

Evaluation of Reduced-Fat Food Emulsions with Cassava Starch

M. Dzhivoderova, K. Nikovska, D. Hadjikinov, R. Hadjikinova

Abstract – The modern food industry must rapidly respond to the consumer preferences for a greater variety of healthier, cheaper and higher quality foods. Most food emulsions are characterized by high fat content and the development of low-fat food emulsions with the same physicochemical, rheological and organoleptic properties as the full-fat emulsions has been a considerable challenge. Reduced-fat food emulsions with cassava starch were prepared and their rheological properties, thixotropic behavior and emulsion stability evaluated. Flow curves of all samples are well described by the Herschel-Bulkley model. The parameters of this models revealed that, the emulsions with 12 % modified cassava starches and 30 % oil content have similar rheological properties as the full-fat sample. The rheological parameters of emulsions with 6 % modified cassava starches and 50 % oil content and the full-fat product exhibited insignificantly differences. Analysis of the relative thixotropic areas calculating by integration showed that low-fat emulsions had thixotropic and antithixotropic properties. The higher thixotropic area of full fat sample than the thixotropy of most emulsions demonstrated that low-fat emulsions with tapioca starch had more stable structure. The emulsions stability increased when the concentration of the starch increased too and emulsions with 14 % and 16 % cassava starch had stability equal to 100 %.

Keywords – Reduced-Fat Food Emulsions, Cassava Starch, Thixotropic Properties.

I. INTRODUCTION

The trends in the food industry are focused on the development of new eating habits and new knowledge about functional foods and reduced-fat food product [5], [12]. The consumer attitude towards healthy foods is increasing which leads to the decreased consumption of some fats [7], [15]. The intention of the food specialists is to achieve characteristics of low fat products which are close to the characteristics of products with a high fat content. The food emulsions are traditionally with a high fat content. The main difficulty and challenge facing food industry is to select ingredients that “mimic” properties of the oil phase in food emulsions. The oil content influence on the appearance, taste, aroma, structure-mechanical characteristics and shelf life of food emulsions [15]. Because of the significant role that fat content has in the food emulsion quality it is necessary to use a combination of different “mimic” the fat ingredients to achieve the desired quality characteristics of the product [12], [13]. When selecting a fat mimetic for a particular function it is important to consider that it can influence the characteristics of the system that may be either desirable or undesirable.

Biopolymers are selected to provide similar relation between viscosity and the shear rate or expansion module to the shear rate, as in full-fat products.

Reducing the size of the fat droplets and adding the thickening ingredients can influence the appearance, flavor, texture and rheological characteristics of the product.

The rheology is one of the most important characteristic of food emulsions [6], [9], [11]. Knowledge of the rheological characteristics of food emulsions is important for a number of reasons. Many of the sensory attributes of food emulsions are related to their rheological properties (e.g., creaminess, thickness, smoothness, spreadability, pourability, flowability, brittleness, and hardness). The stability and the shelf-life of many food emulsions depend on the rheological characteristics of the component phases. The creaming of oil droplets depends on the viscosity of the aqueous phase. Finally, rheological measurements are used by food scientists as an analytical tool to provide fundamental insights about the structural organization and interactions of the components within emulsions. Measurements of viscosity vs. shear rate can be used to provide information about droplet flocculation. The determination of the viscosity depending on the shear rate is used for determining the flocculation of oil droplets i.e. sticking of more globules and formation of larger aggregates, which leads to creamation. Different kind of natural or modified starches are used like thickening agents in the dispersed media of emulsion-type products [16].

Cassava starch (*Manihot Esculenta*) is a starch product recovered from the roots of the cassava plant. The starch has various applications in food industry, including as a thickening and gelling product. Globally, the price of cassava starch is lower than the other starches. The cassava starch forms a colorless gel, without taste and with high viscosity [20]. The properties of starches can be improved by various modifications.

II. MATERIALS AND METHODS

Sunflower oil was used as oil phase (OP) in investigated model oil-in-water (O/W) emulsions. The emulsions were formulated with pregelatinized cassava starch (PCS) and cassava maltodextrin (CM). Model emulsion with 70 wt% OP was the control sample. The reduced-fat emulsions were prepared with 30 wt% and 50 wt% OP and different concentration of starch - from 4 to 12 wt%.

Egg m \acute{e} lange was used as an emulsifier (6 wt %). It is known that the egg m \acute{e} lange is used like a natural emulsifier in oil-in-water emulsions, mainly of mayonnaise type. Amount of the components in model emulsions were specified in Table I. Notations indicated each of the emulsions and they were used in the text below. The composition of model emulsions was shown in Table I.

Table I: Notations of model emulsions and the starch content in each sample

OP,%	PCS,%			CM,%			PCS+CM (1:1), %
70	-	-	-	-	-	-	-
50	4	6	8	4	6	8	6
30	12	14	16	12	14	16	12

The starch and the egg mélange powder were mixed, and then the quantity of necessary water was added. The mixture was stirred until complete dissolution. The water phase was mixed with homogenizer Disho-Labor, Koruma's V 60/10 for 1 min, with rotation frequency 3600 min⁻¹. The oil was added by slowly emulsification, in vacuum about 3-4 kPa. It was homogenized again for 1 min. The starch and egg mélange were mixed and dispersed in water. The water phase preparation was stirred to ensure homogeneous. This phase was vigorously agitated in Homogenizer Disho-Labor, V 60/10 for 1 min, at 3600 rpm and 300 °C. The oil phase was added slowly at vacuum pressure (3-4 kPa).

Rheological measurements were conducted at 25 °C with "Reotest 2" (Germany) with shear rate in the range from 0.17 to 72.9 s⁻¹. Rheological characteristics were determined, using a rotational viscometer used for analyzing non-Newtonian fluids, as the most of emulsions are. The major rheological characteristics were determined - dynamic viscosity (η , Pa.s), yield stress (τ_0 , Pa), consistency coefficient (K) and the flow behavior index (n). The dynamic viscosity (η) was calculated using the formula:

$$\eta = \frac{\tau}{D} \quad (1)$$

where:

τ - is the shear stress, Pa;

D - is the shear rate, s⁻¹.

Thixotropic properties of the model emulsions products were determined by their flow curves (with coordinates D/ τ).

The thixotropic areas, S_{th} , were obtained as the difference between the area enclosed by the up curve, S_{up} , and the area enclosed by the different down curves, S_{dw} , in the shear rate range considered [8], [9].

$$S_{th} = S_{up} - S_{dw} \quad (2)$$

These areas could be calculated by numerical integration or analytical integration if the function relating shear stress and shear rate, $\tau = f(D)$.

$$S = \int_{D_{min}}^{D_{max}} \tau(D) dD \quad (3)$$

Dispersion (emulsion) stability (ES), %, was determined by sedimentation analysis [17]. Sample of 15 g (F_0) was put in a tightly closed test tube, and stored at 50 °C for 48 hours. After storage, the sample was cooled to room temperature and centrifuged at 3200 rpm for 10 min. The content of the separated layer "oil" (F_1) was separated and measured.

$$ES = \left(\frac{F_1}{F_0} \right) 100 \quad (4)$$

Optical microscope observation

The glassy flat was coated with mayonnaise sample and placed on the stage of Microscope Boeco (Germany). Then adjusted the focus knob to get clearly view field. The pictures of the emulsions microstructure were obtained by a digital camera connected with the microscope.

The objective of this study was to determine the influence of type and concentration of cassava starch on the main characteristics - stability and rheological properties of the low-fat emulsions.

III. RESULTS AND DISCUSSION

Flow curves of model oil-in-water emulsions with 30 % OP and different concentration of PCS were shown on Fig. 1. The graphically correlation showed that in rheological terms emulsions are non-ideal plastic bodies.

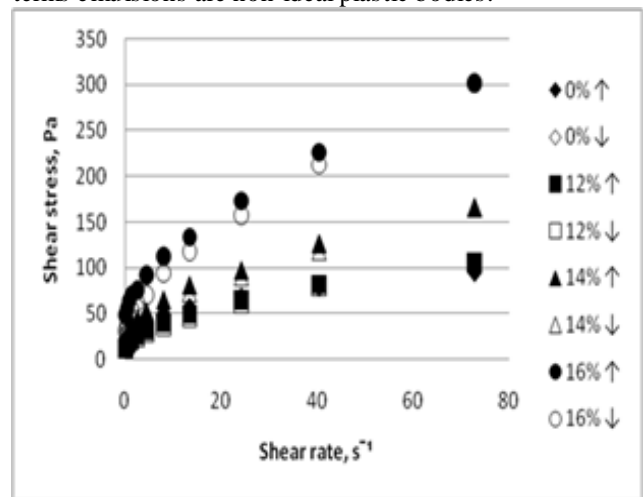


Fig. 1. Flow curves of model oil-in-water emulsions with 30 % OP and PCS \blacklozenge - 0%, \blacktriangle - 12 %, \blacksquare - 14 %, \times - 16 %

The other samples with a composition were shown in Table I. and they have a similar rheological behavior. The flow curves of model oil-in-water emulsions with 50 wt% OP and 6 wt% starch, depend on the type of the starch were presented in Fig. 2.

The rheological behavior of emulsions was typical for the model of the Herschel-Bulkley ($R^2 = 0.97- 0.99$), which is widely used in the analysis of various food systems [1], [3], [9], [14], [18].

$$\tau = \tau_0 + kD^n \quad (5)$$

where:

τ is the shear stress, Pa;

D - is the shear rate, s⁻¹ ;

τ_0 - is the yield stress, Pa ;

K - is the consistency coefficient, Pa.s;

n - is the flow behavior index.

Yield stress is an important characteristic for emulsion products. It is an major parameter for sensory perception in the sensory perception in the mouth cavity, design of pumping installations (fluidity), the degree of adhesion, coverage of food such as dressing or covering and pouring products [2], [16].

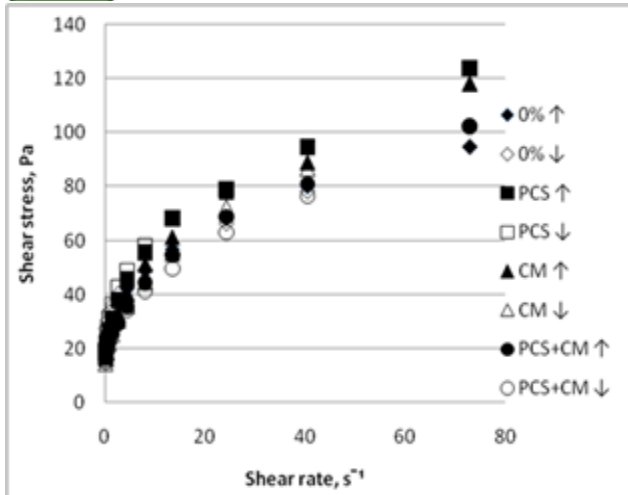


Fig.2. Flow curves of model oil-in-water emulsions with 50 % OP and 6 % starch: ◆ - control, ■ – PCS, ▲ – CM, x – PCS+CM

The yield stress (τ_0) of the emulsions was from 7.6 to 55.2 (Pa). Emulsions with 30 wt% OP and 16 wt% CM had the highest value of τ_0 , and the lowest - emulsions with 30 wt% OP and 12 wt% mix (PCS+CM). Differences between the yield stress of the control sample and the yield stress of the emulsion with 50 wt% OP and 6 wt% PCS were statistically significant. Increasing of the value of τ_0 was proportional of the increase of starch concentration in all investigated emulsions. There were not significant differences between the rheological behavior of the emulsions with 30 wt% OP and 12 wt% PCS and 50 wt% OP and 4 wt% PCS. The type of starch used did not significantly affect the rheological properties of emulsions.

The thixotropic properties of starch gels and emulsions are their typical characteristics [2], [4], [8], [10], [19]. Table III. presented areas of hysteresis loop of model emulsions with cassava starch. The emulsions with 30 wt% OP and 16 wt% tapioca starch had the highest value of thixotropy. The sample with CM had more pronounced thixotropic properties. A thixotropy area of the control was higher than the thixotropy of most emulsions. It means that low-fat emulsions with cassava starch had more stable structure than the control sample. Three samples had antithixotropic properties. Antithixotropy or reopexy still be seen in products exhibiting antihisterezis i.e. the down curve is over the up curve [1], [4], [16]. The antithixotropic properties was detected in model emulsions with 50 wt% OP, 6 and 8 wt% PCS and 6 wt% PCS + CM. This is probably due to the organization of the molecules which make the structure of emulsions.

The emulsion stability (ES) depends on the concentration of starch – pregelatinized cassava starch (PCS) and cassava maltodextrin (CM) and the quantity of the oil phase (OP) (Fig. 3).

High values of thixotropy depend on the destruction of the system structure in the application of mechanical stress [2].

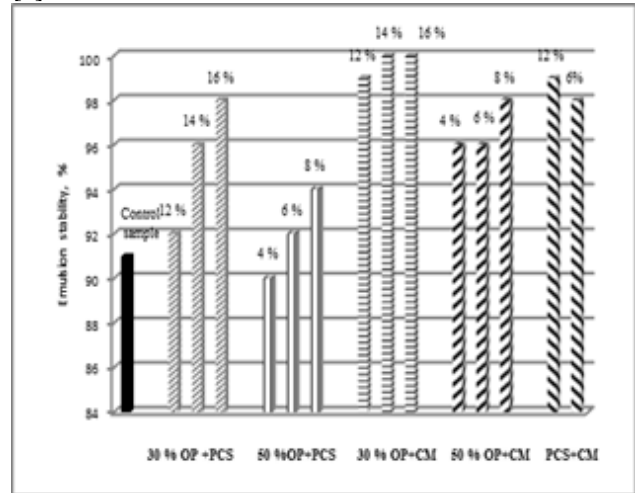


Fig.3. Influence of oil phase, type and concentration of cassava starch to ES of model oil-in-water emulsions

ES of the control sample was high, because emulsions with larger volume of the oil phase (mayonnaise) are stable to cremation, because they form a network from tightly oil droplets [16]. The both types of tapioca starch increased the stability of the emulsions by reducing the gravitational separation. This confirm the information of other authors [15], which considered that the addition of one or a combination of biopolymers to the aqueous phase increases the stability of emulsions to cremation, flocculation and coalescence. Emulsions with low concentration of starch were relatively unstable. ES of the emulsions increased when the concentration of the starch increased too and emulsions with 14 wt% and 16 wt% CM had stability equal to 100%. The results showed that the movement of the oil droplets is reduced or completely prevented by adding starch. Low fat emulsions with cassava starch were more stable than the control sample. Similar results were obtained by other authors [5], [17].

Dispersion characteristics based on the observation analysis of the microstructure of the model oil-in-water emulsions were made to find the relation between them and the rheological properties (Fig. 4). The studied samples had compact structure and there viscosities were quite similar to the control sample.



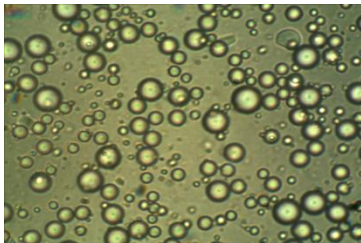
Table II: Parameters of Herschel-Burkley models for flow curves of model oil-in-water emulsions with cassava starchModel emulsions with 70 % OP

%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
0	16.8a	0.59a	8.6a	0.9711	20.2c	0.46d	11.8f	0.9723
Model emulsions with PCS								
30 % OP								
%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
12	10.9b	0.64a	7.5b	0.9868	10.2b	0.62 a	7.4b	0.9878
14	21.9c	0.72c	8.4a	0.9756	16.4a	0.64a	10.5d	0.9809
16	46.3d	0.72c	13.8c	0.9782	27.8 e	0.67a	16.5e	0.9837
50 % OP								
%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
4	10.2 b	0.53b	7.5b	0.9866	2.5cd	0.47d	10.1d	0.9551
6	16.4 a	0.61a	9.7d	0.9766	16.8a	0.57b	11.7f	0.9712
8	42.3 d	0.62a	16.7e	0.9747	39.9d	0.6a	19.8ac	0.9798
Model emulsions with CM								
30 % OP								
%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
12	10.3b	0.52b	9.7d	0.9966	5.1ad	0.55b	8.5a	0.9981
14	26.1e	0.61a	12.4f	0.9821	13.5ef	0.66a	10.9d	0.9882
16	55.2f	0.28 ^d	92.8ab	0.9772	31.6bd	0.36e	64.3n	0.9813
50 % OP								
%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
4	10.9 b	0.63a	4.4bc	0.991	3.8	0.53b	6.6df	0.9948
6	14.7ef	0.6a	9.2d	0.9824	11.8b	0.59a	9.3d	0.9898
8	40.4 d	0.7c	12.1f	0.9727	26.9e	0.57b	19.2ac	0.9701
Model emulsions with PCS+CM (1:1)								
30 % OP								
%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
12	7.6ab	0.59a	6.3df	0.9921	6.3ab	0.58a	5.8df	0.9988
50 % OP								
%	up curve				down curve			
	τ_0	n	K	R ²	τ_0	n	K	R ²
6	14.3ef	0.59a	8.2a	0.9936	12.6b	0.92f	2.8bd	0.9711

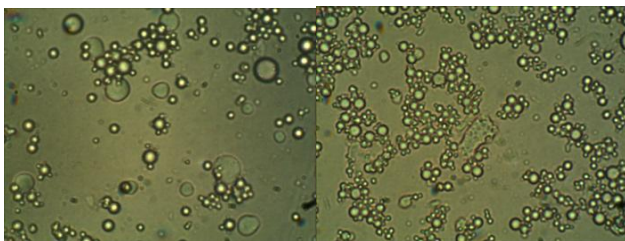
*Parameters in particular columns carrying the same character insignificantly differ from one another at p< 0.05

Table III: Areas of hysteresis loop of model emulsions with cassava starch

30 % OP			
Samples	Area of hysteresis loop, Pa/s	Samples	Area of hysteresis loop, Pa/s
12 % PCS	483	12 % CM	477
14 % PCS	946	14 % CM	485
16 % PCS	1429	16 % CM	3141
12 % PCS+CM	502	–	–
50% OP			
PCS, %	Area of hysteresis loop, Pa/s	Samples	Area of hysteresis loop, Pa/s
4 % PCS	264	4 % CM	398
6 % PCS	-281	6 % CM	351
8 % PCS	-874	8 % CM	1153
6 % PCS+CM	-652	–	–
70% OP			
Control sample	652	–	–

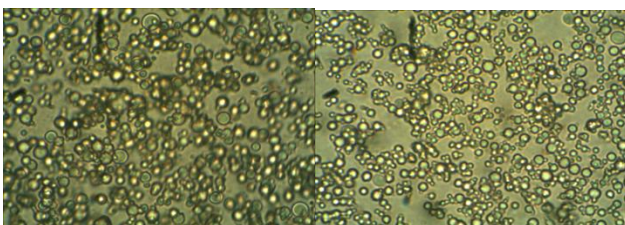


a)



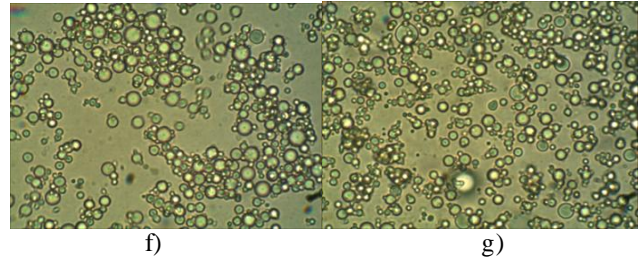
b)

c)



d)

e)



f)

g)

Fig.4 Micrographs by optical microscope of oil-in-water emulsions with different quantity of OP and modified starch a) control; b) 50% OP+6 % PCS; c) 30 % OP+12 % PCS d) 50 % OP+6 % CM; e) 30 % OP+12 % CM; f) 50 % OP+6 % mix (PCS+MC); g) 30% OP+12% mix (PCS+MC);

IV. CONCLUSION

All studied emulsions show properties that may be used by the development of food emulsions with reduced fat content. Cassava starch is an appropriate thickening agent and can be used to provide the food emulsions with desirable rheological characteristics and to improve emulsion stability.

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