Journal of Oleo Science
Copyright ©2023 by Japan Oil Chemists' Society
doi : 10.5650/jos.ess22282
J. Oleo Sci. **72**, *(2) 131-138 (2023)*

Optimization of Olive Oil Oleogel-Based Emulsion Composition: Effect of Oleogel Composition on Emulsion Characteristics

Ezgi Demir Özer[1] and Cem Okan Özer[2]*

[1] *Cappadocia University, School of Applied Science, Department of Gastronomy and Culinary Arts, Nevsehir, TURKEY*
[2] *Nevsehir Hacı Bektaş Veli University, Faculty of Engineering and Architecture, Department of Food Engineering, Nevsehir, TURKEY*

Abstract: In this study, the effects of oil, water, glycerol monostearate, carrageenan and alginate concentrations, which have a significant effect on quality parameters in olive oil oleogel-based emulsion (OOE), were investigated and their optimum amounts were determined by mixture design for oleogel production with desired properties. OOE was produced using olive oil, water, glycerol monostearate (GMS), carrageenan and alginate at various concentrations in the range of 0-70%, 30-60%, 0-2%, 0-2% and 0-2%, respectively. The optimum quality parameters of OOE were evaluated in terms of optimum firmness value (5.5-7 N), minimum oil loss and peroxide value. The optimum composition was determined 53.5% olive oil, 43.5% water, 1.1% carrageenan, 0.92% alginate and 0.98% glycerol monostearate (w/w). Produced OOE under determined optimum conditions had 5.81 N firmness, 1.82 meq/O_2 peroxide value and 21.02% oil loss value. The margin of error between the experimentally obtained data and the estimated data in the study is average 2%. The results showed that the formulation used in OOE production have significant effects on the created OOE structure and quality parameters. In addition, different formulations to be created with the results of the present study will contribute to increasing the applicability of OOE in different foods.

Key words: olive oil, oleogel, optimization of composition

1 Introduction

Oleogelation and oleogels have been one of the issues that have been emphasized in recent years due to their high applicability potential in food production[1)]. Oleogelation increases the possibility of using liquid oils in food products, which are disadvantageous in terms of quality parameters such as texture and sensory properties, as well as shelf life[2)]. Oleogels, which are also considered as one of the fat mimetics, have become an important replacement for trans and saturated fats and in this way, it is aimed to prevent cardiovascular diseases caused by the consumption of foods with high trans and saturated fatty acid content[3, 4)]. Oleogelation is the entrapment of liquid in a three-dimensional network formed by polymeric or low molecular weight oleogelators such as wax, cellulose and glycerides[5)]. There are many successful applications for the use of oleogels in meat and meat products such as fermented sausage, emulsion sausage and patty, as in other food products[6–9)].

As a results of studies about the application of oleogels in different foods, oleogel emulsions containing oil and water phases have also been developed to create other usage areas and properties for oleogels. Oleogel emulsions are formed in the presence of various oleogelators such as monoglyceride, carrageenan, alginate and waxes as a water in oil phase or an oil in water phase[10–12)]. Oil type, oil and water amount, oleogelator type and amount directly affect the properties of the oleogel emulsion[12)]. Previous studies reported that the use of monoglyceride, carrageenan and alginate in oleogel emulsion affected inter-crystal structure of the network, stability and structural properties and also these effects mostly depend on the concentration[13–15)].

This study aims to produce olive oil based oleogel emulsion (OOE) with high oil binding capacity, oxidative stability and textural properties. Therefore, the effects of oil, water, monostearate, carrageenan and alginate concentration on oil loss, firmness and peroxide values were assessed by mixture design.

*Correspondence to: Nevsehir Hacı Bektaş Veli University, Faculty of Engineering and Architecture, Department of Food Engineering, Nevsehir, TURKEY
E-mail: cemokanozer@nevsehir.edu.tr ORCID ID: https://orcid.org/0000-0002-2030-1412
Accepted October 19, 2022 (received for review August 18, 2022)
Journal of Oleo Science ISSN 1345-8957 print / ISSN 1347-3352 online
http://www.jstage.jst.go.jp/browse/jos/ http://mc.manusriptcentral.com/jjocs

CC BY

2 Experimental Procedures

2.1 Materials

Virgin olive oil was obtained from a local producer (Nevsehir, Turkey). Glycerol monostearate (GMS), sodium alginate and κ-carrageenan were provided from Sigma Chemical Co. (St. Louis, MO, USA).

2.2 Methods

The present study was carried out in two stages. First of all, the optimum usage values for the concentration of oil, water and the other components in OOE production were determined depending on the oil loss, firmness, and peroxide values. At the last stage, the model efficiency was determined by determining the properties of the OOEs produced with the optimum determined values.

2.3 Olive oil oleogel-based emulsion preparation and experimental design

Olive oil oleogel-based emulsions (OOE) were prepared as described by Özer and Çelegen[16]. Firstly, the aqueous phase was prepared with water, sodium alginate, carrageenan and glycerol monostearate. And then the oil phase was mixed with the aqueous phase. The ratio of components in the OOE composition in each experimental group (Table 1) was determined by the experimental design created using the extreme vertices mixture design (Minitab 17, Minitab LLC, USA). The maximum and minimum weight for the olive oil, water, sodium alginate, carrageenan and glycerol monostearate were 40-70%, 30-60%, 0-2%, 0-2% and 0-2%, respectively. The sum of the ratios given to each component was 100% in each trial group formulation. The prepared oleogel-based emulsion was kept at 4℃ for 24 h before the analysis.

2.4 Oil loss determination

The oil loss value (%) of OOE sample was determined as described by Meng[17]. In this method, the calculation is made by determining the amount of oil separated from or retained in the structure of the oleogel emulsion against the centrifugal force.

2.5 Peroxide values

The method of AOCS was used to determine peroxide values of OOE[18]. The peroxide values were presented as meq O_2/kg OOE.

2.6 Texture analysis

Texture analysis was performed as described by Demir Özer[19]. To evaluate the firmness, texture profile analysis (TPA) were performed with a Texture Analyzer (TA.XT2, NY/Stable Micro Systems, UK) using 5 kg load cell and conic (90°) probe. OOE samples were filled into a cup (Ø55 mm inner diameter, 70 mm height and Ø45 mm diameter for compression plate) avoiding bubbles formation. Analyses were performed three times for each treatment at 20-22℃. The trigger force was 20 g and the probe penetrated and pulled out the sample up to 1 mm/s.

2.7 Statistical analysis

Optimization of olive oil oleogel-based emulsion composition was carried out using the extreme vertices mixture design (Minitab 17, Minitab LLC, USA). The proportional level of five factors: olive oil (X_1), water (X_2), sodium alginate, (X_3), carrageenan (X_4) and glycerol monostearate (X_5) were determined and analyzed. Table 1 shows the experimental runs, factor levels, and responding variables. An extreme vertices mixture design was used to optimize variables with 33 runs. The best fitting models were determined by mixture regression. Experimental data were analyzed and fitted to a regression model containing the coefficient of linear, quadratic, special cubic and two and three factors interaction effects. The polynomial equation for the regression model of response (Z) of the five independent variables was as follows:

$$Z = \sum_{i=1}^{5}\beta_i X_i + \sum_{i=1}^{5}\beta_{ii} X_i^2 + \sum_{i=1}^{5}\beta_{iii} X_i^3 + \sum_{i=1}^{2}\sum_{j=i+1}^{5}\beta_{ij} X_i X_j + \sum_{i=1}^{2}\sum_{j=i+1}^{5}\sum_{k=j+1}^{5}\beta_{ij} X_i X_j X_k \quad (1)$$

Where Z is the predicted response (oil loss, firmness and peroxide), β_i was the linear coefficient (main effect), β_{ii} was the quadratic coefficient, β_{iii} was the quadratic coefficient, β_{ij} was the two factors interaction coefficient and β_{ijk} was the three factors interaction coefficient. To check and interpret the model and model adequacies, the analysis of variance (ANOVA) and the coefficients which are R_2, the adjusted R_2, and the predicted R_2 were used. In addition, the lack-of-fit test was used to determine the probability of the model's failure to predict the experimental data. When p value is higher than 0.05 ($p > 0.05$), the obtained value should be insignificant. The results were expressed as mean values with standard deviations from the two or three replications of analysis.

3 Results and Discussion

Experimental data which contain experimental groups (runs), factors and responses of variables were presented in Table 1. Mixture regression was used to obtain the best fitting model. It determined that the obtained polynomials equations for firmness, oil loss and peroxide values were highly compatible. Thus, the R^2, adjusted and predicted R^2 values for all obtained variables except for oil loss were quite high which are more than 97% expected oil loss values (Table 2). Adjusted and predicted R^2 values for oil loss were not that high and 63% and 90%, respectively. This indicates that the predictive ability of the obtained model is relatively low[20]. Ghan *et al.*[20] optimized the con-

Table 1 Experimental data of the investigated responses of OOE properties.

Run order	Factor 1 (X_1) Oil (%)	Factor 2 (X_2) Water (%)	Factor 3 (X_3) Carrageenan (%)	Factor 4 (X_4) Alginate (%)	Factor 5 (X_5) Monostearate (%)	Response I (Y_1) Oil loss* (%)	Response II (Y_2) Firmness * (N)	Response II (Y_3) Peroxide * (meq O_2/kg)
1	46.75	50.75	0.5	0.5	1.5	38.55	4.96	2.95
2	60.75	36.75	0.5	1.5	0.5	14.38	8.24	4.68
3	61.75	36.75	0.5	0.5	0.5	36.49	7.12	4.35
4	46.75	50.75	1.5	0.5	0.5	36.16	4.95	2.16
5	40.00	58.00	2.0	0.0	0.0	69.85	4.62	2.71
6	40.00	56.00	2.0	2.0	0.0	68.46	4.28	2.41
7	40.00	56.00	0.0	2.0	2.0	60.49	5.09	3.16
8	46.75	49.75	0.5	1.5	1.5	36.28	7.29	4.34
9	53.50	43.50	1.0	1.0	1.0	21.58	5.41	2.68
10	58.75	36.75	1.5	1.5	1.5	40.67	6.19	3.78
11	46.75	48.75	1.5	1.5	1.5	49.67	6.38	3.89
12	46.75	51.75	0.5	0.5	0.5	52.28	3.28	2.16
13	40.00	60.00	0.0	0.0	0.0	94.68	3.96	2.49
14	66.00	30.00	2.0	2.0	0.0	28.47	11.67	6.45
15	40.00	58.00	0.0	2.0	0.0	84.28	3.84	2.38
16	46.75	49.75	1.5	0.5	1.5	52.61	6.59	3.54
17	68.00	30.00	0.0	2.0	0.0	51.34	5.11	3.19
18	40.00	56.00	2.0	0.0	2.0	78.27	4.69	2.98
19	68.00	30.00	0.0	0.0	2.0	64.15	4.91	3.41
20	40.00	58.00	0.0	0.0	2.0	68.45	4.18	2.86
21	66.00	30.00	2.0	0.0	2.0	59.46	5.29	3.28
22	59.75	36.75	1.5	1.5	0.5	41.38	7.39	4.21
23	60.75	36.75	0.5	0.5	1.5	41.67	7.34	4.40
24	46.75	49.75	1.5	1.5	0.5	52.67	5.91	3.58
25	40.00	54.00	2.0	2.0	2.0	54.68	5.55	3.49
26	59.75	36.75	1.5	0.5	1.5	46.68	6.38	3.95
27	60.75	36.75	1.5	0.5	0.5	40.66	8.65	5.29
28	66.00	30.00	0.0	2.0	2.0	35.18	8.41	5.16
29	59.75	36.75	0.5	1.5	1.5	38.44	8.62	5.00
30	64.00	30.00	2.0	2.0	2.0	46.54	15.47	8.14
31	46.75	50.75	0.5	1.5	0.5	58.99	5.28	3.28
32	70.00	30.00	0.0	0.0	0.0	94.61	3.65	2.28
33	68.00	30.00	2.0	0.0	0.0	78.34	4.59	2.18

* The values presented are the mean values obtained from two replications.

centration of soy lecithin, monostearate, water and palm oil on oleogel formulation by multiple regression with backward elimination on mixture design and adjusted R^2 and predicted R^2 values were found to be similar to R^2 values.

The results showed that the responses for the firmness and peroxide values to the variables were a quite similar trend but shows minor differences. It was determined that there were similar quadratic and cubic effects in both. However, responses to oil loss were quite different from

Table 2 Regression coefficients of predicted models for the investigated responses of OOE properties and independent effects of the factors.

Variables[a]	Regression coefficients for oil loss	Regression coefficients for firmness	Regression coefficients for peroxide value
Linear			
β_1	3.87	− 59.97	− 30.45
β_2	− 185.93	− 23.35	− 9.55
β_3	169183	298992	201715
β_4	− 686507	44786	− 14609.60
β_5	650584	− 321937	− 177551
Quadratic			
β_{12}	3.93 *	1.83 *	0.88 *
β_{13}	−	− 2838 *	− 1944.25 *
β_{15}	−	3286 *	−
β_{23}	−	− 3058 *	− 2063.00 *
β_{25}	−	3286 *	1812.90 *
β_{34}	− 2875.17 *	− 426 *	−
Special Cubic			
β_{123}	−	− 1.99 *	− 1.05 *
β_{125}	0.74 *	−	−
β_{134}	−	− 34.26 *	− 19.08 *
β_{145}	−	29.48 *	20.43 *
β_{234}	−	− 32.07 *	− 17.90 *
β_{245}	−	29.46 *	20.42 *
R^2	0.9714	0.9912	0.9830
Pre-R^2	0.6333	0.7151	0.7962
Adj-R^2	0.8982	0.9685	0.9397
F value	13.28	43.84	22.67
p value	0.001	0.001	0.001

[a] Polynomial model adjusted by mixture regression at the level of 0.1% with the lack-of-fit test, where, β_i is the linear coefficient (main effect), β_{ij} is the two factors interaction coefficient and β_{ijk} is the three factors interaction coefficient. β_1: oil; β_2: water; β_3: carrageenan; β_4: alginate; β_5: monostearate; β_{12}: interaction for oil and water amount; β_{13}: interaction for oil and carrageenan amount; β_{15}: interaction for oil and monostearate amount; β_{23}: interaction for water and carrageenan amount; β_{25}: interaction for water and monostearate amount: β_{34}: interaction for carrageenan and alginate amount; β_{123}: interaction for oil and water amount; β_{125}: interaction for oil and water amount; β_{134}: interaction for oil and water amount; β_{145}: interaction for oil and water amount; β_{234}: interaction for water, carrageenan and alginate amount; β_{245}: interaction for water, alginate and monostearate amount; *, significant at $p \leq 0.05$

others ($p<0.05$). It was determined that water and oil content, which are the main components of the olive oil oleogel-based emulsion, have negative linear effects on peroxide and firmness values ($p<0.05$). For the oil loss value, water and oil content have a negative and positive linear effect, respectively ($p<0.05$). Moreover, the interactions between oil and water content increased oil loss, firmness and peroxide value. In fact, the effect of the cubic effects of water and oil, including other components, on all of the responses was determined. In many studies, it has been reported that the increase in water content of oleogel-based emulsions decreases the emulsion stability and accordingly, the oil binding capacity decreases[20-22]. The water:oil ratio in the emulsion is decisive for the properties and stability of the emulsion. Water-in-oil (W/O) emulsions have a high interfacial area and within this area there is high mobility from the water surface to the oil surface. Therefore, water-in-oil emulsions are thermodynamically unstable[23]. Stabilization can be achieved with an oil crystal network in these systems by Pickering type stabilization or a combination of protein and polysaccharides, which can improve the system[24]. In many studies used for this aim, the positive results of carrageenan, glycerol monostearate and alginate were determined to be dose-dependent[13, 25].

Carrageenan, one of the components used for oleogelation and emulsion process, has a positive linear effect on all responses ($p<0.05$). However, alginate and glycerol monostearate have negative or positive linear effects for each response ($p<0.05$). Small amounts of low molecular weight components such as glycerol monostearate physically capture the oil phase, forming a supramolecular structure[25, 26]. Glycerol monostearate is amphiphilic and this forms a surface film between oil and water, regulating the distribution of oil droplets in the emulsion[27]. Singh *et al.*[28] reported that in the oleogel significantly affects the textural properties such as spreadability and back extrusion. In addition to all these, the effect of carrageenan on the structure is important. Carrageenan molecules irregularly coil up at high temperatures and then form helical structures between molecules when temperature decreased. The helical structures then turn into three-dimensional networks in which water is trapped[29]. Lee *et al.*[30] indicated that in oleogel based emulsion, carrageenan is responsible for the stability and glycerol monooleate are responsible for maintaining the dispersed water phase together. However, it has also been reported that phase inversion occurs using of glycerol monostearate at high levels such as 5%[31]. In this case, it has been reported that reducing the amount of glycerol monostearate and supporting the structure with wax or other polysaccharides will prevent this situation. Researchers reported that oleogels with excellent structured network and stability can be produced by using a combination of glycerol monostearate, carrageenan and beewax[30].

The effectiveness of alginate in emulsion and oleogel systems in previous studies is similar to the results of the present research. It was reported that alginate can be cross-linked with other components to produce emulsion and oleogel-based emulsion[32, 33]. In the systems such as emulsion, alginate protects against factors such as oxygen and UV-light and improves its mechanical properties. The effect of alginate on antioxidant and structural properties has also been reported in some previous studies[34, 35]. Soukoulis *et al.*[36] indicated that alginate cross-linking, which occurs as a result of electrostatic interactions between ions such as alginate and calcium, causes a decrease in oxygen diffusion. This gel formation, which is a specific structure and also called "egg box" model, is also important in terms of textural properties. In the presence of cross-linked ions, sol to gel transition can occur even at ambient temperature and gel can retain its form when heated[37]. In addition, alginate, an anionic polysaccharide, is also an emulsion stabilizer that forms hydrophilic coatings on the surface of oil droplets[38]. Willett and Akoh[39] stated that the use of alginate in oleogel production increased the efficiency and stability of the oleogel and it has high oil absorption and holding capacity.

Emulsion-based oleogels are disadvantageous in terms of oxidation considering the production conditions and parameters and this is a limiting factor for use in food products. The coexistence of oil and water, the application of heat, and the need for mixing in production cause to increase in the oxidation level of emulsion-based oleogels[40]. In the present study, it has been determined that the quadratic and cubic interactions for the amounts of all components significantly affect the peroxide value, similar to the results in the literature. Gravelle *et al.*[41] reported that the use of sorbitan monostearate in the oleogel content improves both the textural properties and oxidation of the oleogel. And also, it was indicated that the type of wax in oleogels used affects oxidation and the oxidation stability of oleogels produced with candelilla wax is higher than that of carnauba and beeswax[42]. In general, it can be said that oleogels with a high firmness value have a high oxidative stability, which is explained by the limited mobility of the oil[42].

To determine the optimum mixture of olive oil oleogel-based emulsion structure, optimum firmness value (5.5-7 N) and lowest peroxide and oil loss value were preferred. The most optimal values for all responses were determined by using multiple response optimizers for the determined parameters. The optimization process was performed in Minitab statistical program as described by Palla *et al.*[43]. The optimum composition was determent 53.5% olive oil, 43.5% water, 1.1% carrageenan, 0.92% alginate and 0.98% glycerol monostearate (w/w) (Table 3). Furthermore, the properties of the experimentally produced OOE with the obtained optimal formulation and the values obtained with the obtained mathematical model are present-

Table 3 OOE properties manufactured by optimum concentration.

Optimum concentration (%)	
Oil	53.50
Water	43.50
Carrageenan	1.10
Alginate	0.92
Monostearate	0.98
Total	100.00

Table 4 OOE properties manufactured by optimum determined concentration.

	Experimental*	Predicted
Firmness	5.81 ± 0.16 N	5.91 N
Oil loss	21.02 ± 0.19%	17.95%
Peroxide	1.82 ± 0.14 meq/O_2	1.75 meq/O_2

* The values presented are the mean values obtained from three replications

ed in Table 4. Experimentally produced OOE under determined optimum conditions had 5.81 N firmness, 1.82 meq/O_2 peroxide value and 18.02% oil loss value. By the data presented by the R^2 values, the difference between the experimental and predicted data is very low for the peroxide and firmness values. There is a difference of almost 2%. However, this is somewhat more for oil loss value and is almost 15%. In general, it can be said that the obtained models show high validity and correctness in predicting response variables.

4 Conclusion

In this study, olive oil emulsion-based oleogel formulation with desired properties was optimized with a mixture design. It has been determined that each of the components has linear, quadratic and cubic effects on the oleogel structure and properties. The optimum composition was determent 53.5% olive oil, 43.5% water, 1.1% carrageenan, 0.92% alginate and 0.98% glycerol monostearate (w/w). With obtained optimal formulation, olive oil emulsion-based oleogel with optimum hardness and high oxidative stability and oil holding capacity can be produced. The results of this study provide important data on the development and use of formulations of oleogels that can be used in various food systems.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

1) Marangoni, A.G.; Garti, N. *Edible oleogels: structure and health implications*. Elsevier (2018).
2) Chen, K.; Zhang, H. Fabrication of oleogels via a facile method by oil absorption in the aerogel templates of protein–polysaccharide conjugates. *ACS Appl. Mater. Interfaces* **12**, 7795-7804 (2020).
3) Silva, T.J.; Barrera-Arellano, D.; Ribeiro, A.P.B. Oleogel-based emulsions: Concepts, structuring agents, and applications in food. *J. Food Sci.* **86**, 2785-2801 (2021).
4) Marangoni, A.G.; Van Duynhoven, J.P.; Acevedo, N.C.; Nicholson, R.A.; Patel, A.R. Advances in our understanding of the structure and functionality of edible fats and fat mimetics. *Soft Matter* **16**, 289-306 (2020).
5) Wang, F.C.; Gravelle, A.J.; Blake, A.I.; Marangoni, A.G. Novel *trans* fat replacement strategies. *Curr. Opin. Food Sci.* **7**, 27-34 (2016).
6) da Silva, S.L.; Amaral, J.T.; Ribeiro, M.; Sebastião, E.E.; Vargas, C. *et al.* Fat replacement by oleogel rich in oleic acid and its impact on the technological, nutritional, oxidative, and sensory properties of Bologna-type sausages. *Meat Sci.* **149**, 141-148 (2019).
7) Franco, D.; Martins, A.J.; López-Pedrouso, M.; Cerqueira, M.A.; Purriños, L. *et al.* Evaluation of linseed oil oleogels to partially replace pork backfat in fermented sausages. *J. Sci. Food Agric.* **100**, 218-224 (2020).
8) Franco, D.; Martins, A.J.; López-Pedrouso, M.; Purriños, L.; Cerqueira, M.A. *et al.* Strategy towards replacing pork backfat with a linseed oleogel in frankfurter sausages and its evaluation on physicochemical, nutritional, and sensory characteristics. *J. Sci. Food Agric.* **8**, 366 (2019).
9) Oh, I.; Lee, J.; Lee, H.G.; Lee, S. Feasibility of hydroxypropyl methylcellulose oleogel as an animal fat replacer for meat patties. *Food Res. Int.* **122**, 566-572 (2019).
10) Duffy, N.; Blonk, H.C.; Beindorff, C.M.; Cazade, M.; Bot, A.; Duchateau, G.S.M.J.E. Organogel-based emulsion systems, micro-structural features and impact on *in vitro* digestion. *J. Am. Oil Chem. Soc.* **86**, 733-741 (2009).
11) Bot, A.; den Adel, R.; Regkos, C.; Sawalha, H.; Venema, P.; Flöter, E. Structuring in β-sitosterol+γ-oryzanol-based emulsion gels during various stages of a temperature cycle. *Food Hydrocoll.* **25**, 639-646 (2011).
12) Öğütcü, M.; Arifoğlu, N.; Yılmaz, E. Preparation and characterization of virgin olive oil-beeswax oleogel emulsion products. *J. Am. Oil Chem. Soc.* **92**, 459-

471(2015).
13) Toro-Vazquez, J.F.; Mauricio-Pérez, R.; González-Chávez, M.M.; Sánchez-Becerril, M.; de Jesús Ornelas-Paz, J.; Pérez-Martínez, J.D. Physical properties of organogels and water in oil emulsions structured by mixtures of candelilla wax and monoglycerides. *Food Res. Int.* **54**, 1360-1368(2013).
14) Wijaya, W.; Sun, Q.-Q.; Vermeir, L.; Dewettinck, K.; Patel, A.R.; Van der Meeren, P. pH and protein to polysaccharide ratio control the structural properties and viscoelastic network of HIPE-templated biopolymeric oleogels. *Food Struct.* **21**, 100112(2019).
15) Tavernier, I.; Patel, A.R.; Van der Meeren, P.; Dewettinck, K. Emulsion-templated liquid oil structuring with soy protein and soy protein: κ-carrageenan complexes. *Food Hydrocoll.* **65**, 107-120(2017).
16) Özer, C.O.; Çelegen, Ş. Evaluation of quality and emulsion stability of a fat-reduced beef burger prepared with an olive oil oleogel-based emulsion. *J. Food Process Pres.* **45**, e14547(2021).
17) Meng, Z.; Qi, K.; Guo, Y.; Wang, Y.; Liu, Y.J. Macro-micro structure characterization and molecular properties of emulsion-templated polysaccharide oleogels. *Food Hydrocoll.* **77**, 17-29(2018).
18) AOCS. *AOCS Official Method Cd 8b-90: Peroxide value acetic acid-isooctane method, official methods and recommended practices of the AOCS*. American Oil Chemists Society Press, Champaign (2011).
19) Demir Özer, E.; Esen, M.K.; İçigen, M.; Özer, C.O. Investigation of usage possibilities of Kalaba Yoghurt(local cream yoghurt)in cheesecake production. *Int. J. Gastron. Food Sci.* **25**, 100376(2021).
20) Ghan, S.Y.; Siow, L.F.; Tan, C.P.; Cheong, K.W.; Thoo, Y.Y. Palm olein organogelation using mixtures of soy lecithin and glyceryl monostearate. *Gels* **8**, 30(2022).
21) Angelico, R.; Ceglie, A.; Colafemmina, G.; Delfine, F.; Olsson, U.; Palazzo, G. Phase behavior of the lecithin/water/isooctane and lecithin/water/decane systems. *Langmuir* **20**, 619-631(2004).
22) Worakitkanchanakul, W.; Imura, T.; Fukuoka, T.; Morita, T.; Sakai, H. *et al.* Phase behavior of ternary mannosylerythritol lipid/water/oil systems. *Colloids Surf. B* **68**, 207-212(2009).
23) Ghosh, S.; Tran, T.; Rousseau, D. Comparison of pickering and network stabilization in water-in-oil emulsions. *Langmuir* **27**, 6589-6597(2011).
24) García-Ortega, M.; Toro-Vazquez, J.; Ghosh, S. Development and characterization of structured water-in-oil emulsions with ethyl cellulose oleogels. *Food Res. Int.* **150**, 110763(2021).
25) Wijarnprecha, K.; de Vries, A.; Santiwattana, P.; Sonwai, S.; Rousseau, D. Microstructure and rheology of oleogel-stabilized water-in-oil emulsions containing crystal-stabilized droplets as active fillers. *LWT.* **115**, 108058(2019).
26) Patel, A.R.; Dewettinck, K. Edible oil structuring: An overview and recent updates. *Food Funct.* **7**, 20-29 (2016).
27) Goldstein, A.; Marangoni, A.; Seetharaman, K. Monoglyceride stabilized oil in water emulsions: An investigation of structuring and shear history on phase behaviour. *Food Biophys.* **7**, 227-235(2012).
28) Singh, V.K.; Anis, A.; Banerjee, I.; Pramanik, K.; Bhattacharya, M.K.; Pal, K. Preparation and characterization of novel carbopol based bigels for topical delivery of metronidazole for the treatment of bacterial vaginosis. *Mater. Sci. Eng. C* **44**, 151-158(2014).
29) Wurm, F.; Nussbaumer, F.; Pham, T.; Bechtold, T. Structural elucidation of mixed carrageenan gels using rheometry. *Food Hydrocoll.* **95**, 533-539(2019).
30) Lee, M.C.; Tan, C.; Ravanfar, R.; Abbaspourrad, A. Ultrastable water-in-oil high internal phase emulsions featuring interfacial and biphasic network stabilization. *App. Mat. Interfaces* **11**, 26433-26441(2019).
31) Patel, A.R.; Rodriguez, Y.; Lesaffer, A.; Dewettinck, K. High internal phase emulsion gels(HIPE-gels)prepared using food-grade components. *RSC Adv.* **4**, 18136-18140(2014).
32) Silva, K.C.G.; Feltre, G.; Hubinger, M.D.; Sato, A.C.K. Protection and targeted delivery of β-carotene by starch-alginate-gelatin emulsion-filled hydrogels. *J. Food Eng.* **290**, 110205(2021).
33) Li, D.; Wei, Z.; Xue, C. Alginate-based delivery systems for food bioactive ingredients: An overview of recent advances and future trends. *Compr. Rev. Food Sci. Food Saf.* **20**, 5345-5369(2021).
34) Hamedi, H.; Kargozari, M.; Shotorbani, P.M.; Mogadam, N.B.; Fahimdanesh, M. A novel bioactive edible coating based on sodium alginate and galbanum gum incorporated with essential oil of *Ziziphora persica*: The antioxidant and antimicrobial activity, and application in food model. *Food Hydrocoll.* **72**, 35-46(2017).
35) Morales, E.; Rubilar, M.; Burgos-Díaz, C.; Acevedo, F.; Penning, M.; Shene, C. Alginate/Shellac beads developed by external gelation as a highly efficient model system for oil encapsulation with intestinal delivery. *Food Hydrocoll.* **70**, 321-328(2017).
36) Soukoulis, C.; Cambier, S.; Hoffmann, L.; Bohn, T. Chemical stability and bioaccessibility of β-carotene encapsulated in sodium alginate o/w emulsions: Impact of Ca^{2+} mediated gelation. *Food Hydrocoll.* **57**, 301-310(2016).
37) Draget, K. *Alginates: Fundamental Properties and Food Applications*. Reference Module in Food Science. Elsevier(2016).
38) Zhang, R.; Belwal, T.; Li, L.; Lin, X.; Xu, Y.; Luo, Z. Recent advances in polysaccharides stabilized emulsions

for encapsulation and delivery of bioactive food ingredients: A review. *Carbohydr. Polym.* **242**, 116388 (2020).
39) Willett, S.A.; Akoh, C.C. Encapsulation of menhaden oil structured lipid oleogels in alginate microparticles. *LWT.* **116**, 108566(2019).
40) Yılmaz, E.; Öğütcü, M. The texture, sensory properties and stability of cookies prepared with wax oleogels. *J. Funct. Foods* **6**, 1194-1204(2015).
41) Gravelle, A.J.; Barbut, S.; Marangoni, A.G. Ethylcellulose oleogels: Manufacturing considerations and effects of oil oxidation. *Food Res. Int.* **48**, 578-583 (2012).
42) Lim, J.; Hwang, H.S.; Lee, S. Oil-structuring characterization of natural waxes in canola oil oleogels: Rheological, thermal, and oxidative properties. *J. Appl. Biol. Chem.* **60**, 17-22(2017).
43) Palla, C.; Giacomozzi, A.; Genovese, D.B.; Carrín, M.E. Multi–objective optimization of high oleic sunflower oil and monoglycerides oleogels: Searching for rheological and textural properties similar to margarine. *Food Struct.* **12**, 1-14(2017).

CC BY 4.0(Attribution 4.0 International). This license allows users to share and adapt an article, even commercially, as long as appropriate credit is given. That is, this license lets others copy, distribute, remix, and build upon the Article, even commercially, provided the original source and Authors are credited.