



New food, new technology: innovative spreadable cream with strawberry syrup

Gabriela Basto de Lima^{1,5,6} · Sofia Ganhão¹ · Paula Ruivo^{1,5,6} · M. Adelaide Oliveira^{1,5,6} · Antónia Macedo² · Carlos Brandão³ · Manuela Guerra³ · Cátia Morgado³ · Marco Alves⁴ · Marília Henriques^{1,5,6}

Received: 27 June 2022 / Revised: 15 November 2022 / Accepted: 20 November 2022
© The Author(s) 2023

Abstract

A strawberry spreadable cream was developed, valorizing regional raw materials, contributing to food waste reduction and agri-food ecosystem sustainability. Spreadable creams are water-in-oil emulsions whose lipid phase normally contains a blend of vegetable oils, natural colourants, stabilizers, emulsifiers, flavourings, antioxidants, lecithin, and fat-soluble vitamins. The aqueous phase normally contains skim milk proteins and small quantities of other ingredients, such as salt, preservatives, thickeners, and water-soluble vitamins. The methodology involved the experimental technological development articulated with microbiological, proximal, physicochemical, and sensorial analysis. This new product revealed nutritional advantages over similar products already on the market. The final prototype was subjected to food pairing and food design with incremental acceptance according to gastronomic use, in addition to its direct use as a spreadable cream. This work was part of the project Agrio et Emulsio—new products development (POCI-01-0145-FEDER-023583), whose main objective was the formulation and design of innovative food emulsions based on processed raw materials, with potential application in certain markets such as gourmet, diet, and vegan.

Keywords Water-in-oil food emulsion · Strawberry syrup · Innovative spreadable cream · Sustainable agri-food system

Introduction

To pursue a healthy lifestyle, consumers are looking for new, diversified and more convenient products. The development of new products to meet these consumers' expectations must be done to achieve sustainable development goals [1,2]. With this purpose, innovative food emulsions, as spreadable creams, could be developed, valuing secondary agricultural raw materials with potential application in food industry and thus reducing waste. Based on sustainable methodologies, an innovative spreadable cream, with different additions, was developed for markets in general, but also suitable for diet and vegan consumers [3].

An emulsion is a multiphase thermodynamically unstable system, consisting of two immiscible phases, an aqueous and a lipidic, where one of the phases is dispersed in the other (continuous phase) in the form of spherical droplets. The mean diameter of the droplets in emulsified food products typically falls somewhere in the range of 0.1 to 100 µm. Emulsions can be conveniently classified according to the relative spatial distribution of the different phases [4]. The lipidic phase consists of hydrophobic substances: a blend

✉ Gabriela Basto de Lima
maria.lima@esa.ipsantarem.pt

¹ Food Technology Biotechnology and Nutrition Department, School of Agriculture of Santarém, Polytechnic Institute of Santarém, Quinta do Galinheiro-S. Pedro, 2001-904 Santarém, Portugal

² School of Agriculture of Beja, Polytechnic Institute of Beja, Rua Pedro Soares, 7800-295 Beja, Portugal

³ Estoril Higher Institute for Tourism and Hotel Studies, Avenida Condes de Barcelona, n.º 808, 2769-510 Estoril, Portugal

⁴ Tagus Valley Technological Park, Rua José Dias Simão, 2200-062 Abrantes, Portugal

⁵ Life Quality Research Centre (CIEQV), IPSantarém/IPLeiria, 2040-413 Rio Maior, Portugal

⁶ IPSantarém Research Unity, Polytechnic Institute of Santarém, Complexo Andaluz, Santarém, Portugal

of vegetable oils and/or oils and animal fats, saturated and unsaturated free fatty acids, sterols, phytosterols, several emulsifiers like mono-acyl glycerol (MAG), di-acyl glycerol (DAG), and tri-acyl glycerol (TAG), natural colourants, stabilizers, flavourings, antioxidants, phospholipid such as lecithin and liposoluble vitamins. The aqueous phase consists of hydrophilic substances: polysaccharides, alkalis, acidity regulator, salt, water-soluble vitamins, preservatives, thickeners, and milk proteins [5,6]. Emulsions can basically be of two types: oil-in-water (o/w), wherein the dispersed phase is lipidic; and the continuous phase is aqueous, forming a normal micelle at the interface and water-in-oil (w/o) wherein the dispersed phase is aqueous, and the continuous phase is lipidic, forming an inverse micelle at the interface [7,8]. The preparation of emulsions that are kinetically stable over time that is of practical use to the food industry (e.g. a few days, weeks, months, or years) requires the incorporation of substances known as stabilizers. Stabilizers can be classified according to their mode of operation as either “emulsifiers” or “texture modifiers”. An emulsifier is a surface-active substance that adsorbs to the surface of emulsion droplets to form a protective coating that prevents the droplets from aggregating with one another, e.g. certain proteins, polysaccharides, phospholipids, small molecule surfactants, and solid particles [4,5]. An emulsifier also reduces the interfacial tension and therefore facilitates the disruption of emulsion droplets during homogenization, which aids in the formation of emulsions containing smaller droplets [9,10]. The membrane that supports the droplets stabilizes the system and is located at the interface, where there is competition for the adsorption of various emulsifying components, as they are substances with affinity for both phases [9–12]. A vegetable spreadable cream is essentially a water-in-oil (w/o) emulsion, with solid fat crystals forming a three-dimensional network. The network of fat crystals surrounds the droplets of the dispersed aqueous phase and is embedded in the continuous lipidic phase, forming a membrane at the interface [13,14]. So, the rheological behaviour of a spreadable cream mainly depends on the crystalline form of the fatty acids (polymorphic form α , β or β') and the processing techniques used [15–17]. The polymorphic form have Greek letters, namely, a is α , b is β and b' is β' . The lipidic content, continuous and dispersed phases between the aggregated crystalline network, together with the solid fraction are, according to Walstra [9] and McClements [4,5], responsible for the viscoelastic behaviour, denoting solid-like behaviour.

The innovative nature of these spreads corresponds to the fact that other ingredients have been incorporated within the product, such as strawberry syrup, maintaining the rheological characteristics of a normal spreadable cream, i.e. its spreadability [18,19]. As new products, it is necessary to ensure not only the regulatory requirements for food safety,

but also the quality perceived and demanded by consumers [20–22].

Spreadable creams are known to become unstable at temperatures above 8 °C. Since they have lipidic crystals in their structure, if the product is subjected to heat treatment, the lipidic crystals melt, and the network is destroyed destabilizing the emulsion, resulting in phase separation [4,5,9,14–16].

Materials and methods

Technological development

The methodology [3] used for food emulsions prototyping process development included technological assays articulated with sensorial and analytical evaluation.

Technological process strawberry syrup development

The main constituents of syrup were strawberry, sweetener (fructose), acidity regulator (lemon juice), and a thickener (pectin). The strawberry syrup was produced at a temperature about 90 °C.

There were developed four strawberry syrup pre-prototypes A1, A2, A3 and A4 with different formulations. For each of them, the total soluble solids content (TSS in °Brix), total acidity (TA), and pH were determined. These results, of pre-prototypes, are not presented here.

Technological process of production of spreadable creams

In emulsion production, the aqueous phase was prepared with a mixture of a beverage of vegetable origin acquired in the market and natural lemon juice (as an acidity regulator). The lipidic phase consisted of a blend of sunflower oil, coconut fat (solid), and soy lecithin (emulsifier).

All this procedure was carried out at low temperature, always bearing in mind the good manufacturing practices in terms of hygiene and food safety. The process was performed at laboratory scale in five steps:

First: melting of coconut fat (solid) and addition of vegetable oil and emulsifier, promoting agitation at a temperature about 0 °C approximately; fat crystal creation—crystallization (chilling).

Second: addition of an aqueous phase mix, with continuous agitation, at a temperature about 0 °C, forming a w/o emulsion.

Third: addition of strawberry syrup, with continuous agitation, at a temperature of about 0 °C.

Fourth: formation of spreadable cream.

Fifth: filling and storage at a temperature of about 5 °C.

At the beginning, five prototypes were developed in series No. 1, with the following conditions: different formulations of strawberry fructose syrups; different beverages of vegetable origin for aqueous phase and different formulations of spreadable creams. The prototype codes of series No. 1 were designated by: A12, A13, A24, A33 and A44, where the first digit corresponds to the syrup formulation and the second digit the emulsion formulation used. Physicochemical analyses were performed such as determination of pH, total acidity (TA), and total soluble solid content (TSS in °Brix). Beyond analytical characterization, these prototypes were also evaluated by an untrained taster's panel. According to sensorial results and panellists' suggestions, the added syrup and w/o emulsion were reformulated, pursuing technological development to formulate three new prototypes for series No. 2: A55, A65, and A75. For these new prototypes, the same physicochemical analyses were carried out and samples were also subjected to sensorial evaluation. Based on the results of the taster's panel, a final prototype, A55, was selected. Microbiological, physicochemical, and proximal analyses were carried out. This final prototype was subjected to food pairing and food design, as described elsewhere [23,24].

Sensorial evaluation

The sensorial tests were hedonic, performed with an untrained taster's panel and the parameters evaluated followed Richardson-Harman et al.'s [25] recommendations. The evaluated attributes were appearance, associated with the vision sense (colour and brightness), texture associated with mechanoreceptor senses (consistency and spreadability), aroma associated with the olfactory sense (strawberry, coconut, lemon), taste associated with the palate sense (sweetness, acid, fat, strawberry, and coconut), and overall assessment. For this evaluation, depending on test sessions, the number of panel members varied between 25 and 35. For treatment of the results and considering the scores assigned by each panellist in the tasting sheet, the weighted average for each attribute was computed and radar and circular (overall assessment) charts were built.

Microbiological analyses

Microbiological evaluation followed the recommendations and rules for microbiological analyses of food, according to International Organization for Standardization ISO 7218:2007 [26]. For microbiological characterization and stability evaluation, the following microbiological analyses were performed: enumeration of aerobic mesophilic microorganisms according to ISO 4833-1:2013 [27];

enumeration of lipolytic microorganisms at 30 °C according to Bourgeois et al. 1991 [28]; enumeration of yeasts and moulds according to ISO 21527-1:2008 [29]; enumeration of osmophilic or osmotolerant yeasts and moulds according to ISO 21527-2:2008 [30]; enumeration of *Enterobacteriaceae* according to ISO 21528-2:2004 [31]; and the detection of spores of sulphite-reducing *Clostridia* according to NP 2262:1986 [32]. The results are expressed in logarithm of colony forming units per gram of spreadable cream (log c.f.u./g).

Physicochemical and nutritional analyses

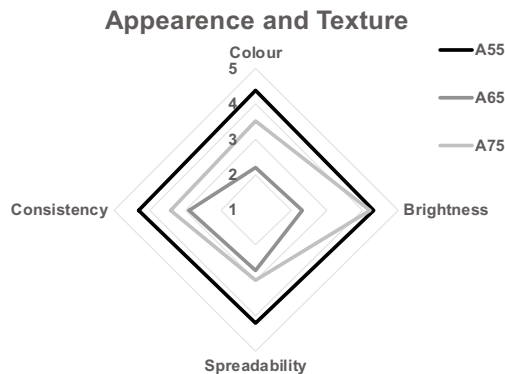
Physicochemical and nutritional analyses were performed for strawberry syrup spreadable cream (SSC). For physicochemical characterization, the parameters analysed were total acidity (TA) in (% w/w) oleic acid (spreadable cream) or % (w/w) citric acid (jam and jellies), according to NP No. 1412:1981 [33]; total soluble solid content (TSS in °Brix); pH measured on an emulsion prepared in isotonic solution of KCl 0,1 N using an immersion electrode. Nutritional assessment was performed according to AOAC 2002 [34]. The parameters analysed were caloric content, moisture content (935.36), crude protein (950.36), total lipids (935.38), carbohydrates, total fibre (950.37), salt content (930.23), and ash (930.23). For each parameter, three replicate experiments were carried out. The results were evaluated using Statistic version 7.0 program (Stat Soft Inc.). Mean and standard deviation were calculated for each analytical parameter.

Results

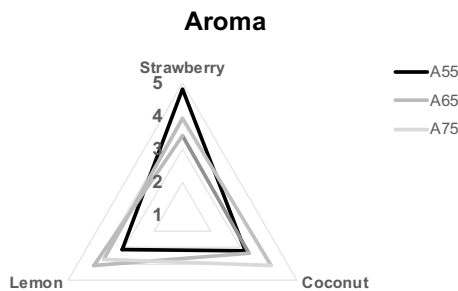
Sensorial evaluation

Sensorial evaluation is the consumer's first approach of a food product, whether colour is appealing or not and whether the product is bright or not, giving consumer an indication of its conservation. The rheological behaviour is critical for spreadable creams and the texture attributes are very important, namely, spreadability and consistency. For the current strawberry syrup spreadable cream (SSC), it is important to emphasize the predominance of strawberry aroma and taste. Less favourable scores can be associated with fat intensity, coconut and acidic taste, and aroma. Figure 1 presents the results of sensorial evaluation for the three prototypes of series No. 2 (A55, A65 and A75). Bearing in mind the desired organoleptic characteristics of this type of product, the untrained taster's panel gave the most favourable evaluation to A55 prototype.

Appearance and Texture				
Sample	Colour	Brightness	Spreadability	Consistency
A55	4.40	4.30	4.20	4.30
A65	2.20	2.30	2.70	2.90
A75	3.50	4.20	3.00	3.40



Aroma			
Sample	Strawberry	Coconut	Lemon
A55	4.80	3.20	3.10
A65	3.40	3.30	4.10
A75	3.90	4.10	3.74



taste				
Sample	Sweetness	Acid	Fat	Strawberry
A55	3.64	3.30	3.30	4.90
A65	3.64	4.60	4.20	2.40
A75	3.64	2.83	2.30	3.50

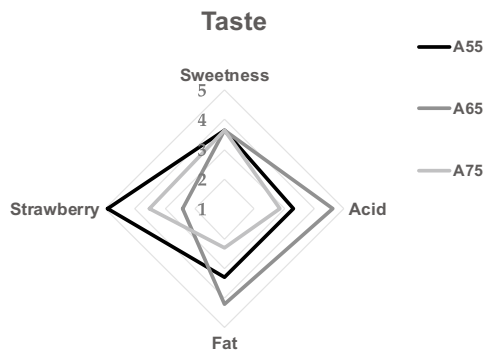


Fig. 1 Radar chart (a) appearance and texture, (b) flavours, and (c) taste attributes for A55 A65 and A75 prototypes (series no. 2)

Figure 2 presents the overall assessment results that confirms A55 as the final prototype.

Microbiological evaluation

The results for samples kept under refrigeration conditions are presented in Table 1. These samples remained stable at a temperature of about 5 °C compared to the sample after production (1 day). In the tests performed, *Enterobacteriaceae* were not detected, and the results were negative in 1 g; and spores of sulphite-reducing *Clostridia* were negative in 1 g. These indicators are relevant in terms of the production control, hygiene, and food safety. These results showed that samples had satisfactory microbiological characteristics and, so, quality, and microbiological stability of the final prototype can be guaranteed by good manufacturing practices.

Physicochemical and nutritional evaluation

The results of physicochemical and nutritional analyses for SSC are shown in Table 2.

Being a new product, there are no reference values to enable a comparison with the results obtained. Therefore, an analogy was established with vegetable-based spreadable creams (CSC) without additions, already on the market. The reference values for CSC were taken from US Patent De Groot WA (2006) [36] and from Food Composition Table (TCA) [37] of the National Health Institute Dr. Ricardo Jorge (INSA). In addition, the Portuguese legislation for jams and jellies was used—Portaria No. 1548/2002 [38] and Decreto-Lei No. 97/84 (jams and sweets) [39].

The results highlight the following:

- The pH values obtained were within the recommended range for this type of product, 4.2–4.4 [36].
- Total acidity results were much higher than the reference values of CSCs 1.0–2.2% ((w/w) oleic acid), according to TCA [37], and those of jellies were according to Portuguese legislation [38,39], as expected, since the added syrup was acidified.
- The average value of TSS for this new product is lower than the reference values of Portuguese legislation [38,39], which establishes a range of 60–70°Brix, emphasizing its potential as a possible substitute for jams and similar products.
- SSC caloric content was very similar to strawberry jam reference values, but significantly lower than the caloric content of CSCs, which is a beneficial and differentiating characteristic.
- The results obtained for lipid content of SSC were very promising in comparison to TCA-referred values [37] for vegetable-based spreadable creams (CSC).

Fig. 2 Chart of overall assessment for A55 A65 and A75 prototypes (series no. 2)

Amostra	Overall assessment
A55	3.90
A65	2.10
A75	3.10

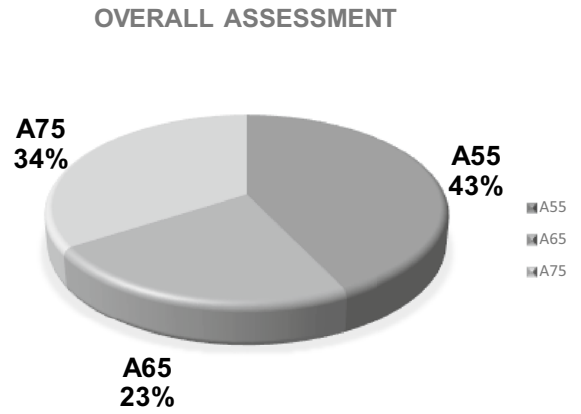


Table 1 Microbiological stability tests results for strawberry spreadable cream

Time days	Enumeration of aerobic mesophilic microorganisms (log c.f.u./g)	Enumeration of lipolytic microorganisms at 30 °C (log c.f.u./g)	Enumeration of osmophilic or osmotolerant yeasts and moulds (log c.f.u./g)	Enumeration of <i>Enterobacteriaceae</i> (log c.f.u./g)	Guidelines of INSA*[35]
	Mean ± Std	Mean ± Std	Mean ± Std	Mean ± Std	
1	a	a	a	a	Satisfactory
30	a	a	a	a	Satisfactory
45	1.78 ± 0.01	2.78 ± 0.02	a	a	Satisfactory
90	2.38 ± 0.03	a	a	a	Satisfactory

a < 1 c.f.u./g

*[35] INSA Instituto Nacional de Saúde Doutor Ricardo Jorge

Table 2 Physicochemical and nutritional characterization for strawberry spreadable cream

Parameter	Analytical method: [33] and [34]	Units per 100 g product	Strawberry spreadable cream (SSC) Results	Vegetable-based spreadable creams* (CSC): [36] and [37]	Strawberry jam: [37,38] and [39]
			Mean ± Std	Reference values	
pH	Potentiometry	–	4.37 ± 0.04	4.2–4.4	3.65–3.75
Total acidity	Potentiometric titration	% (w/w)**	3.68 ± 0.06	1.0–2.2	1.34
Total soluble solid content TSS	Refractometry	°Brix	51.53 ± 0.00	–	60–70
Caloric content	Calculation	kJ	1195	2600	1040
			kcal	286	632
Moisture content	935.36	g	49.97 ± 0.11	26.0	38.0
Total lipids	935.38	g	19.06 ± 0.65	70.0	0.0
Crude protein	950.36	g	0.15 ± 0.00	0.1	0.2
Carbohydrates	Calculation	g	28.3	0.3	60.5
Total fibre	950.37	g	2.22 ± 0.22	0.0	1.0
Salt content	930.23	g	0.0	3.0	0.0
Ashes	935.36	g	0.25 ± 0.02	–	–

kJ kilojoule (energy unit of the international system of units, 1 cal = 4.185 J)

*CSC 70% fat, with salt

**% (w/w) oleic acid (spreadable) or % (w/w) citric acid (jam and jellies)

Fig. 3 Strawberry spreadable cream (from left to right) end of production filling and food pairing



– The result obtained for carbohydrates in the final prototype (SSC) was about half of the value reported for strawberry jam in TCA [37].

– The result obtained for total fibre in the final prototype (SSC) was twice the value reported for strawberry jam in TCA [37].

These reported results suggest that the final prototype (A55) of this spreadable cream with added strawberry syrup (SSC, has the potential to be part of a healthy diet. Furthermore, sensorial tests carried out on food pairing and food design showed that SSC had a very pleasant strawberry flavour, good spreadability, and, in addition to its direct use, suitable for gastronomic applications [23,24].

Figure 3 shows the final prototype. From left to right: end of production, filling and packaging; gastronomic application—food pairing.

Discussion

To promote the diversification of new spreads, and aligned with current food trends, the present work developed a new and stable spreadable cream of vegetable origin, with addition of strawberry syrup. Simultaneously, it was shown that it may be possible to minimize the waste of agricultural products with low commercial value. This product allows better use of agricultural raw materials and stimulates the reducing of wastes, in line with the policies promoted by the European Union, vital to achieve the Sustainable Development Goals of the United Nations, particularly “12”. Ensure sustainable consumption and production patterns”. The choice of strawberry for syrup production is one of the examples of the valorization of agricultural products that would not be in conformity with the regulations for fresh market introduction. The results obtained for strawberry syrup cream (SSC), by analogy with reference values of similar products already on the market, show that this new spreadable cream with additions has several nutritional advantages. In fact, considering the reference for commercial spread creams (Table 2), the caloric and total lipid contents in CSC are both higher than in SSC, and crude protein and fibre are lower. The pH values are within the standard range required for CSC. This new

product revealed a nutritional composition in the range of values recommended for a possible classification as healthy food as mentioned in references [1,2]. In general, the microbiological stability of the products in terms of safety and quality indicators was achieved. Sensorial tests were carried out on this prototype (A55) and the results indicated that this spreadable cream had a very pleasant taste and good spreadability, with future perspective of gastronomic applications. Finally, it is intended to proceed with scale-up by adjusting the manufacturing process to meet the requirements from the nutritional point of view, always ensuring the quality and food safety. In future, other spreads with other additions already developed will be described and presented in other manuscripts. The aim is to diversify the potential use of food emulsions, valorizing agricultural raw materials, in line with the necessary sustainability of the agro-industrial sector.

Acknowledgements The results presented in this manuscript were obtained during the project *Agrio et Emulsio – New product development* (reference POCI-01-0145-FEDER-023583), approved within the scope of Competition No.02/SAICT/2016 and financed by the Operational Competitiveness and Internationalization Program (FEDER), and Life Quality Research Centre (LQRC/CIEQV) - Financed by national funds through FCT (Foundation for Science and Technology, I.P.) under the project No. UID/CED/04748/2020.

Data availability statement The datasets generated and analyzed during the currently study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will

need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

1. Skelhon TS, Grossiord N, Morgan AR, Bon SA (2012) Quiescent water-in-oil Pickering emulsions as a route toward healthier fruit juice infused chocolate confectionary. *J Mater Chem* 22(36):19289–19295. <https://doi.org/10.1039/C2JM34233B>
2. Lee YY, Tang TK, Phuah ET, Tan CP, Wang YL, Cheong KZ, Lai OM (2019) Production, safety, health effects and applications of diacylglycerol functional oil in food systems: a review. *Crit Rev Food Sci Nutr* 11:2509–2525. <https://doi.org/10.1080/10408398.2019.1650001>
3. Lima MGOLB, Laranjeira CM, Henriques MOI, Ganhão, S (2018) *Agrio et Emulsio - Creme de barrar de morango*. *Revista UL_IPSantarém* 6(3):64–72. <https://doi.org/10.25746/ruiips.v6.i3.16148>
4. McClements DJ (2016) *Food emulsions: principles, practice, and techniques*, 3rd edn. CRC Press
5. McClements DJ, Jafari SM (2018) Improving emulsion formation, stability and performance using mixed emulsifiers: a review. *Adv Coll Interface Sci* 251:55–79. <https://doi.org/10.1016/j.cis.2017.12.001>
6. Zembyla M, Murray BS, Radford SJ, Sarkar A (2019) Water-in-oil Pickering emulsions stabilized by an interfacial complex of water-insoluble polyphenol crystals and protein. *J Colloid Interface Sci* 548:88–99. <https://doi.org/10.1016/j.jcis.2019.04.010>
7. Yi J, Zhu Z, Dong W, McClements DJ, Decker EA (2013) Influence of free fatty acids on oxidative stability in water-in-walnut oil emulsions. *Eur J Lipid Sci Technol* 115(9):1013–1020. <https://doi.org/10.1002/ejlt.201200438>
8. Guanghui L, Wan JL, Ning L, Xuanxuan L, Chin PT, Oi ML, Chaoying Q, Yong W (2021) Stabilization mechanism of water-in-oil emulsions by medium- and long-chain diacylglycerol: post-crystallization vs. pre-crystallization. *LWT Food Sci Technol* 146:111649. <https://doi.org/10.1016/j.lwt.2021.111649>
9. Walstra P (2003) *Physical chemistry of foods*. Marcel Decker.
10. Dickinson E (2013) Stabilising emulsion-based colloidal structures with mixed food ingredients. *J Sci Food Agric* 93(4):710–721. <https://doi.org/10.1002/jsfa.6013>
11. Yi J, Zhu Z, McClements DJ, Decker EA (2014) Influence of aqueous phase emulsifiers on lipid oxidation in water-in-walnut oil emulsions. *J Agric Food Chem* 62(9):2104–2111. <https://doi.org/10.1021/jf404593f>
12. Silva PS, Starov VM, Holdich RG (2017) Membrane emulsification: formation of water in oil emulsions using a hydrophilic membrane. *Colloids Surf A* 532:297–304. <https://doi.org/10.1016/j.colsurfa.2017.04.077>
13. Nelis V, De Neve L, Balcaen M, Dewettinck K, Courtin T, Martins JC, der Meeren PV (2021) Influence of fat crystallization in W/O emulsions on the water droplet size determination by NMR diffusometry. *J Colloid Interface Sci* 598(2021):314–323. <https://doi.org/10.1016/j.jcis.2021.04.039>
14. Rafanan R, Rousseau D (2017) Dispersed droplets as active fillers in fat-crystal network-stabilized water-in-oil emulsions. *Food Res Int* 99:355–362. <https://doi.org/10.1016/j.foodres.2017.04.008>
15. Di Bari V, Macnaughtan W, Norton J, Sullo A, Norton I (2017) Crystallisation in water-in-cocoa butter emulsions: role of the dispersed phase on fat crystallisation and polymorphic transition. *Food Struct* 12:82–93. <https://doi.org/10.1016/j.foostr.2016.10.001>
16. Ghosh S, Rousseau D (2011) Fat crystals and water-in-oil emulsion stability. *Curr Opin Colloid Interface Sci* 16:421–431. <https://doi.org/10.1016/j.cocis.2011.06.006>
17. Nadin M, Rousseau D, Ghosh S (2014) Fat crystal-stabilized water-in-oil emulsions as controlled release systems. *LWT-Food Sci Technol* 56(2):248–255. <https://doi.org/10.1016/j.lwt.2013.10.044>
18. Iqbal S, Xu ZC, Huang H, Chen XD (2019) Controlling the rheological properties of oil phases using controlled protein-polysaccharide aggregation and hetero aggregation in water-in-oil emulsions. *Food Hydrocolloids* 96:278–287. <https://doi.org/10.1016/j.foodhyd.2019.05.028>
19. Okuro PK, Gomes A, Costa ALR, Adame MA, Cunha RL (2019) Formation and stability of W/O-high internal phase emulsions (HIPEs) and derived O/W emulsions stabilized by PGPR and lecithin. *Food Res Int* 122:252–262. <https://doi.org/10.1016/j.foodres.2019.04.028>
20. Picone CSF, Bueno AC, Michelon M, Cunha RL (2017) Development of a probiotic delivery system based on gelation of water-in-oil emulsions. *LWT Food Sci Technol* 86:62–68. <https://doi.org/10.1016/j.lwt.2017.07.045>
21. Clausse D, Lanoisell'e JL, Pezron I, Saleh K (2018) Formulation of a water-in-oil emulsion encapsulating polysaccharides to improve the efficiency of spraying of plant protection products. *Colloids Surfaces A* 536:96–103. <https://doi.org/10.1016/j.colsurfa.2017.07.032>
22. Iqbal S, Xu ZC, Huang H, Chen XD (2019) Structuring of water-in-oil emulsions using controlled aggregation of polysaccharide in aqueous phases. *J Food Eng* 258:34–44. <https://doi.org/10.1016/j.jfoodeng.2019.04.008>
23. Silva AT, Morgado C, Félix N, Brandão C, Guerra M, Lima G, Laranjeiro C (2020). Gastronomic potential and pairings of new emulsions of vegetable origin. In: *Experiencing food, designing sustainable and social practices—Proceedings of the 2nd International Conference on Food Design and Food Studies (EFOOD 2019):30–34*. CRC Press. <https://doi.org/10.1201/9781003046097>
24. Silva AT, Morgado C, Félix N, Lima M, Laranjeiro C, Brandão C, Guerra M (2021) Development of gastronomic strategies for the application and valorization of new inverse emulsions of vegetable origin. In *Sustainable Innovation in Food Product Design* (pp. 87–103). Springer, Cham. https://doi.org/10.1007/978-3-030-61817-9_5 and <https://www.springer.com/gp/book/9783030618162>
25. Richardson-Harman NJ, Stevens R, Walker S, Gamble J, Miller M, Wong M, McPerson A (2000) Mapping consumer perceptions of creaminess and liking for liquid dairy products. *Food Quality Preference* 11(3):239–246. [https://doi.org/10.1016/S0950-3293\(99\)00060-9](https://doi.org/10.1016/S0950-3293(99)00060-9)
26. International Organization for Standardization (2007) *Microbiology of food and animal feeding stuffs—general requirements and guidance for microbiological examinations* (ISO Standard No. 7218:2007).
27. International Organization for Standardization (2013) *Microbiology of the food chain—Horizontal method for the enumeration of microorganisms—part 1: colony count at 30 °C by the pour plate technique* (ISO Standard No. 4833-1:2013(en)).
28. Plusquellec A (1991) In *CM Bourgeois & JV Leveau* (Coord.) *Techniques d'analyse et de contrôle dans les industries agro-alimentaires*, 2nd ed, Vol. 3. Lavoisier – Tec& Doc.
29. International Organization for Standardization (2008a) *Microbiology of food and animal feeding stuffs—horizontal method for enumeration of yeasts and moulds. Part 1: colony count technique in products with water activity greater than 0,95* (ISO Standard No. 21527-1:2008).
30. International Organization for Standardization (2008b) *Microbiology of food and animal feeding stuffs—horizontal method for*

- enumeration of yeasts and moulds. Part 2: colony count technique in products with water activity less than or equal to 0,95 (ISO Standard No. 21527-2:2008).
31. International Organization for Standardization (2004) Microbiology of food and animal feeding stuffs—horizontal methods for the detection and enumeration of Enterobacteriaceae—Part 2: colony-count method. (ISO Standard No. 21528-2:2004).
 32. Instituto Português da Qualidade (1986) *Microbiologia Alimentar – Regras gerais para a pesquisa de esporos de clostrídios sulfito-redutores* (NP n.º 2262:1986). (Portuguese standards from/ by Portuguese Institute/Organization for Quality).
 33. Instituto Português da Qualidade (1981) Manteiga. *Determinação da acidez total* (NP n.º 1712:1981).
 34. Association of Official Analytical Chemists (2002) Guidelines for single laboratory validation of chemical methods for dietary supplements and botanicals. Official Method of Analyses (16th ed.).
 35. Instituto Nacional de Saúde Doutor Ricardo Jorge (2019) Interpretação de resultados de ensaios microbiológicos em alimentos prontos para consumo e em superfícies do ambiente de preparação e distribuição alimentar: valores-guia. <http://hdl.handle.net/10400.18/5610>. Accessed 18 Jan 2021
 36. De Groot WA (2006) Food product comprising a phytosterol (Pub. No.: US 2006/0115574 A1). US Patent and Application Publication. <https://patentimages.storage.googleapis.com/d2/91/6c/033b541887335d/US20060115574A1.pdf>. Accessed 18 Jan 2021
 37. Instituto Nacional de Saúde Doutor Ricardo Jorge (2019) Tabela de composição dos alimentos (Versão 4.1).
 38. Portaria n.º 1548/2002 da Presidência do Conselho de Ministros e Ministérios da Economia e da Agricultura, Desenvolvimento Rural e Pescas e da Saúde (2002). Diário da República: I série – B, n.º 298/02. <https://dre.pt/dre/detalhe/portaria/1548-2002-405337>. Accessed 18 Jan 2021
 39. Decreto-Lei n.º 97/84 da Presidência do Conselho de Ministros e Ministérios da Agricultura, Florestas e Alimentação, do Comércio e Turismo e da Qualidade de Vida (1984). Diário da República: I série, n.º 74/84. <https://dre.tretas.org/dre/455/decreto-lei-97-84-de-28-de-marco>. Accessed 18 Jan 2021

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH (“Springer Nature”).

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users (“Users”), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use (“Terms”). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval, sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com