

WATER-SOLUBLE BEAN-BASED EXTRACTS

Background of the invention

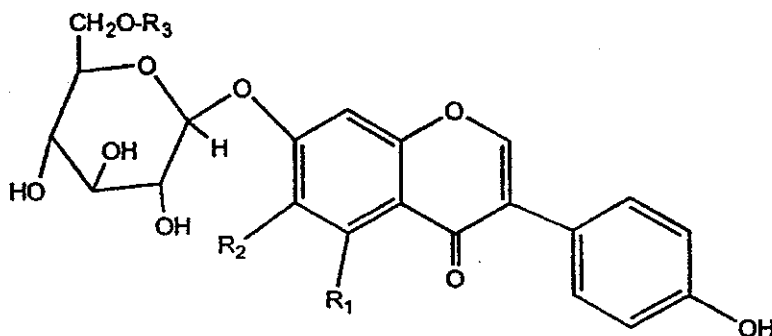
One of the newest and most intriguing areas of nutrition investigation involves food components called phytochemicals. Phytochemicals, such as isoflavones and their derivatives, are found only in plants, and although they are not classified as nutrients, they profoundly affect our health. See, for example, "Phytochemicals, A new paradigm" edited by W. R. Bidlack et al., published by Technomic publishing Co., Inc, 1998.

The discovery of phytochemicals has caused the dawning of a new era in nutrition. The phytochemicals found in beans, such as soybeans, are of particular interest. Beans and the products made from them, e.g., soybeans and soybean products, offer a unique approach to lowering the incidence of many chronic diseases such as cancer. See, for example, Journal of Agricultural Food Chemistry, 42, 1666 (1994); i.d., 43, 1184 (1995). Recently, research shows that consuming just one serving of soy foods a day may be enough to obtain the benefits of these phytochemicals. (See "The simple soybean and your health" by M. Messina et al., published by Avery publishing Group, Garden City Park, NY, 1994).

Many people, however, do not like to eat soy foods because of their smell, taste, and texture. One way to obviate the dislike of soy foods would be to take soybean isoflavones as dietary supplements. Unfortunately, soybean isoflavones and their derivatives have not been utilized as dietary supplements because of their low solubility in water. See "Genestein" by R. Elkins, published by Woodland Publishing, Pleasant Grove, Utah 1998.

Summary of the invention

In one aspect, the invention features a water-soluble bean-based dry or wet extract including one or more isoflavone derivatives of the formula:



where R₁ is hydrogen or hydroxy, R₂ is hydrogen or methoxy, R₃ is hydrogen or CO-R₄, R₄ being methyl or carboxymethyl. The water-soluble bean-based extract, in dried form, includes from about 5 to about 50 parts by weight of isoflavone derivatives and has a solubility from about 10 mg/ml to about 1,000 mg/ml in water at about 25°C. Examples of isoflavone derivatives present in the water-soluble bean-based extract include daidzin, genistin, glycitin, 6"-O- acetyldaidzin, 6"-O- acetylgenistin, 6"-O- acetylglycitin, 6"-O- malonyldaidzin, 6"-O- malonylgenistin, or 6"-O- malonylglycitin.

The water-soluble bean-based extract of this invention includes one or more isoflavone derivatives, e.g., an isoflavone glycoside, which complex with other components contained in beans to unexpectedly enhance their solubility in water.

In another aspect the invention features a method of preparing a water-soluble bean-based extract. The method includes mixing a pulverized crude bean extract with water, heating the mixture, adding a coagulant to the mixture to form a suspension, heating the suspension, and collecting the supernatant to obtain a water-soluble bean-based extract. The water-soluble bean-based extract of this invention has a pleasant taste and smell, and exhibits desirable composition and performance when used as an ingredient in any food product. For example, the water-soluble bean-based extract can be combined with a food product such as milk, tea, soft drink, juice, coffee, seasoning, cereal, water, beer, cookies, chewing gum, chocolate, or soup.

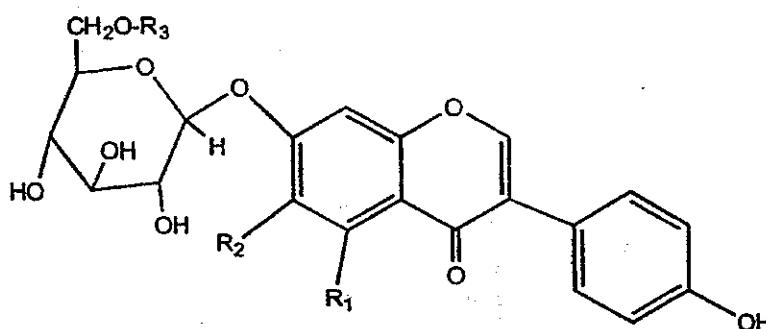
Other features and advantages of the invention will be apparent from the following detailed description, and from the claims.

Brief description of the drawings

Fig. 1 shows the HPLC chart of the major components in the water-soluble bean-based extract prepared in Example 1.

Detailed Description

The present invention relates to a water-soluble bean-based extract including isoflavone derivatives having the formula:



wherein R₁ is hydrogen or hydroxy, R₂ is hydrogen or methoxy, R₃ is hydrogen or CO-R₄, R₄ being methyl or carboxymethyl.

Examples of isoflavone derivatives present in an extract of this invention are daidzin, genistin, glycitin, 6"-O- acetyldaidzin, 6"-O- acetylgenistin, 6"-O- acetylglycitin, 6"-O- malonyldaidzin, 6"-O- malonylgenistin, and 6"-O- malonylglycitin. Isoflavone glycosides, such as daidzin and genistein, are absorbed in the stomach or small intestine and metabolized to isoflavones via aglycones by human intestinal microflora producing rhamnosidase, exo-beta-glucosidase, endo-beta-glucosidase or beta-glucuronidase. See, for example, Biol. Pharm. Bull, 21 (1998); Biol. Pharm. Bull, 17, 1369 (1994); and Arch. Pharm. Res., 21, 17 (1998).

The water-soluble bean-based extract of this invention has increased water solubility which improves the physiological absorption of the isoflavone derivatives into the body when used in food products. For instance, the solubility of genistin is about 5 mg/ml in methanol and about 1 mg/ml in water at 25°C, whereas the solubility of the water-soluble bean-based extract of this invention, containing at about 10 percent of isoflavone derivatives, is about 300 mg/ml in water. Typically, the water-soluble bean-

based extract of the invention provides an increase of about 30 fold in the solubility of isoflavone derivatives. In dried form, it includes from about 5 to about 50 parts by weight of isoflavone derivatives and has a solubility from about 10 mg/ml to about 1,000 mg/ml in water at about 25°C; preferably, about 10 to about 20 parts by weight
5 of isoflavone derivative and having a solubility from about 30 mg/ml to about 300 mg/ml; and more preferably, about 10 to about 20 parts by weight of isoflavone derivatives and having a solubility from about 50 mg/ml to about 200 mg/ml. Of course, the weight percentage of isoflavone derivatives affects the overall solubility of the water-soluble bean-based extract. For instance, the overall solubility of an extract
10 having a higher weight percentage of isoflavone derivatives will be less than an extract containing a lower weight percentage of isoflavone derivatives.

Any variety of beans can be used to make the water-soluble bean-based extract of this invention. Examples of beans used in making the water-soluble bean-based extracts include but are not limited to soybeans, mung beans, black beans, and kidney
15 beans. Preferably the beans are soybeans. In general, there are two different types of soybeans, e.g., food beans and oil beans, which can be used to make the water-soluble bean-based extract of this invention. Oil beans are preferred since they have smaller amounts of proteins relative to food soybeans. Typically, oil soybeans are first processed to produce "processed" soybeans by eliminating soybean oil. Examples of
20 processes for eliminating soybean oil can be found in "Soybean Chemistry, Technology, and Utilization", by K. S. Liu, Aspen Publishers, Inc. Gaithersburg, Maryland 1999.

The method of preparing the water-soluble bean-based extract of this invention includes mixing about 1 to about 50 parts by weight of a pulverized bean
25 crude extract with about 100 parts by weight of water (hot or cold). A pulverized bean crude extract can be produced by extracting crushed beans with about 50% to about 90% aqueous alcohol or 100% organic solvents, such as ethanol, methanol, or acetonitrile. An example of a pulverized bean crude extract is soy germ. Soy germ represents about 1% by weight of soybeans yet contains a higher concentration of
30 isoflavone derivatives relative to the remaining soybean portions. For example, the concentration of isoflavone derivatives in soy germ is about 6 times greater than the remaining soybean portions. See, for example, "Soybean Chemistry, Technology, and Utilization", by K. S. Liu, Aspen Publishers, Inc.

Gaithersburg, Maryland 1999. Pulverized bean crude extracts, such as soy germs, can be obtained from Schousten USA, Inc. as SoyLife 150 and SoyLife 25. Alternatively, pulverized soybean crude extracts can be purchased from Archar Daniels Midland Company as NOVASOY.

5 The mixture of water and pulverized bean crude extract is then heated to between about 60°C and about 100°C for about 10 to about 120 minutes and between about 0.001 to about 3.0 parts by weight of coagulant per about 100 parts by weight of water is added to the mixture to form a suspension, which is heated again to between about 30°C and about 100°C for about 1 to about 120 minutes. The supernatant is
10 subsequently collected, e.g., by filtration or centrifugation, to obtain a water-soluble bean-based extract having increased solubility. Additionally, the pH of the suspension or supernatant can be adjusted by adding acids or bases to avoid precipitating isoflavone derivatives. Typically, the pH is adjusted to about 6.0.

 The supernatant thus obtained can be decolorized to remove any undesirable
15 color. Decolorizing methods include, but are not limited to, hydrogenation with the aid of a nickel catalyst, and other bleaching techniques used in the manufacture of soybean oils. Decolorizing methods can be found, for example, in "Soybeans, Chemistry, Technology, and Utilization" by K. Liu, published by An Aspen Publication, 1999, and "In Introduction to oils and fats Technology" edited by P. J.
20 Wan, p-95, published by AOCS Press, Champaign, IL. The supernatant can also be concentrated by any distillation system known in the art, including but not limited to molecular distillation or evaporation. An example of a molecular distillation system is a Wiped-Film Still, available from POPE SCIENTIFIC, INC, located at 351 N. Dekora Woods Blvd. Saukville, WI 53080, USA. Additionally, the supernatant can
25 be dried by any drying method known in the art, such as lyophilization or spray-drying. (See, for example, U. S. Patent No. 5,882,717).

 The water-soluble bean-based extract of this invention can be produced by a batch method or a flow method, i.e., a continuous extraction and filtration process. Typically, flow processes are used to help maintain reasonable manufacturing costs.

30 The solubility of isoflavone glycosides is enhanced by the addition of about 0.001 to 3.0 parts by weight of a coagulant, such as CaCl₂, CaSO₄, MgCl₂, MgSO₄, any organic or inorganic acid, (e.g., citrus juice, fumaric acid, lactic acid, malic acid, tartaric acid,

H₂SO₄, H₃PO₄, or HCl), saccharin, glucono-D-lactone, and papain in 100 parts by weight of water. When preparing the extract, adding the coagulant tends to form insoluble aggregates of bean proteins or polysaccharides by simple cross-linking or denaturing. The concentration of coagulant directly affects the amount of proteins or polysaccharides in the extract. For example, larger amounts of coagulant cause more insoluble aggregates to form. This effect permits control of the total amount of water-soluble proteins and polysaccharide in the extract, as well as the solubility of the isoflavone derivatives. The amount of coagulant to be added can be determined by measuring the fat, protein, and inorganic salt content of the resultant bean-based extract. In general, enough coagulant is added to produce an extract having less than about 1% of fat, between about 1% to about 5% of protein, between about 0.01% to about 3% of Na, between about 0.01% to about 3% of Ca, and between about 0.01% to about 3% of any acids. The amount of fat, protein, Na, Ca, and acid in the water-soluble bean-based extract can be determined by any known analytical method, such as by following the analytical methods recommended by the Food and Drug Administration (FDA). Typically, about 0.3 parts by weight of citric acid is added to the extract. In general, if too much coagulant is added, the water-soluble bean proteins, polysaccharides, or isoflavone derivatives co-precipitate out of the extract thereby decreasing the concentration of isoflavone derivatives in the extract or the solubility of the isoflavone derivatives. If too little coagulant is added, the bean-based mixture forms a colloid from which the water-soluble bean-based extract is not easily separated.

The water-soluble bean-based extract of this invention can be added to a food product either in dried or wet form. The food product can be a solid, a paste, or a liquid food product, such as milk, tea, soft drinks, juices, coffee, seasonings, cereals, water, beer, cookies, chewing gum, chocolate, or soups.

The water-soluble bean-based extract of this invention can also include co-extracts from other grains, such as barley, rice, and malts. For example, one or more other grains can be processed together with beans by the methodology described above to produce a water-soluble bean-based extract of this invention. Additionally the water-soluble bean-based extract can be fortified with electrolytes, flavors, preservatives, and other additives, (e.g., vitamin supplements and maltodextrin). Examples of preservatives include, but are

not limited to, ascorbic acid and propyl gallate. Examples of electrolytes include, but are not limited to, magnesium sulfate and potassium chloride.

Without further elaboration, it is believed that the above description has adequately enabled the present invention. The following specific examples are, therefore, to be construed as merely illustrative, and not limitative of the remainder of the disclosure in any way whatsoever. All of the publications cited herein, including patents, are hereby incorporated by reference in their entirety.

Example 1

Pulverized soybean crude product (1 kg) extracted with about 90% aqueous EtOH, i.e., SoyLife150 purchased from Schousten USA, Inc., was added to 3 liters of hot water at 70°C. The mixture was stirred at 90°C for 30 min and then at 50°C for 30 min. The residue and solution were roughly separated by centrifuging the mixture at 10,000 x g at 50°C. After decanting, 6 g of CaCl₂, food additive grade (about 0.02 M), was added to the supernatant and additional stirring was continued at 30°C for 30 min. The supernatant was filtered through a 1-μm pore size microfilter and yielded a yellow solution (2.5 liters). The filtrate was then transferred into a 5-liter glass flask and was hydrogenated in the presence of catalytic amounts (about 3 grams) of 5% Pd/C at 10 atm of hydrogen for 5 hrs. The decolorized mixture was microfiltered (0.2-μm pore size) to yield a clear water-soluble soybean-based extract solution (2.3 liters).

The water-soluble soybean-based extract solution was characterized by high-pressure liquid chromatography (HPLC). The HPLC was conducted on a C 18-reverse phase column 150mm x 4.6mm, Symmetry Shield RP18 available from Waters, using a gradient elution method, 1 ml/min for 20 minutes with 15%-40% aqueous acetonitrile and 0.1% trifluoroacetic acid at 30°C. The HPLC detector was set at 254 nm. Figure 1 shows the HPLC chart of the major components in the soluble soybean product in Example 1. Each of the peaks from the HPLC chart is listed in table 1 below along with their retention time, peak area, and percent area. Several individual components of the extract were identified by comparing the retention times of the unknown components to retention times

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of known isoflavone glycosides analyzed by HPLC under the same experimental conditions.

The water-soluble soybean-based extract solution was also characterized to determine the relative amounts of the components of the extract. A sample of the extract
5 was sent to and analyzed by Food Products Laboratory Inc., located in Portland, Or, USA, using FDA approved methods. The extract included <0.1% fat, 5% protein, 65% carbohydrates (polysaccharides), 20% isoflavones, 8% minerals, and 1% moisture.

Table 1. HPLC analysis of soluble soybean product in Example 1

Peak	Retention Time	Peak Area	Area	
#	(min)	(mAU * sec)	(%)	Compound
1	6.940	56.95	0.35	N.D.
2	7.231	85.42	0.53	N.D.
3	7.661	164.09	1.02	N.D.
4	8.090	5129.91	31.85	Daidzin
5	8.507	2722.58	16.90	Glycitin
6	10.376	19.68	0.12	N.D.
7	10.652	23.89	0.15	N.D.
8	11.069	34.82	0.22	N.D.
9	11.685	367.98	2.28	N.D.
10	11.990	1378.49	8.56	Genistin
11	12.766	75.19	0.47	Malonyl Daidzin
12	13.048	52.95	0.33	Malonyl Glycitin
13	13.461	3038.54	18.86	Acetyl Daidzin
14	13.771	1421.88	8.83	Acetyl Genistin
15	15.723	33.08	0.21	N.D.
16	15.942	43.63	0.27	N.D.
17	17.265	58.45	0.36	N.D.
18	17.737	867.85	5.39	Acetyl Glycitin
19	18.236	288.12	1.79	Glycitein
20	18.822	196.99	1.22	Daidzein
21	25.657	47.89	0.30	Genistein
Total		16108.41	100.00	N. D.: Not Determined

Example 2

Pulverized soybean crude product (1 kg) extracted with about 90% aqueous EtOH, i.e., SoyLife 150 purchased from Schousten USA, Inc., was added to 27 liters of hot water.

- 5 The mixture was stirred at 90°C for 15 min and then an aqueous solution (3 liters) of citric acid (90 g) was added to the mixture. The mixture was stirred at 90°C for 15 min. The residue and solution were filtered through a Celite bed on paper filter under vacuum. The filtrate was a pale yellow clear solution (27 liters). Potassium carbonate (50 g) was added to the filtrate to adjust pH at 6.0. The filtrate was purified to remove bacteria by further
- 10 filtering the filtrate with a 0.45 μ m pore size filter (Millipore Corporation) under vacuum. The purified filtrate was then concentrated by using 2 inches wiped-film stills (Pope Scientific Inc.) at 70°C under 20 mmTorr to yield a light yellow water-soluble soybean based extract solution (18 liters).

Example 3

- 15 A clear water-soluble soybean-based extract (2 liters) obtained in the same manner as described in Example 1. The extract solution was then lyophilized using a lyophilizer manufactured by Bertis Corp for 2 days at -85°C under 10 mm Torr, resulting in 350 g of a pale yellow dry cake. The cake, which contained 70 g of isoflavone derivatives, had a
- 20 solubility of approximately 200 mg/ml. The solubility was tested by first adding 1g of the dried extract into 1 ml of pure water at 25°C with agitation for 5 min. If the extract was not completely dissolved (visual inspection), another 1 ml of water was added and the resulting mixture agitated for 5 minutes at 25°C. Next, the mixture was visually inspected to determine if the extract had completely dissolved. If not, water at 25°C was added in 1
- 25 ml increments and agitated for 5 minutes after each addition of water until the extract was completely dissolved by visual inspection. .

Other Embodiments

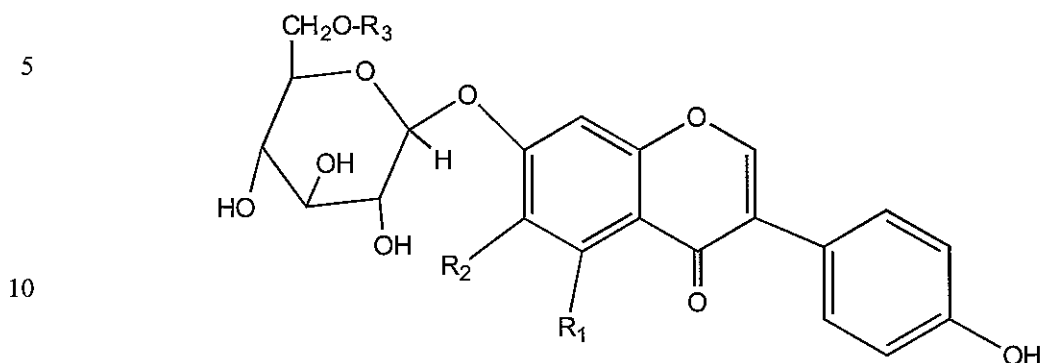
- All of the features disclosed in this specification may be combined in any
- 30 combination. Each feature disclosed in this specification may be replaced by an alternative feature serving the same, equivalent, or similar purpose. Thus, unless

expressly stated otherwise, each feature disclosed is only an example of a generic series of equivalent or similar features.

Furthermore, from the above description, one skilled in the art can easily ascertain the essential characteristics of the present invention, and without departing from the spirit
5 and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions. Thus, other embodiments are also within the claims.

What is claimed is:

1. A water-soluble bean-based extract comprising one or more isoflavone derivatives of the formula



- 15
- Wherein R_1 is hydrogen or hydroxy, R_2 is hydrogen or methoxy, R_3 is hydrogen or CO-R_4 , R_4 being methyl or carboxymethyl; and the water-soluble bean-based extract, in dried form, includes from about 5 to about 50 parts by weight of isoflavone derivatives and has a solubility from about 10 mg/ml to about 1,000 mg/ml in water at about 25°C.

- 20
2. The water-soluble bean-based extract of claim 1, wherein the bean-based extract is based on soybeans, mung beans, black beans, or kidney beans.

3. The water-soluble bean-based extract of claim 1, wherein the bean-based extract is based on soybeans.

- 25
4. The water-soluble bean-based extract of claim 1, wherein the water-soluble bean-based extract, in dried form, includes from about 10 to 20 parts by weight of isoflavone derivatives and has a solubility from about 30 mg/ml to about 300 mg/ml in water at about 25°C.

- 30
5. The water-soluble bean-based extract of claim 1, wherein the water-soluble bean-based extract, in dried form, includes from about 10 to about 20 parts by weight of isoflavone derivatives and has a solubility from about 50 mg/ml to about 200 mg/ml in water at about 25°C.

6. The water-soluble bean-based extract of claim 1, wherein the isoflavone derivative is daidzin, genistin, glycitin, 6"-O-acetyldaidzin, 6"-O-acetylgenistin, 6"-O-acetylglycitin, 6"-O-malonyldaidzin, 6"-O-malonylgenistin, or 6"-O-malonylglycitin.

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7. The water-soluble bean-based extract of claim 6, wherein the bean-based extract is based on soybeans.

8. The water-soluble bean-based extract of claim 6, wherein the water-soluble bean-based extract, in dried form, includes from about 10 to about 20 parts by weight of isoflavone derivatives and has a solubility from about 30 mg/ml to about 300 mg/ml in water at about 25°C.

9. The water-soluble bean-based extract of claim 6, wherein the water-soluble bean-based extract, in dried form, includes from about 10 to about 20 parts by weight of isoflavone derivatives and has a solubility from about 50 mg/ml to about 200 mg/ml in water at about 25°C.

10. A method of preparing a water-soluble bean-based extract comprising:
mixing a pulverized crude bean-based extract with water;
heating the mixture;
adding a coagulant to the mixture to form a suspension;
heating the suspension; and
collecting the supernatant to obtain a water-soluble bean-based extract.

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11. The method of claim 10, wherein the bean-based extract is based on soybeans, mung beans, black beans, or kidney beans.

12. The method of claim 10, wherein the bean-based extract is based on soybeans.

13. The method of claim 10, wherein about 0.01 to about 3 parts by weight of the coagulant is added to about 100 parts by weight of water.

14. The method of claim 13, wherein the coagulant is citric acid.

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15. The method of claim 10, wherein the supernatant is collected by filtering the suspension.

16. The method of claim 10, further including drying the supernatant to
5 obtain a dried water-soluble bean-based extract.

17. A method of preparing a water-soluble bean-based extract comprising:
mixing about 1 to about 50 parts by weight of a pulverized crude bean-based
extract with about 100 parts by weight of water;
10 heating the mixture to between about 60°C and about 100°C for about 10 to
about 120 minutes;
adding a coagulant to the mixture to form a suspension;
heating the suspension to between about 30°C and about 100°C for about 1 to
about 120 minutes; and
15 collecting the supernatant to obtain a water-soluble bean-based extract.

18. The method of claim 17, wherein the bean-based extract is based on
soybeans, mung beans, black beans, or kidney beans.

19. The method of claim 18, wherein the bean-based extract is based on
20 soybeans.

20. A water-soluble bean-based extract prepared by the method of claim
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21. A water-soluble bean-based extract prepared by the method of claim
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22. A water-soluble bean-based extract prepared by the method of claim
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23. A water-soluble bean-based extract prepared by the method of claim
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24. A water-soluble bean-based extract prepared by the method of claim
35 14.

25. A water-soluble bean-based extract prepared by the method of claim
15.

16. 26. A water-soluble bean-based extract prepared by the method of claim 16.
- 5 17. 27. A water-soluble bean-based extract prepared by the method of claim 17.
28. 28. A food product comprising the water-soluble bean-based extract of claim 1.
- 10 29. 29. The food product of claim 28, wherein the bean-based extract is based on soybeans, mung beans, black beans, or kidney beans.
30. 30. The food product of claim 29, wherein the bean-based extract is based on soybeans.
- 15 31. 31. A food product comprising the water-soluble bean-based extract of claim 9.
- 20 32. 32. A food product comprising the water-soluble bean-based extract of claim 20.
- 25 33. 33. The food product of claim 28, wherein the food product is milk, tea, soft drink, juice, coffee, seasoning, cereal, water, beer, cookies, chewing gum, chocolate, or soup.
- 30 34. 34. The food product of claim 29, wherein the food product is milk, tea, soft drink, juice, coffee, seasoning, cereal, water, beer, cookies, chewing gum, chocolate, or soup.
- 35 35. 35. The food product of claim 30, wherein the food product is milk, tea, soft drink, juice, coffee, seasoning, cereal, water, beer, cookies, chewing gum, chocolate, or soup.
36. 36. The food product of claim 31, wherein the food product is milk, tea, soft drink, juice, coffee, seasoning, cereal, water, beer, cookies, chewing gum, chocolate, or soup.
- 40 37. 37. The food product of claim 32, wherein the food product is milk, tea, soft drink, juice, coffee, seasoning, cereal, water, beer, cookies, chewing gum, chocolate, or soup.

38. A method of preparing a water-soluble bean-based extract from bean germs, comprising:

mixing pulverized bean germs with water;

heating the mixture;

5 adding a coagulant to the mixture to form a suspension;

heating the suspension; and

collecting a supernatant of the suspension to obtain a water-soluble bean-based extract.

10 39. The method of claim 38, wherein the bean-based extract is based on soybeans, mung beans, black beans, or kidney beans.

40. The method of claim 39, wherein the bean-based extract is based on soybeans.

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41. The method of claim 40, wherein the coagulant is an acid.

42. The method of claim 41, wherein the coagulant is an organic acid

20 43. The method of claim 42, wherein the coagulant is citric acid, fumaric acid, lactic acid, malic acid, or tartaric acid.

44. The method of claim 43, wherein the coagulant is citric acid.

25 45. The method of claim 41, wherein the coagulant is an inorganic acid.

46. The method of claim 45, wherein the coagulant is HCl, H₂SO₄, or H₃PO₄.

30 47. The method of claim 38, wherein the coagulant is an acid.

48. The method of claim 47, wherein the coagulant is an organic acid.

49. The method of claim 48, wherein the coagulant is citric acid.

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50. A method of preparing a water-soluble bean-based extract from bean germs, comprising:

stirring pulverized bean germs and a coagulant in heated water to form a suspension; and

5 collecting a supernatant of the suspension to obtain a water-soluble bean-based extract;

wherein the heated water has a temperature of 30-100°C.

10 51. The method of claim 50, wherein the bean-based extract is based on soybeans, mung beans, black beans, or kidney beans.

52. The method of claim 51, wherein the bean-based extract is based on soybeans.

15 53. The method of claim 52, wherein the coagulant is an acid.

54. The method of claim 53, wherein the coagulant is an organic acid.

20 55. The method of claim 54, wherein the coagulant is citric acid, fumaric acid, lactic acid, malic acid, or tartaric acid.

56. The method of claim 55, wherein the coagulant is citric acid.

25 57. The method of claim 53, wherein the coagulant is an inorganic acid.

58. The method of claim 57, wherein the coagulant is HCl, H₂SO₄, or H₃PO₄.

30 59. The method of claim 50, wherein the coagulant is an acid.

60. The method of claim 59, wherein the coagulant is an organic acid.

61. The method of claim 60, wherein the coagulant is citric acid.