BIO Web of Conferences **103**, 00077 (2024) https://doi.org/10.1051/bioconf/202410300077
FIES 2023

Prospects for production and application of bioactive vegetable oil emulsions in food technology

Natalya Rodionova, *Evgeny* Popov*, *Natalya* Zakharova, *Ekaterina* Pozhidaeva, *Jana* Dymovskih and *Sergej* Krjachko

Voronezh State University of Engineering Technologies, 19, Revoljucii Avenue, Voronezh, 394036, Russian Federation

Abstract. The paper shows possibility of obtaining stable emulsions of bioactive vegetable oils in fermented milk medium with concentration of lipid fraction up to 50 %. Emulsifying capacity of fermented fermented milk medium in emulsions of bioactive vegetable oils is found to be 8.2–8.5 %. The influence of the rotation speed of the working element of the emulsifier in the range of 1000–3000 rpm on the emulsifying capacity of the dispersion medium and sedimentation stability of emulsions has been established. Possibility of increasing capacity and stability of emulsions by 1.3–3.9 times when emulsifiers and stabilizers of structure – egg white, lecithin, guar gum are introduced into dispersion medium in concentration up to 3.0 % is revealed. Approximating dependence of emulsifying capacity of dispersion medium on emulsifier concentration is obtained taking into account linear, quadratic and cubic influence of factor. Based on the results of experimental studies, a technology for producing emulsion drinks based on fruits and spices has been developed. The assessment of the vitamin-mineral composition of the developed beverages showed their high nutritional value, established a significant content of vitamins B_3, B_9, A, D, E. Satisfaction of the daily need of the body when consuming 100 g of the beverage according to these nutrients is 8.2–43.3 %. The data obtained make it possible to classify the developed emulsion drinks as products with improved consumer properties.

1. Introduction

The design of food products containing biologically active substances of lipid nature, on the one hand, and a water-soluble fraction – biomass of probiotic microorganisms on the other, is based on the process of emulsification – the formation of stable heterogeneous oil-in-water systems [1, 12, 13, 15, 17, 27-35, 43-48].

Despite many positive clinical effects, the use of pumpkin seed oil in the diet of the population is very limited. Food products – carriers of pumpkin seed oil, are practically not on the market. In addition, it is known that the efficiency of absorption of biologically active substances from food increases when they are combined with probiotics [16, 19–24, 36-42, 49-55].

The research goal is to develop the technology of new stable probiotic bioactive emulsions enriched with microbial metabolites, polyunsaturated fatty acids, vitamins, antioxidants based on the lipid fraction of domestic plant raw materials.

2. Materials and methods

Pumpkin seed oil, which is a source of vitamins A, E, T, K, minerals Mg, Mn, Fe, is used as a dispersed phase in the development of the technology of probiotic emulsions [2, 3, 10, 18]. The dispersion medium was a biomass of a consortium of commercial probiotic microorganisms fermented on a milk defatted base, including Str. thermophilus, L. acidophilus, L. plantarum, L. Fermentum at a concentration of at least 10^9 CFU/ml, the titrated acidity of the prototypes was 80–100 ° T, pH 4.61-4.65, mold yeast in 1 g, bacteria of the E. coli group, pathogens, including salmonella, were absent. As a nutrient medium, skimmed milk was studied. Samples of emulsions of test oils obtained in skimmed milk medium served as a control. Egg white, lecithin, guar gum were investigated as emulsifiers and stabilizers of the structure [11, 14, 26]. The study of emulsifying capacity (EA, %) of the samples was carried out in accordance with the recommendations of L.V. Antipova [4, 5]. The experimental data were processed using regression analysis using multivariate planning, gradient method and least squares method, linear programming implemented in Microsoft Excel [6, 7]. The mass fraction of fat in the developed probiotic emulsion drink was carried out using the Soxhlet method, the mass fraction of protein using the Kjeldahl method [4]. The weight fraction of carbohydrates was determined using size exclusion gel permeation chromatography [8]. The mineral composition of the probiotic emulsion beverage was determined using a

* Corresponding author: e_s_popov@mail.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

CarlZeis AAS-1N flame atomic absorption spectrometer (Germany) according to the instrument manual. The vitamin composition of the probiotic emulsion beverage was determined using high-performance liquid chromatography and spectrophotometry [9].

3. Discussion of the results

Experimentally, on model systems, the presence of pronounced emulsifying properties of a probiotic acid-milk system fermented by a consortium of probiotic microorganisms was revealed. Emulsifying capacity of biomass of probiotic microorganisms in emulsions containing pumpkin seed oil is found to be 8.2–8.5%. In the control sample, the emulsifying capacity was – 2.2–2.4 %, which is 3.5–3.7 times lower than in the experimental one.

To provide higher stability parameters for the pumpkin seed oil emulsion in the probiotic lactic acid medium, the influence of a number of known surfactants and stabilizing agents used in food technology has been investigated. Egg white, lecithin, guar gum were studied as emulsifiers and stabilizers of the structure [11, 14].

In the process of emulsification, a fermented milk system with a microbial number of at least 10^9CFU/ml was subjected to intensive mechanical action using various types of mixing devices, the rotational speed of which ranged from 1500 to 2500 rpm.

The introduction of emulsifiers and stabilizers of the structure into the emulsion medium in the concentration range of 0.5–3.5% led to an increase in the stability of emulsions by 1.4–3.8, 1.7–5.7, 1.3–3.9 times for egg white, lecithin, guar gum, respectively.

The presence of a wide range of intensity of the influencing factor results in heterogeneous structures with different area of the dispersed phase, which necessitates the introduction of emulsifiers with different concentrations to achieve sufficient emulsifying capacity of the system. It has been found that the emulsifying capacity of the studied emulsifiers in probiotic emulsions obtained during homogenization in the range of 1000–3000 rpm reaches maximum values in the range of concentrations of 2.5–5.0 %. Obtained data make it possible to state increase of concentration of introduced emulsifier by 25–35 % with increase of working member rotation frequency by 1.5–1.7 times [25].

A slight decrease in the concentration of probiotic microorganisms to 10^8 CFU/ml was found with a rotation frequency of the working member of the emulsifier up to 2000 rpm. Further increasing the intensity of exposure to 2500 rpm leads to a significant decrease in the concentration of active cells to 10^6 CFU/ml.

It was found that the emulsifying capacity of the test substances in the probiotic emulsion reaches maximum values at a concentration of not more than 3.0 % (Table 1).

Table 1. Justification of emulsifier concentration

Name of vegetable oil	Name of emulsifier, structure stabilizer	Emulsifier concentration (C), %	Emulsifying ability (EA), %
Pumpkin seeds	Lecithin	3.0	47.2
	Guar gum	3.0	32.2
	Egg white	3.0	31.6

The calculation of the pairwise correlation coefficient of the independent value (emulsifier concentration (C), %) and the dependent value (emulsifying capacity (EA), %) was carried out for the tested pumpkin seed oil with emulsifiers at different concentrations (1)

$$r_{xy} = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i-\bar{x})^2\sum_{i=1}^{N}(y_i-\bar{y})^2}} \quad (1)$$

where N is the number of observations, xi is the ith value of the independent value, yi is the ith value of the dependent value,, are the average values of the observed values calculated according to formulas (2), (3)

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \quad (2)$$

$$\bar{y} = \frac{\sum_{i=1}^{N} x_i}{N} \quad (3)$$

Numerical values of the pairwise correlation coefficient between C (%) and EA (%) for probiotic emulsion test samples are given in Table 2.

Table 2. Pairwise correlation coefficient values

Name of vegetable oil	Name of emulsifier, structure stabilizer	Pair correlation coefficient
Pumpkin seeds	Lecithin (3.0 %)	0.976
	Guar gum (3.0 %)	0.953
	Egg white (3.0 %)	0.998

It was found that there is a statistically significant relationship between C (%) and EA (%), since the pairwise correlation coefficient is close to 1.

The structure of the approximating relationship takes into account the linear, quadratic and cubic influence of factor C (%) on EA (%) (4)

$$EA=a_0+a_1C+a_2C^2+a_3C^3 \quad (4)$$

where a_0, a_1, a_2, a_3 – parameters determined from experimental data.

The estimation of the dependence parameters (4) was carried out by the Levenberg method of the Mathcad 15 library, based on the minimization of the criterion, which is the sum of the squares of the deviations of the calculated values from the experimental data. The results of the sensitivity analysis of changes in the modulus of the difference of the minimum values of criterion to the sequential addition of terms (4) showed that it is sufficient to use 4 terms to ensure an acceptable average absolute and relative errors. The approximating dependences $EA=f(C)$ for a probiotic emulsion with pumpkin seed oil of the following type were obtained (5)

$$EA=8,904+6,793C+0,716C^2–0,209C^3 \quad (5)$$

The average absolute error was – 0.24, the average relative error was 1.88%, the maximum error did not exceed – 5.6%, respectively.

The results of experimental studies provide a scientific justification for the production of stable probiotic emulsions containing pumpkin seed oil.

Microscopic studies revealed changes in the microstructure of probiotic systems during emulsification. Effect of lecithin concentration on emulsion microstructure, elimination of fat ball agglomerates and reduction of their size by 25–40% – from 55–65 mcm to 30–40 mcm at increase of lecithin concentration from 1.5 to 3.0 % is found, which proves expediency and efficiency of use of emulsifiers as components providing additional emulsifying capacity of probiotic systems.

Table 3. Chemical composition and nutritional value of the probiotic emulsion beverage

Name component	Daily requirement of the human body	Satisfaction dailyrequirement, %	Contentofc omponent
Fe, mg	14	4.57	0.64
Ca, mg	1000	5.82	58.22
Na, mg	1300	1.86	24.13
K, mg	2500	2.90	72.64
P, mg	800	5.55	44.40
Zn, mg	12	0.43	0.06
Mg, mg	400	2.36	9.44
Mn, mg	2	5.0	0.10
Vitamin A, mg	0.9	22.23	0.20
VitaminD, mg	0.01	35.0	0.0035
Vitamin E, mg	15	43.30	6.59
Vitamin B_1, mg	1.5	0.67	0.01
Vitamin B_2, mg	1.8	3.33	0.06
Vitamin B_3, mg	5.0	8.20	0.41
Vitamin B_6, mg	2.0	0.50	0.01
Vitamin B_9, mg	0.4	22.50	0.09
Proteins, g	60–104	3.45–5.98	3.59
Fats, g	60–150	28.90–72.48	43.49
Carbohydrates, g	300–590	1.30–2.50	7.79

In the course of subsequent experimental studies, a technology for the production of probiotic emulsion drinks has been developed, which, using the example of a drink with turmeric and lemon, includes the following technological operations: acceptance of a probiotic emulsion, additional raw materials and materials according to the recipe, preparation of raw materials; combining turmeric and lemon confitur, stirring; obtaining a probiotic emulsion beverage by combining a probiotic emulsion (85% by weight) with a pre-prepared mass of lemon confitur (14% by weight) and turmeric (1% by weight), whipping for 2–3 minutes; portioning; cooling to a temperature of 4–6 ^{o}C; vacation.

Organoleptic evaluation of the developed probiotic beverages was carried out: taste – fermented milk, complex, lemon-tart; smell – lemon, slightly sweet, with light sharpness; color, consistency – bright lemon, with inclusions of lemon pieces.

The assessment of the satisfaction of the daily requirement of the body in macro- and micronutrients was carried out based on the norms of physiological requirements with the use of 100 g of the developed probiotic emulsion drink (Table 3).

The assessment of the vitamin-mineral composition of the developed probiotic drinks showed their high nutritional value, which makes it possible to classify these drinks as products with improved consumer properties, to enrich the diet with vitamins B_3, B_9, A, D, E.

4. Conclusion

Thus, it has been found that the emulsifying capacity of fermented fermentedfermented milk medium in emulsions of bioactive vegetable oils is 8.2–8.5 %. Additional introduction of emulsifiers in concentration of not more than 3.0 % into probiotic emulsions allows to achieve maximum values of emulsions stability at maximum oil concentration of 50 %. A further increase in the concentration of emulsifier in the system is impractical due to a slight corresponding increase in emulsifying capacity. The introduction of emulsifiers at the specified concentration into the probiotic base allowed to increase the total emulsifying capacity of the system by 1.4–3.8, 1.7–5.7, 1.3–3.9 times for egg white, lecithin, guar gum, respectively at the speed of the working member of the emulsifier about 2000 rpm. A further increase in exposure to 2500 rpm leads to a significant loss of metabolic activity and a decrease in the concentration of active cells to 10^6 CFU/ml.

The results of statistical processing of the obtained experimental data indicate a fairly high convergence of the experimental and calculated data, the value of the average relative error does not exceed 8.56 %.

It was established that the developed emulsion probiotic drink has high organoleptic indices, are sources of vitamins and minerals. The satisfaction of the daily needs of the body when consuming 100 g of the drink according to vitamins B_3, B_9, A, D, E varies in the range of 8.2–43.3 %. Thanks to the presence of bioactive vegetable oils in combination with probiotic microorganisms, fruits, spices, it can be recommended for nutrition of people exposed to high psycho-emotional and mental loads, working under extreme or harmful conditions.

The study was carried out with a grant from the Russian Science Foundation № 23-26-00256, https://rscf.ru/project/23-26-00256/.

References

1. W.W. Mwangi, H.P. Lim, L.E. Low, B.T. Tey et al., Trends Food Sci. Technol. **100**, 323 (2020)
2. Z. Cai, K. Li, W.J. Lee, M.T.G. Reaney et al., Fund. Res. **1**, 772 (2021)

3. G. Bai, C. Ma, X. Chen, GOST **4**, 33 (2021)
4. L.V. Antipova, S.A. Storublevtsev, *Modern methods for the study of raw materials and animal products* (Voronezh State Univ. of Eng. Technol., Voronezh, 2016)
5. L.V. Antipova, N.I. Dunchenko, *Food chemistry* (Russ. state agrar. Univ., St. Petersburg, 2019)
6. U.P. Grachev, *Mathematical methods for planning experiments* (Food industry, Moscow, 2005)
7. H. Draper, C. Harry, *Applied regression analysis* (Dialectics, Moscow, 2017)
8. G.F. Pruglo, *Chromatographic methods of analysis* (Grad. school of technol. and energy, St. Petersburg, 2017)
9. S.N. Sychev, *High performance liquid chromatography* (Oryol state techn. Univ., Eagle, 2010)
10. N. Lammari, O. Louaer, A. Meniai, H Fessi, A. Elaissari, Int. J. Pharm. **601**, 15 (2021).
11. C.K.W. Koo, C. Chung, J.T.R. Fu et al., Food Res. Int. **123**, 783 (2019)
12. L. Wang, M. Song, Z. Zhao, X. Chen et al., LWT-Food Sci. Technol. **121**, 4 (2020)
13. C.C. Berton-Carabin, K. Schroën, Curr. Opin. Food Sci. **27**, 77 (2019)
14. J. Li, J. Zhai, G. Luping, Y. Su, Trends Food Sci. Technol. **115**, 14 (2021)
15. S. Gallier, D. Acton, M. Gang, H. Singh, Food Struct. **13**, 18 (2017)
16. L. Cassani, A. Gomez-Zavaglia, J. Simal-Gandara, Food Res. Int. **129**, 9 (2020)
17. F.G. Rodrigues, M.F. Cedran, J.L. Bicas, H.H. Sato, Food Res. Int. **137**, 6 (2020)
18. A.M. Hamdani, I.A. Wani, N.A. Bhat, Int. J. Biol. Macromol. **135**, 58 (2019)
19. Z. Hathi, S. Mettu, A. Priya, S. Athukoralage et al., Biochem. Eng. J. **176**, 5 (2021)
20. K. Fenster, B. Freeburg, C. Hollard, C. Wong et al., Microorganisms **7**, 83 (2019)
21. N. Dinkçi, V. Akdeniz, A.S. Akalin, Elsevier 202 (2019)
22. A. Terpou, A. Papadaki, I.K. Lappa et al, Nutrients **11**, 1591 (2019)
23. E.A. Trush, E.A. Poluektova, A.G. Beniashvilli, O.S. Shifrin et al, Proteins **12**, 1293 (2020)
24. U. Roobab, Z. Batool, M.F. Manzoor, M.A. Shabbir, M.R. Khan, R.M. Aadil, Curr. Opin. Food Sci. **32**, 19 (2020)
25. Y. Li, M. Wengerter, I. Gerken et al., Chem. Eng. Res. Des. **108**, 26 (2016)
26. B. Ozturk, D.J. McClemements, Curr. Opin. Food Sci. **7**, 3 (2016)
27. J. Tawseefa, R. Negi, B. Sharma et al., Agric. Biotechnol.53, 12 (2023)
28. Y. Zhang, Y. Xie, H. Liu et al., LWT-Food SciTechnol163, 4-7 (2022)
29. S. Misra, P. Pandey, HW Mishra, Trends Food Sci Tech 109, 345 (2021)
30. SM El-Sayed, HS El-Sayed, AM Youssef, Bioact. Carbohydr.Diet.Fibre.31, 6-8 (2024)
31. F. Adinepour, S. Pouramin, A. Rashidinejad, S.M. Jafari, Food Res. Int. 157, 23 (2022).
32. S. Bhosale, R.J. Desale, Y.G. Fulpagare, Int J Pharm Biomed Eng6, 7-11 (2020).
33. M. CalderÓn-Oliver, E. Ponce-Alquicira, Molecules27(5), 1499 (2022).
34. E. Hadjimbei, G. Botsaris, S. Chrysostomou, Foods11(17), 2691 (2022).
35. K. Huang, Y. Yuan, X. Baojun, Food Rev. Int.39(5), 2594-2634 (2023).
36. X. Hong, Q. Zhao, Y. Liu, J. Li, Crit Rev Food SciNutr. 63(10), 1406-1436 (2023).
37. V. Raikos, L.P. Pirie, S. Gürel, H.E. Hayes, Molecules 26(6), 1504 (2021).
38. R.K. Saini, P. Prasad, R.V. Sreedhar et al., Antioxidants 10(10), 1627 (2021).
39. M. Trilokia, J.D. Bandral, A. Chib, P. Choudhary, Pharma Innovation.11, 1174-1180 (2022).
40. J. Yammine, N.E. Chihib, A.Gharsallaoui et al., Polym. Bull.1-46 (2023).
41. M. Yao, J. Xie, H. Du et al., Compr. Rev. Food Sci. Food Saf.19(2), 857-874 (2020).
42. CE Gumus, SMT Gharibzahedi, Trends Food Sci Tech 110, 267-279 (2021).
43. S. Lillo-Pėrez, M. Guerra-Valle, P. Orellana-Palma, G. Petzold, LWT-Food SciTechnol151, 1-8 (2021).
44. D. Fiocco, A. Longo, M.P. Arena et al.,Crit Rev Food SciNutr. 60(9), 1552–1580 (2020)
45. J. Szutowska., Eur. Food Res. Technol. 246 (3), 357-372 (2020)
46. Z. Hathi, S. Mettu, A. Priya et al., Biochem. Eng. J. 176, 6 (2021)
47. F.S. Aldawsari, B.S.B. Helel, Y.T. Alharbi et al., Ther. Innov. Regul. Sci. 54, 365-369 (2020)
48. S.S. Hassan, I.N.A. Fadzil, A. Yusoff, K.A. Khalil, Sci. Lett. 14, 1 (2020)
49. T. Amin, M. Thakur, S. Jain, J. Microbiol. Biotechnol. Food Sci. 9, 35-43 (2020).
50. L. Cassani, A. Gomez-Zavaglia, J. Simal-Gandara, Food Res. Int. 129, 108852 (2020)
51. M. Sultana, E-S Chan, J. Pushpamalar, WS Choo, Trends Food Sci. Technol. 123, 69-86 (2022)
52. S. Misra, P. Pandey, H.N. Mishra, Trends Food Sci. Technol. 109, 340-351 (2021)
53. P.M. Reque, A. Brandeli, Trends Food Sci. Technol. 114, 1-10 (2021)
54. H. Gao, L. Ma, W. Sun et al., Food Hydrocoll 126, 107478 (2022)

55. G. Frakolaki, V. Giannou, D. Kekos, C. Tzia, Crit Rev Food Sci Nutr 61, 1515-1536 (2021)