of these edible compositions, rye bran, oat and faba bean. For many of these compositions, viscoelastic properties where measured, including the storage modulus (G') and loss modulus (G'') and phase angle values, finally concluding that the compositions usable for printing and further having self-supporting once printed should have a G' lower than 1900 Pa. In any other cases, obstruction of the extruders with high viscous compositions or phase-separation of the components took place. The printed structures were made with a VTT's micron scale dispensing environment based on nScrypt technology (nScrypt, Inc, Orlando, Florida), and a CAD-controlled xyz-motion control system guiding the nozzles to deposit 3D structures in a layer-by-layer approach. Lille et al., also assessed the capability of the printed material in terms of self-supporting abilities, as well as the effects of lyophilisation and of heating in oven after the printing.

Many efforts have been made to obtain edible fibrous materials that in addition can be easily manufactured and processed. However, the rheological parameters of highly fibrous materials compositions require particular devices, such as a Couette cell, in order to obtain a texture resembling partially fibrous anisotropic food (meat). These rheological properties imply, in addition, obstruction of extruders in case of 3D printing device are used, thus being highly difficult to print a highly fibrous food and limiting 3D printing strategies to edible compositions with soft textures (snacks, chocolate patterns, pizza bases, etc.).The existing technologies producing plant-based products are not able to simultaneously mimic time the flavour, appearance, consistency, fibrous texture and elasticity of meat from live animals. Clean meat technologies based on tissue engineering have a series of drawbacks, including the cost, complexity and time-consuming characteristics of their processes

Thus, there is a need of additional processes and materials that could provide all essential nutrients while reducing, in particular, animal meat production, said materials avoiding the above-mentioned drawbacks.

Summary

It has been surprisingly found that the combination of a particular viscoelastic composition or material, which could be microextruded while having self-supporting properties once microextruded, and the particular disposition of layers comprising microextruded elements made of the said viscoelastic composition, gave as a result an edible product with a final texture and mechanical properties resembling traditional meat or a type of food with high fibrous consistency. Therefore, a product was obtained with desired nutritional properties (due to the composition of the viscoelastic material), tridimensional (3D) shape,

macroscopic and microscopic morphology, consistency, elasticity under both tensile and compressive stresses and texture to mimic specific mechanical and nutritional properties of different animal and vegetable native tissues.

Thus, as will be depicted and illustrated in examples below, many of the mechanical properties of the edible microextruded product, makes it as a useful meat replacer, meat analogueor as tissue engineered meat that can include the desired composition of nutrients provided by the said viscoelastic composition.

Thus, a first aspect of the disclosure relates to a process for the manufacturing of an edible microextruded product comprising two or more layers of viscoelastic microextruded elements, wherein each extruded element comprises protein, an edible pseudoplastic polymer and an appropriate edible solvent, comprising the steps of:
(i) providing a viscoelastic composition comprising in an appropriate edible solvent, protein and an edible pseudoplastic polymer, said viscoelastic composition comprising a percentage by weight of protein from 19 % to 49 %, and at least 45 % of edible solvent, both percentages in relation with total weight of the viscoelastic composition, said edible solvent balancing up to 100% by weight of the viscoelastic composition;
(ii) microextruding the viscoelastic composition through an orifice with a width or diameter of from 10 μm to 1000 μm to obtain one or more microextruded elements; and
(iii) stacking the two or more layers comprising microextruded elements in such a way that a vertical section of the edible microextruded product shows intersected microextruded elements within a layer, or microextruded elements superimposed and differentially oriented between the different layers; or alternatively the two or more layers are stacked in such a way that mixcroextruded elements between layers are oriented in parallel.

Particular modes of carrying out this process are detailed in next sections.

The disclosure relates to and provides an edible microextruded product comprising two or more layers of viscoelastic microextruded elements, wherein each extruded element comprises protein, an edible pseudoplastic polymer and an appropriate edible solvent, wherein:
- the percentage by weight of protein in relation with total weight of the microextruded element is from 19 % to 49 %, and the percentage by weight of edible solvent in relation with total weight of the microextruded element is at least 45 %;
- the microextruded elements have a cross section width from 10 μm to 1000 μm;
- the compressive elastic modulus of the edible microextruded product is from $1.0x10^3$ Pa to $5.0x10^6$ Pa and the tensile Young's modulus of the edible microextruded product is from $5.0x10^3$ Pa to $11.0x10^6$ Pa, said compressive elastic and the tensile Young's moduli

measured in a servo-hydraulic test system with a clamp displacement rate equal to 1 mm/min, at 23 ºC and with a solvent amount in the edible microextruded product from 45 % to 90 % w/w; and

- the two or more layers of microextruded elements are stacked in such a way that a vertical section of the edible microextruded product shows intersected microextruded elements within a layer, or microextruded elements superimposed and differentially oriented between the different layers; or alternatively the two or more layers are stacked in such a way that mixcroextruded elements between layers are oriented in parallel.

Thus, a second aspect of the disclosure is an edible microextruded product obtainable by a method as defined in above, said product comprising two or more layers of viscoelastic microextruded elements, as previously defined, and wherein the compressive elastic modulus of the edible microextruded product is from $1.0x10^3$ Pa to $5.0x10^6$ Pa and the tensile Young's modulus of the edible microextruded product is from $5.0x10^3$ Pa to $11.0x10^6$ Pa, said compressive elastic and the tensile Young's moduli measured in a servo-hydraulic test system with a clamp displacement rate equal to 1 mm/min, at 23 ºC and with a solvent amount in the edible microextruded product from 45 % to 90 % w/w.

These compressive elastic and Young's moduli result from qualitative and quantitative features of the viscoelastic composition from which viscoelastic microextruded elements are made, in combination with the other features of the edible microextruded product, namely cross section of elements and stacking of the layers of microextruded elements

This edible microextruded product is obtained through different mechanical and optionally chemical steps that do not affect its edibility and nutritional properties. In addition, microextrusion can be carried out by 3D printing, using a viscoelastic composition as injectable ink for 3D printing from which the microextruded elements are made. This is due to the rheological properties of said viscoelastic composition comprising proteins and pseudoplastic polymers in appropriate solvent, in particular in water.

Yet another aspect of the disclosure is the use of an edible microextruded product as defined above, as a meat replacer. This aspect can also be formulated as a meat replacer comprising or consisting of the edible microextruded product of the first aspect of the disclosure. A "Meat replacer" according to this disclosure is a product used to reduce or "replace" real meat coming from animals to obtain a mixture of both meat from animals (steak, sausages, etc.) and the meat replacer.

Further another aspect of the disclosure is the use of an edible microextruded product as defined above as a meat analogue. This aspect can also be formulated as a meat

analogue comprising or consisting of the edible microextruded product of the first aspect of the disclosure. ”Meat analogues” are commonly understood as a meat alternative, meat substitute, mock meat, faux meat, imitation meat, vegetarian meat, plant-based meat or vegan meat, approximates certain aesthetic qualities (such as texture, flavour, appearance) or chemical characteristics of specific types of meat. Sometimes they are also termed as “meat replacer” (see Krintiras et al. *supra*)

One hit of the disclosure is, as above exposed, the effective combination of a particular qualitative viscoelastic composition that can be microextruded to obtain self-supporting microextruded elements, and the disposition of the said microextruded elements within the two or more layers. This viscoelastic composition has appropriate viscoelastic parameters that make it able for microextrusion due to the presence of the pseudoplastic polymer. A pseudoplastic polymer is a polymeric compound with shear thinning, or which is the same with a viscosity that decreases under shear strain.

It has been surprisingly found that new mixtures of proteins and pseudoplastic polymers in a solvent (i.e. in water) having particular viscoelastic parameters are in particular good to be used in the preparation of the edible microextruded product of the first aspect. Thus, particular new viscoelastic compositions have been also developed, with high protein contents (from 19% to 49% in the composition) and comprising also an edible pseudoplastic polymer in an edible solvent. Parametrically defined, these new viscoelastic compositions have a storage modulus G’ higher than the loss modulus G’’, said G’ and G’’ measured at a frequency of 0.16 Hz and at a temperature of 23 ºC in a pair of parallel serrated plates and with a solvent amount in the composition from 45 % to 90 % w/w, being the storage modulus G’ higher than 1700 Pa and the loss modulus G’’ higher than 350 Pa, and wherein the ratio G’’/G’ in the viscoelastic composition is from 0.24 to 0.88. This ratio is also known as the loss tangent (tan(δ)).

Thus another aspect of the disclosure is an edible viscoelastic microextrudable composition comprising, in an appropriate edible solvent, protein in a percentage by weight in relation with the total weight of the viscoelastic composition from 19 % to 49 %, said protein selected from plant-origin protein, insect protein, algae-origin protein, bacterial origin protein, and combinations thereof; and an edible pseudoplastic polysaccharide selected from alginate, xanthan gum, glycosaminoglycans, agarose, gellan gum, pectin, carrageenan and combinations thereof, in a percentage by weight in relation with the total viscoelastic composition from 0.2 % to 40 %; and wherein the viscoelastic composition comprises at least 45 % by weight of edible solvent, in relation with the total weight of the composition. The balance of the weight is the solvent until 100% of the viscoelastic composition.

This viscoelastic composition is microextrudable, thus with an homogeneous distribution of particle sizes of the mixture of ingredients (i.e. protein, edible solvent and pseudoplastic polymer) lower than 60% of the width or diameter of orifice through which is to be microextruded. Homogeneous distribution means that more than 90% by weight of the particles have a particle size which is lower than 60% of the width or diameter of orifice through which is to be microextruded.

Thus, if the viscoelastic composition is to be microextruded through orifices with a particular width or diameter ranging from 10 μm to 1000 μm, the viscoelastic composition has a homogeneous distribution of particle sizes from lower than 6 μm to lower than 600 μm. Thus more than 90% by weight of the particles have a particle size lower than 6 μm if width or diameter of orifice through which is to be microextruded is of 10 μm; or more than 90% by weight of the particles have a particle size lower than 600 μm if width or diameter of orifice through which is to be microextruded is of 1000 μm.

With this 60% of the width or diameter of orifice, obturation of extruders used in step (ii) of the process of the disclosure are avoided.

Obtention of viscoelastic compositions with high protein contents (19%-49%) and pseudoplastic polymers with an homogeneous distribution of particle sizes is not trivial, since the mixture of proteins in a high weight percentage and pseudoplastic tends to phase-separate, thus making extrusion not possible due to clog of extruders and/or decomposition of the material to be microextruded. On the other hand, the mixture has to preserve protein structure to assure once microextruded the palatability (mouthfeel) and texture of animal-based (or meat like) fibrous material.

Inventor surprisingly found that a homogenous mixture of proteins with a percentage by weight in the mixture from 19% to 49%, a pseudoplastic polymer and at least 45% of an edible solvent balancing 100% of the mixture, was obtainable by:
(a) mixing the proteins, the edible pseudoplastic polymer and the edible solvent in a container; and
(b) applying agitation to high centrifugal forces during a raising of temperature from room temperature (i.e, 20ºC) to lower than 95ºC and maintaining agitation and temperature for a period of time from 1 minute (min) to 30 minutes (min).

Despite the high agitation, protein structure was not damaged in such an extend to lose structural and organoleptic properties while the mixture was constituted by particles with sizes that were adequate to pass through a microextruder without clog of the same.

These high gravity forces are usually employed in the ceramic field, to obtain homogeneous mixtures of cements or ceramic materials. However, their use in compositions comprising proteins as fibrous material is discouraged due to the denaturation effect on said proteins.

Thus, another aspect of the disclosure is a new edible viscoelastic microextrudable composition comprising, an edible pseudoplastic polymer, a percentage by weight of protein from 19 % to 49 % w/w, and at least 45 % w/w of an edible solvent, said solvent balancing up to 100 % w/w of the viscoelastic composition, both percentages in relation with total weight of the viscoelastic composition, said viscoelastic composition having an homogeneous distribution of particle sizes from lower than 6 µm to lower than 600 µm, and being obtainable by:
(a) mixing the proteins, the edible pseudoplastic polymer and the edible solvent in a container; and
(b) applying one or more agitation cycles to a centrifugal force or relative centrifugal force (rcf) from 10g to 4000g, optionally in more than one direction, while raising the temperature from 20 ºC to a temperature lower than 95 ºC, and maintaining agitation and temperature for a period of time from 1 minute to 30 minutes.

In another aspect, the present disclosure refers to an edible composite product comprising a portion of the edible microextruded product as described herein, and a portion of a solidified composition comprising a fat selected from one or more triglycerides, cholesterol, one or more phospholipids, one or more fatty acids and combination thereof; and/or a portion of a solidified composition comprising cartilaginous material; and/or a portion comprising bone material, said portion of composition comprising fat and/or cartilaginous material and/or bone material, adjacently and in contact with the portion of the edible microextruded product.

Relative centrifugal forces around 10g correspond to 300 revolutions per minute (rpm) in a rotor with a radius of 10 cm. 4000g correspond to about 6000 rpm, namely 5976 rpm. Relative centrifugal forces around 60g correspond to 730 revolutions per minute (rpm) in a rotor with a radius of 10 cm.

Brief Description of Drawings

FIG. 1 in A depicts a microextrudable formulation (viscoelastic composition), composed of 25 w/w% of rice protein, 5 w/w% of sodium alginate and 70 w/w% of water. FIG. 1 in B

depicts a non- microextrudable formulation, composed of 55 w/w% of rice protein and 45 w/w% of water.

FIG. 2 depicts an example of a formulation generating self-supporting microextruded filaments, composed of 25 w/w% of rice protein, 5 w/w% of sodium alginate and 70 w/w% of water (FIG. 2 A). FIG 2 B depicts a formulation generating non self-supporting microextruded filaments, composed of 5 w/w% sodium alginate and 95 w/w% of water.

FIG.3 A and FIG. 3 B depict the process of 3D microextrusion printing of two multi-layered microextruded products, with different composition and viscoelastic moduli. The products depicted in FIG.3 A and FIG. 3 B were generated using the compositions with 25 w/w% of

Claims

1. A process for the manufacturing of an edible microextruded product comprising two or more layers of viscoelastic microextruded elements, wherein each extruded element comprises protein, an edible pseudoplastic polymer and an appropriate edible solvent, comprising the steps of:
(i) providing a viscoelastic composition comprising in an appropriate edible solvent, protein and an edible pseudoplastic polymer, said viscoelastic composition comprising a percentage by weight of protein from 19 % to 49 %, and at least 45 % of edible solvent, both percentages in relation with total weight of the viscoelastic composition, said edible solvent balancing up to 100% by weight of the viscoelastic composition;
(ii) microextruding the viscoelastic composition through an orifice with a width or diameter of from 10 µm to 1000 µm to obtain one or more microextruded elements; and
(iii) stacking the two or more layers comprising microextruded elements in such a way that a vertical section of the edible microextruded product shows intersected microextruded elements within a layer, or microextruded elements superimposed and differentially oriented between the different layers; or alternatively the two or more layers are stacked in such a way that mixcroextruded elements between layers are oriented in parallel.

2. The process according to claim 1, further comprising after any one of steps (ii) and (iii), a step (iv) of adding one or more additives selected from the list consisting of emollients, flavour compounds, aromatizing compounds, lipids, colourants, metal chelants, oligoelements, vitamins, mineral salts, cells and extracts of said cells, and combinations of all these compounds and/or cells and/or cell extracts.

3. The process according to any of claims 1-2, further comprising after any one of steps (ii) and (iii), a step (v) of adding between microextruded elements within a layer and/or on a layer of microextruded elements, a composition comprising a fat selected from one or more triglycerides, cholesterol, one or more phospholipids, one or more fatty acids and combination thereof; and/or a composition comprising cartilaginous material; and/or a composition comprising bone material.

4. The process according to any of claims 1-3, wherein the viscoelastic composition comprises, an edible pseudoplastic polymer, a percentage by weight of protein from 19 % to 49 % w/w, and at least 45 % w/w of an edible solvent, both percentages in relation with total weight of the viscoelastic composition and the said solvent balancing up to 100 % w/w of the viscoelastic composition, said viscoelastic composition having an homogeneous distribution of particle sizes from lower than 6 µm to lower than 600 µm,

and being obtainable by:

(a) mixing the proteins, the edible pseudoplastic polymer and the edible solvent in a container; and

(b) applying one or more agitation cycles to a centrifugal force from 10g to 4000g, optionally in more than one direction, while raising the temperature from 20 ºC to a temperature lower than 95 ºC, and maintaining agitation and temperature for a period of time from 1 minute to 30 minutes.

5. The process according to any of claims 1-4, wherein the said viscoelastic composition has a storage modulus G' higher than the loss modulus G'' when measured at a frequency of 0.16 Hz and at a temperature of 23 ºC in a pair of parallel serrated plates and with a solvent amount in the edible microextrudable composition from 45 % to 90 % w/w; being the storage modulus G' equal to or higher than 1700 Pa and the loss modulus G'' equal to or higher than 350 Pa, and the ratio G''/G' in the viscoelastic composition being from 0.24 to 0.88.

6. The process according to claim 5, wherein storage modulus G' of the viscoelastic composition is from 1700 Pa to 140000 Pa, and the loss modulus G'' of the viscoelastic composition is from 350 Pa to 40000 Pa; and wherein the ratio G''/G' in the viscoelastic composition is from 0.24 to 0.88.

7. The process according to any one of claims 1-6, wherein the percentage by weight of protein is from 25 % to 49 %, and the percentage by weight of edible solvent is at least 45 %.

8. The process according to any one of claims 1-7, wherein the protein is selected from animal origin protein, plant origin protein, algae origin protein, yeast origin protein, bacterial origin protein, and combinations thereof.

9.The process according to claim 8, wherein the protein is animal protein.

10. The process according to claim 9, wherein animal protein is insect protein.

11. The process according to claim 8, wherein the protein is selected from plant origin protein, algae origin protein, yeast origin protein, bacterial origin protein, and combinations thereof.

12. The process according to any one of claims 1-11, wherein the percentage by weight of edible pseudoplastic polymer in relation with total weight of the viscoelastic composition,

is from 0.2 % to 40 %, and the percentage by weight of edible solvent is at least 45 %.

13.The process according to any one of claims 1-12, wherein the edible pseudoplastic polymer is selected from a polysaccharide, a pseudoplastic protein, and combinations thereof.

14.The process according to claim 13, wherein the pseudoplastic polymer is a polysaccharide selected from alginic acid, and an edible salt of alginic acid, xanthan gum, glycosaminoglycans, agarose, gellan gum, pectin, carrageenan and combinations thereof.

15. The process according to any one of claims 1-14, wherein the viscoelastic composition further comprises cells and/or extracts of said cells.

16. An edible microextruded product obtainable by a method as defined in any of claims 1 -15, comprising two or more layers of viscoelastic microextruded elements and wherein the compressive elastic modulus of the edible microextruded product is from $1.0x10^3$ Pa to $5.0x10^6$ Pa and the tensile Young's modulus of the edible microextruded product is from $5.0x10^3$ Pa to $11.0x10^6$ Pa, said compressive elastic and the tensile Young's moduli measured in a servo-hydraulic test system with a clamp displacement rate equal to 1 mm/min, at 23 ºC and with a solvent amount in the edible microextruded product from 45 % to 90 % w/w.

17. The edible microextruded product according to claim 16, wherein the microextruded elements are selected from microextruded sheets, microextruded filaments and combinations thereof.

18. The edible microextruded product according to any one of claims 16-17, comprising between two or more of the microextruded elements of each layer and/or between one or more of the layers of microextruded elements, a composition comprising a fat selected from one or more triglycerides, cholesterol, one or more phospholipids, one or more fatty acids and combination thereof; and/or a composition comprising cartilaginous material; and/or a composition comprising bone material.

19. Use of an edible microextruded product as defined in any one of claims 16-18, as a meat replacer.

20. Use of an edible microextruded product as defined in any one of claims 16-18 as a meat analogue.

21. Edible viscoelastic microextrudable composition comprising, in an appropriate edible solvent, protein in a percentage by weight in relation with the total weight of the viscoelastic composition from 19 % to 49 %, said protein selected from plant-origin protein, insect protein, algae-origin protein, bacterial origin protein, and combinations thereof; and an edible pseudoplastic polysaccharide selected from alginate, xanthan gum, glycosaminoglycans, agarose, gellan gum, pectin, carrageenan and combinations thereof, in a percentage by weight, in relation with the total viscoelastic composition, from 0.5 % to 40 %; and wherein the viscoelastic composition comprises at least 45 % by weight of edible solvent, in relation with the total weight of the composition.

22. The edible viscoelastic microextrudable composition according to claim 21, which has a storage modulus G' higher than the loss modulus G'' when measured at a frequency of 0.16 Hz and at a temperature of 23 ºC in a pair of parallel serrated plates, and with a solvent amount in the edible microextrudable composition from 45 % to 90 % w/w, being the storage modulus G' higher than 1700 Pa and the loss modulus G'' higher than 350 Pa, and wherein and the ratio G''/G' in the viscoelastic composition being from 0.24 to 0.88.

23. A viscoelastic microextrudable composition comprising, an edible pseudoplastic polymer, a percentage by weight of protein from 19 % to 49 % w/w, and at least 45 % w/w of an edible solvent, said solvent balancing up to 100 % w/w of the viscoelastic composition, both percentages in relation with total weight of the viscoelastic composition, said viscoelastic composition having an homogeneous distribution of particle sizes from lower than 6 µm to lower than 600 µm, and being obtainable by:
(a) mixing the proteins, the edible pseudoplastic polymer and the edible solvent in a container; and
(b) applying one or more agitation cycles to a centrifugal force from 10g to 4000g, optionally in more than one direction, while raising the temperature from 20 ºC to a temperature lower than 95 ºC, and maintaining agitation and temperature for a period of time from 1 minute to 30 minutes.

24. An edible composite product comprising a portion of the edible microextruded product according to any one of claims 16-18, and a portion of a solidified composition comprising a fat selected from one or more triglycerides, cholesterol, one or more phospholipids, one or more fatty acids and combination thereof; and/or a portion of a solidified composition comprising cartilaginous material; and/or a portion comprising bone material, said portion of composition comprising fat and/or cartilaginous material and/or bone material, adjacently and in contact with the portion of the edible microextruded product.