CLAIMS

What is claimed is:

1. A composition suitable as food ingredient comprising a preparation from an algae strain~~, wherein the algae strain overexpresses or accumulates~~ overproducing protoporphyrin IX (PPIX).

2. The composition of claim 1, wherein the preparation comprises an algae ~~is a~~ biomass comprising ~~from~~ the algae strain overproducing PPIX.

3. The composition of claim 1 or claim 2, wherein the preparation comprises one or more algal cells or portions thereof~~is a fractionated biomass from the algae strain~~.

4. The composition of any one of claims 1-3 ~~claim 3~~, wherein the preparation has a red or red-like color and ~~fractionated biomass~~ comprises a PPIX ~~enriched fraction~~ content greater than a chlorophyll content by at least 50%.

5. The composition of~~claim 4~~ any one of claims 2-3, wherein the algae biomass comprises a PPIX ~~enriched fraction further comprises a protein enriched fraction~~content in an amount greater than a heme content.

6. The composition of any one of claims 1-3, wherein the~~preparation is an extracellular fraction of the algae culture~~ algae biomass comprises at least about 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, or 3.0% PPIX on a weight per total weight basis.

7. The composition ~~according to~~ of~~-~~ any one of claims 1-6, wherein the~~preparation is red or red-like in color~~ algae is a Chlamydomonas sp.

8. The composition ~~according to any~~ of claim~~s 1-~~ 7, wherein the~~preparation contains a greater amount of PPIX than of heme~~ Chlamydomonas sp. is *Chlamydomonas reinhardtii*.

9. The composition ~~according to~~ of any one of claims ~~1~~2-8, wherein the~~preparation contains less than about 1%, 0.5%, 0.1%, 0.05%, 0.01%, 0.005% or 0.001% heme~~ algae biomass is concentrated, dried, lyophilized or any combination thereof.

10. The composition ~~according to~~of any one of claims ~~1-9~~ 2-8, wherein the preparation ~~contains less than about 1%, 0.5%, 0.1%, 0.05%, 0.01%, 0.005% or 0.001% heme-protein~~ is a powder.

11. The composition ~~according to~~of ~~-~~any one of claims 1-~~10~~6, wherein the preparation ~~does not contain a detectable amount of heme-protein~~ confers a meat or meat-like color, flavor, or texture to the composition.

12. An uncooked food product comprising t~~T~~he composition ~~according to~~ of any one of claims 1-1~~0~~1~~-~~, wherein the preparation ~~does not contain a detectable amount of heme~~ imparts a red color or a color similar to red to the uncooked food product.

13. ~~The composition according to any of claims 1-4~~The uncooked food product of claim 12, wherein the ~~preparation does not contain a detectable amount of protein~~ uncooked food product is selected from the group consisting of a clean meat, a cultured meat, a synthetic meat, a plant-based meat, and a non-animal cell-based meat.

14. ~~The composition according to any~~ The uncooked food product of claim~~s 1-~~13, wherein the ~~preparation has a protoporphyrin IX content greater than chlorophyll content~~ uncooked food product is selected from the group consisting of a burger, a sausage, a kebab, a filet, a ground meat like product, and a meatball.

15. The ~~composition according to any of claims 1-4 or 6~~ uncooked food product of claim 12, wherein the ~~preparation provides at least 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 99% or 100% of the total protein content to the edible composition~~ uncooked food product is a fish-like product.

16. The ~~composition according to any~~uncooked food product ~~-~~of claim~~s 1-~~15, wherein the ~~preparation provides vitamin A, beta carotene or a combination thereof to the composition~~ uncooked food product is a tuna-like product.

17. A method of producing a ~~The~~ composition ~~of claim 16, wherein the vitamin A, the beta carotene or the combination thereof is at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 99% or 100% of the daily recommended requirement~~ suitable as food ingredient comprising:

growing an algae in liquid culture, wherein the algae is a PPIX over-producer and the algae comprises a PPIX content greater than a chlorophyll content by at least 50%.

18. The ~~composition according to any~~method of claim~~s 1-~~17, wherein the~~ preparation provides less than about 0.01%, 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1.0%, 1.2%, 1.5%, 2%, 5% or 10% of total saturated fat present in the composition~~ algae is grown by aerobic fermentation and with acetate or sugar as a carbon source.

19. The ~~composition according to any~~method of claim~~s~~ 17 ~~-~~ or claim 18, wherein the ~~preparation provides at least about 5 mg, 10 mg, 15 mg, 20 mg, 25 mg, 30 mg, 35 mg, 40 mg, 45 mg, 50 mg, 55 mg, 60 mg, 65 mg, 70 mg, 75 mg, 80 mg, 85 mg, 90 mg, 95 mg, 100 mg, 125 mg, 150 mg, 175 mg, 200 mg, 250 mg, 300 mg, 350 mg, 400 mg, 450 mg or 500 mg of omega-3 fatty acids to the composition~~ algae is grown to a density greater than 10g/L, 20 g/L, 30 g/L, 40g/L, 50g/L, 75 g/L, 100g/L, 125 g/L or 150g/L.

20. The ~~composition according to~~method of any one of claims 17-19, wherein the ~~composition has a red or red-like color derived from the preparation~~ algae (a) is deficient for its ability to produce chlorophyll, (b) is deficient for its ability to produce a functional Mg-chelatase enzyme, (c) lacks a functional ChlD1, ChlD2, ChlDH, ChlB, ChlL, or ChlN gene product, or (d) lacks a functional light dependent protochlorophyllide or a functional light independent protochlorophyllide, or (e) any combination of (a)-(d).

21. The ~~composition according to~~method of any one of claims 17-20, wherein the ~~composition has a meat or meat-like flavor derived from the preparation~~ algae overexpresses a gene selected from the group consisting of glutamyl-tRNA reductase, glutamyl-1-semialdehyde aminotransferase, ALA dehydrogenase, porphobilinogen deaminase, UPG III synthase, UPG III decarboxylase, CPG oxidase, PPG oxidase, and ferrochelatase.

22. The ~~composition according to~~method of any one of claims 17-21, wherein the ~~composition has a meat or meat-like texture derived from the preparation~~ algae is red or has a color similar to red when grown in liquid culture.

23. The ~~composition according to~~ method of any one of claims 1~~7~~-22, ~~wherein the algae is a *Chlamydomonas* sp~~ further comprising isolating the algae biomass from the liquid culture.

24. The method of any one ~~composition~~ of claim~~s 23~~17-22, ~~wherein the algae is *Chlamydomonas reinhardtii*~~ further comprising isolating a PPIX composition from the culture.

25. The ~~composition~~ method of any one of claim~~s 23~~17-24, wherein the algae is a Chlamydomonas sp. ~~is strain CC-125 deposited to the University of Minnesota *Chlamydomonas* collection center or a derivative thereof.~~

26. The ~~composition~~ method of claim 2~~3~~5, wherein the algae ~~has reduced or an absence of ferrocheletase activity or expression of ferrocheletase~~ is a *Chlamydomonas reinhardtii*.

27. ~~A food product comprising the composition~~A dried preparation of algae biomass produced by the method~~-~~ according to any one of claims 1~~7~~-26.

28. ~~The food product~~ A powder comprising the dried preparation of claim 27~~, wherein the food product comprises a clean meat, a cultured meat, a synthetic meat, a plant based meat or a non-animal cell-based meat~~.

29. ~~The food product of~~ A composition suitable as food ingredient produced by the method according to any one of claims ~~2~~1~~7~~-2~~8~~6~~, wherein the food product is selected from the group consisting of a beef-like food product, a fish-like product, a chicken-like product, a pork-like product and a meat replica~~.

30. ~~The~~ A food product comprising the composition ~~of any of~~ claim~~s 27~~-29, wherein the food product is ~~vegan, vegetarian or gluten-free~~ selected from the group consisting of a clean meat, a cultured meat, a synthetic meat, a plant-based meat, and a non-animal cell-based meat.

31. ~~An edible ingredient~~ A food product comprising the composition ~~according to any~~ of claim~~s 1~~-2~~6~~9, wherein the food product is a fish-like product.

~~32. The edible ingredient of claim 31, wherein the edible ingredient is part of a finished product, and wherein the finished product has a red or red-like color derived from the ingredient.~~

~~33. The edible ingredient of claim 31, wherein the edible ingredient is part of a finished product, and wherein the finished product has a meat or meat-like flavor derived from the ingredient.~~

~~34. The edible ingredient of claim 31, wherein the edible ingredient is part of a finished product, and wherein the finished product has an appearance of blood derived from the ingredient.~~

~~35. The edible ingredient according to any of claims 31-34, wherein the finished product is an ingredient for a burger, a sausage, a kebab, a filet, a ground meat-like product or a meatball.~~

~~36. The edible ingredient according to any of claims 31-34, wherein the edible composition is part of a finished product and wherein the finished product is an animal feed.~~

~~37. The edible ingredient according to any of claims 31-36, wherein the edible ingredient is combined with a protein source, a fat source, a carbohydrate, a starch, a thickener, a vitamin, a mineral, or any combination thereof.~~

~~38. The edible ingredient of claim 35, wherein the protein source is textured wheat protein, textured soy protein, fungal protein or algal protein.~~

~~39. The edible ingredient according to any of claims 37 or 38, wherein the finished product is free of animal proteins.~~

~~40. The edible composition of any of claims 37-39, wherein the fat source comprises at least one of refined coconut oil or sunflower oil.~~

~~41. The edible composition of any of claims 37-40, further comprising at least one of potato starch, methylcellulose, water, or a flavor, wherein the flavor is selected at least one of yeast extract, garlic powder, onion powder, and salt.~~

~~42. A meat substitute comprising the composition according to any of claims 1-26 or the edible ingredient according to any of claims 31-41.~~

43. The meat substitute of claim 42, further comprising:

(a) 0.01%-5% (by weight of the meat replica matrix) of a non-animal protoporphyrin IX;

(b) a compound selected from the group consisting of glucose, ribose, fructose, lactose, xylose, arabinose, glucose-6-phosphate, maltose, and galactose, and any combination thereof;

(c) at least 1.5 mM of a compound selected from the group consisting of cysteine, cystine, thiamine, methionine, and any combination thereof; and

(d) one or more proteins selected from the group consisting of plant proteins, fungal proteins and algal proteins,

wherein the meat substitute is a ground beef-like food product that contains no animal product, and wherein cooking the ground beef-like food product results in the production of at least two volatile compounds which have a beef-associated aroma.

44. A method of producing a protoporphyrin IX composition, comprising:

(a) growing an algae population comprising an algae that is a protoporphyrin IX over-producer in a culture; and

(b) isolating a protoporphyrin IX composition from the culture.

45. The method of claim 44, wherein the step of growing comprises culturing the algae in an aerobic fermentation condition.

46. The method of claim 44 or claim 45, wherein the algae contains a chloroplast.

47. The method of claim 46, wherein biosynthesis of the protoporphyrin IX occurs in the chloroplast.

48. The method according to any of claims 44-47, wherein the algae is deficient for its ability to produce chlorophyll.

49. The method according to any of claims 44-48, wherein the algae is deficient for the ability to produce a functional Mg-chelatase enzyme.

50. The method according to any of claims 44-49, wherein the algae is reduced in or lacks one or more of CHLD, CHLI1, CHLI2 or CHLH1.

~~51. The method according to any of claims 44-50, wherein the algae is reduced in or lacks a functional light dependent protochlorophyllide.~~

~~52. The method according to any of claims 44-51, wherein the algae is reduced in or lacks a functional light independent protochlorophyllide.~~

~~53. The method according to any of claims 44-52, wherein the algae is reduced in or lacks ChlB, ChlL, or ChlN.~~

~~54. The method according to any of claims 44-53, wherein the algae overexpresses one or more of glutamyl-tRNA reductase, glutamate-1-semialdehyde aminotransferase, ALA dehydratase, porphobilinogen deaminase, UPG III synthase, UPG III decarboxylase, CPG oxidase, or PPG oxidase.~~

~~55. The method according to any of claims 44-54, wherein the algae is generated by mating to produce a generated strain, and wherein the generated strain is red or red-like in color.~~

~~56. The method according to any of claims 44-54, wherein the algae is generated by mutagenesis.~~

~~57. The method according to any of claims 44-56, wherein the algae is red or red-like in color.~~

~~58. The method according to any of claims 44-57, wherein the isolated protoporphyrin IX composition is an algae biomass.~~

~~59. The method of claim 58, wherein the algae biomass is fractionated.~~

~~60. The method of claim 59, wherein the algae biomass is fractionated to produce a protein-enriched fraction comprising protoporphyrin IX .~~

~~61. The method according to any of claims 44-57, wherein the isolated protoporphyrin IX composition is isolated from extracellular media of the algae culture.~~

~~62. The method according to any of claims 44-61, wherein the isolated protopophyrin IX composition is isolated away from algae protein.~~

~~63. The method according to any of claims 44-62, wherein the algae is deficient for carotenoids.~~

~~64. The method according to any of claims 44-63, wherein the algae is a *Chlamydomonas* sp.~~

~~65. The method according to any of claims 44-64, wherein the algae is a *Chlamydomonas reinhardtii*.~~

~~66. The method of claim 64, wherein the *Chlamydomonas* sp. is strain CC-125 deposited to the University of Minnesota *Chlamydomonas* collection center or a derivative thereof.~~

~~67. The method according to any of claims 44-66, wherein progeny of a protoporphyrin IX overexpressing algae strain grows faster than its parental strain following a mating with another algae.~~

~~68. The method according to any of claims 44-66, wherein the protoporphyrin IX overexpressing algae is a strain produced by mating a strain deficient for carotenoids with a strain exhibiting a red or red-like color.~~

~~69. The method according to any of claims 44-66, wherein the protoporphyrin IX overexpressing algae is generated by mutagenesis of a first starting strain and selection of a second strain that grows faster in the dark than the first starting strain.~~

~~70. The method according to any of claims 44-66, wherein the protoporphyrin IX overexpressing algae is generated by mutagenesis of a first strain and selection of a second strain that lacks one or more carotenoids from the mutated first strain.~~

~~71. The method according to any of claims 44-70, wherein the algae lacks a functional ferrocheletase enzyme.~~

~~72. The method according to any of claims 44-70, wherein the algae is reduced in the amount of, or activity of, a ferrocheletase enzyme.~~

~~73. The method according to any of claims 44-70, wherein the algae is reduced in the amount of or lacks heme as compared to a wildtype strain.~~

74. A protoporphyrin IX-containing composition produced by the method according to any of claims 43-70.

75. The composition of claim 74, wherein the composition does not contain a detectable level of heme, heme-binding protein or a combination thereof.

76. The method according to any of claims 44-73, further comprising the steps of: (a) culturing the algae strain under a dark condition, wherein the strain does not produce or is reduced in the production of chlorophyll, and (b) collecting a portion of the algae culture that is red or red-like in color to produce the protoporphyrin IX composition.

77. The method of claim 76, wherein the algae is a *Chlamydomonas* sp.

78. The method of claim 77, wherein the algae is a *Chlamydomonas reinhardtii*.

79. The method according to claim 76, wherein the algae exhibits a red or red-like color when grown in the dark condition.

80. The method of claim 76, wherein the collected portion is extracellular media from the algae culture.

81. The method of claim 76, wherein the collected portion is a biomass or fractionated biomass from the algae culture.

82. The method of claim 76, wherein the algae is grown in an aerobic fermentation condition.

83. The method of claim 76, wherein the algae is grown to a density greater than about 10g/L, 20 g/L, 30 g/L, 40g/L, 50g, L, 75 g/L, 100g/L, 125 g/L, or 150g/L.

84. The method of claim 76, wherein the algae is grown with acetate as a reduced carbon source.

85. The method of claim 76, wherein the algae is grown with sugar as a reduced carbon source.

86. The method of claim 76, wherein the algae culture is supplemented with iron during the culturing step.

87. The method of claim 76, wherein the algae culture is inoculated at a density greater than about 0.1 g/L, 1.0 g/L, 5.0 g/L, 10 g/L, 20 g/L, 50 g/L, 80 g/L, or 100 g/L.

88. The method of claim 76, further comprising fractionating the collected portion, wherein the fractionating removes from the collected portion substantially all or most of a component selected from the group consisting of carotenoids, starch, and protein.

89. The method of claim 76, further comprising fractionating the collected portion, wherein the fractionating removes from the collected portion substantially all or most of heme, heme-binding protein or a combination thereof.

90. The method of claim 76, further comprising fractionating the collected portion, wherein the fractionating produces a protein-enriched fraction.

91. The method of claim 76, wherein the algae lacks or is reduced in one or more of magnesium chelatase, magnesium protoporphyrinogen IX, protochlorophyllide, chlorophyllide, and chlorophyll.

92. The method of claim 76, wherein the algae lacks or is reduced in ferrocheletase.

93. The method according to any of claims 44-73 or 76-92, wherein the algae is not a transgenic strain.

94. A clean meat product produced by the method according to any of claims 76-93, wherein the method further comprises combining the collected portion with a clean meat manufacturing composition, wherein the collected portion provides a red or red-like color to the clean meat product.

95. The clean meat product of claim 94, wherein the collected portion is a PPIX-enriched fraction or purified PPIX.

96. An edible ingredient produced by the method according to any of claims 44-73 or 76-93, wherein the protoporphyrin IX composition confers a meat or meat-like flavor, texture, odor or any combination thereof to the edible ingredient.

97. The edible ingredient of claim 96, wherein the edible ingredient is incorporated in a finished product selected from the group consisting of a beef-like food product, a fish-like product, a chicken-like product, a pork-like product and a meat replica.

~~98. The edible ingredient of any of claims 96-97, wherein the edible ingredient is vegan, vegetarian or gluten-free.~~

~~99. The edible ingredient of any of claims 96-98, wherein the edible ingredient is free of animal proteins.~~

~~100. The edible ingredient of any of claims 96-99, wherein the edible ingredient does not contain any genetically modified components.~~