1.41^{c}	$13.4 \pm 0.\ 2^{c}$	22.55 ± 1.62^{d}	1.75 ± 0.16^{b}
Cookie- 4%	5.16 ± 0.04^{cb}	$19.9 \pm 0.\ 9^{b}$	74.65 ± 1.06^{c}	2.02 ± 0.06^{a}
Cookie- 8%	8.91 ± 2.30^{b}	22.7 ± 1.1^{b}	102.90 ± 1.27^{b}	2.04 ± 0.06^{a}
Cookie – 12%	21.34 ± 0.92^{a}	$40.8 \pm 1.\ 2^{a}$	139.60 ± 4.8^{a}	2.16 ± 0.01^{a}

The different letters in each column indicate a significant difference ($p<0.05$) between the samples.

3.7. Fiber (dietary and non- dietary fiber) content

According to the definition of AACC, dietary fiber is a nutrition unit of the plant, similar to carbohydrates, that is resistant to digestion and absorption in the small intestine of humans, but it can be fermented completely or partially in the colon. Fiber composed of a large amount of cellulose, hemicellulose, and lignin is insoluble (non-dietary), while fibers containing high levels of polyfructose and pectin, are soluble (dietary) (Elleuch et al., 2008; O'Shea et al., 2012). The results of the analysis of the dietary and non-dietary fiber content of the samples are shown in Table 3. Moreover, based on the results of the analysis of variance, the addition of the banana peel powder has a significant effect on the amount of dietary and non-dietary fiber samples, so that the sample containing 12% banana peel powder has the highest amount of dietary and non-dietary fiber.

Table 3
Influence of the banana peel powder on dietary and non-dietary fiber of samples

Treatment	Non-dietary fiber (g/100g sample)	Dietary Fiber (g/100g sample)	Crude Fiber (g/100g sample)
Control	0.56±0.02[d]	0.29±0.03[d]	0.51±0.05[d]
Cookie- 4%	0.78±0.02[c]	0.47±0.02[c]	0.74±0.01[c]
Cookie- 8%	1.15±0.04[b]	0.76±0.04[b]	1.06±0.01[b]
Cookie- 12%	1.50±0.04[a]	0.99±0.04[a]	1.42±0.02[a]

The different letters in each column indicate a significant difference ($p<0.05$) between the samples

3.8. Best choice of produced sample

In the hierarchy analysis, there is a possibility of an inconsistency in the judgments. Therefore, a measure called the "inconsistency rate" is used to determine the degree of inconsistency of the judgments. These coefficients determine the magnitude of the probability that the pairwise matrix is completely randomly filled. An incompatibility percentage of 0.1 is the acceptable maximum (Prevc, Šegatin, Ulrih, & Cigić, 2013; Saaty, 2008; Sardh et al., 2017). Therefore, in order to evaluate and prioritize the four products, according to the hierarchical analysis based on the two physical criteria (with sub-criteria texture, aroma, taste, color and porosity) and a chemical measure (with the sub-criteria fiber content, antioxidant activity, TPC, moisture content and ash content), the results showed that the cookie that contained 4% banana peel powder with the weight of 0.178 was optimal when compared to the other products. Moreover, the results showed that the rate of inconsistency was 0.77, and since it was less than 0.1, the results are highly reliable (Figure 2).

Figure 2 Prioritization of the formulation of gluten-free cookies

4. Conclusion

When considering the several factors affecting the quality of gluten-free cookies, choosing the optimal formula based on multi-criteria decision making is complex and not easy. Therefore, in this study the Analytic Hierarchy Process (AHP) method was used to optimize the best formula for gluten-free cookies containing banana peel powder. For this purpose, physicochemical aspects such as texture, aroma, taste, color and porosity, fiber content, antioxidant activity, phenolic compounds, moisture content and ash content were evaluated to determine the optimal formula of gluten-free cookies containing banana peel powder. The results showed that the cookie that contained 4% banana peel powder with the weight of 0.178 was optimal when compared to the other products. Moreover, the results showed that the rate of inconsistency was 0.77, and since it was less than 0.1 the results are highly reliable.

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