Influence of the used starch on the structure, stability and rheological properties of a starch-milk dessert cream

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Abstract. The stability and rheological properties of starchy dairy dessert creams thickened with corn, potato, wheat, rice, and tapioca starches were compared. A difference in structure was also reported in microscopic imaging. The stability of the creams was assessed by analysing the amount of liquid separated by centrifugation of the samples. Potato starch cream was found to have the least stability after 24, 120, and 240 hours of storage. Wheat starch shows the lowest retrograde properties. Rheological studies were performed at 50 °C in a controlled shear rate mode. The data show that all systems studied are non-Newtonian fluids. The resulting flow curves were analysed using the Herschel-Bulkley model. All creams are pseudoplastic, thinning liquids with time-varying properties. The consistency of creams thickened with rice and wheat starch is significantly more stable than those thickened with corn, potato, and tapioca starch, which was also confirmed by the calculated thixotropic areas.

1 Introduction

Starch is a low-cost polysaccharide, thickening and gelling agent that is most widely used in the food industry [1, 2]. Despite this widespread use, the processing of starch is never simple and many parameters are known to be involved in its flowability properties [3, 4]. Starch consists of two chemically different polymer structures, amylose and amylopectin. The ratio of these polymers and their physical organization within the granular structure confers physicochemical and functional properties that are typical of starches. This relationship depends on the botanical source of origin [5, 6, 7]. When heated in excess water, the amylopectin structure melts and the granules swell in a process known as gelatinization. The degree of gelatinization of the starch depends on the cooking process and the type of starch used [8, 9, 10]. Gelatinization was defined as the disruption of the molecular order in the starch granule manifested by irreversible changes such as granule swelling, natural melting and starch dissolution. During cooling, retrogradation occurs when the dissolved starch polymers and remaining granules dissociate into an ordered structure. Apart from the wide range of flow properties caused by differences in botanical origin, many other parameters can be implied, such as the presence of other components (sugars, hydrocolloids) and also the heat treatment conditions (heating temperature, heating rate, shear conditions) [11, 12]. Starch is widely used as a thickener in milk-based cakes and jellies, sauces, creams and desserts. Starches are becoming an increasingly popular addition to dairy systems because of their relatively low cost, availability, and advantages. Recently, studies have investigated the interactions between milk proteins and starch or starch molecules (amylose and amylopectin) in solutions and in model milk-based food products such as processed cheeses and acidified milk gels [13].

Starch-based dairy desserts are widely consumed worldwide ("Natillas" in Spain, "Vanilla vla" in the Netherlands or "Crème dessert" and "Blancmange" in France, "Palouza" in Algeria, "Muhallebi" - Middle Eastern milk pudding, “Sahlab” in Jordan, Colada de Maizena – Colombian cornstarch pudding). Their nutritional and sensory characteristics favour their consumption by several consumer groups, such as children or the elderly. They are mainly formulated with milk, thickener (starch or starch and hydrocolloids, with the botanical species used being typical of the geographical area), sucrose, flavours and colours. In general, this type of product exhibits time-dependent and shear-thinning flow behaviour and viscoelastic properties typical of weak gels [14, 15, 16].

In general, the flow properties of this type of product, e.g. time dependence and pseudoplasticity, follow the same pattern as those of starch pastes, whose rheological behaviour corresponds to the shear resistance of a biphasic structure determined by the characteristics of the dispersed phase (starch granules) and by the viscosity of the dispersing phase [17, 18].

The aim of this study was to investigate the influence of starch type on the structure, stability and rheological properties of starch-milk dessert creams. Five types of starch were used: wheat, corn, rice, potato and tapioca. Therefore studying the changes in the flow behavior, which might occur during the process, will help in

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establishing methods of producing an acceptable product with consistent quality. In this way, the most suitable starch could be selected for the production of this type of product.

2 Material and methods

2.1. Materials

The following materials were used: sugar, starches from different sources (corn (CS), wheat (WS), potato (PS), tapioca (TS) and rice (RS)), milk powder with 1,5 % fats, from the market.

2.2 Methods

2.2.1 Obtaining a starch-milk dessert cream

Starch-milk dessert creams are prepared in laboratory conditions. First, the dry ingredients are weighed – starch (7.9%), milk powder (10.25%) and sugar (13.4%). They are homogenized and the pre-weighed water (to 100%) is added in small portions. The mixture prepared in this way is heated to a temperature of +/- 80±2°C, with continuous stirring, and boiled until the dry matter reaches 31%.

The following technological scheme has been developed for the starch dessert creams:

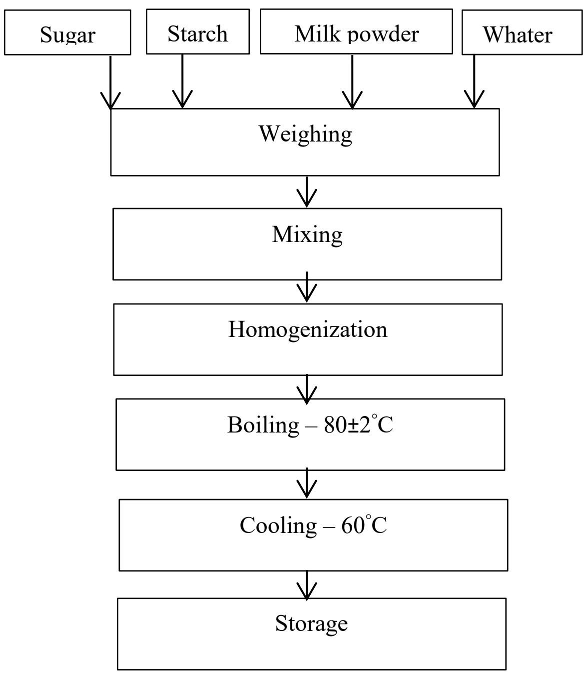

Figure 1. Technology for obtaining starch-milk dessert cream

2.2.2 Digital images of starch granules

Digital images were made with a Boeco microscope (Germany), Video camera ocular 5MP, USB 2.0 and Scope Photo program.

2.2.3 Determination of syneresis resistance

The samples were stored for 24, 120, and 240 hours at 8°C. Syneresis was measured as % amount of water released after centrifugation of centrifuge Hettich Zentrifugen EBA 200 at 5000 rpm for 15 minutes.

2.2.4 Rheological and thixotropic properties

Rheological characteristics were determined using a Rheotest-2 rotational viscometer (Rheotest Medingen GmbH, Medingen, Germany), operating at 50°C within the shear rate range from 0.17 to 72.9 s^{-1}. The dynamic viscosity (η) was calculated using the formula:

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

Where τ is the shear stress, Pa; D is the shear rate, s^{-1}.

$$\tau = \tau_0 + k.D^n \qquad (2)$$

where τ_0 - is the yield stress, Pa ; k – is the consistency coefficient, Pa.s; n – is the flow behavior index.

Thixotropic properties of the starch-milk creams with tahini 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.

$$S_{th} = S_{up} - S_{dw} \qquad (3)$$

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

$$S = \int_{D_{min}}^{D_{max}} \tau(D)dD \qquad (4)$$

2.2.5 Data analysis

All data was made threefold (n=3). The results were expressed as the mean± standard deviation (SD).

3 Results and discussion

Starch-dairy systems are a combination of starch and dairy products that give characteristic properties and texture to the product. Starch contributes to the thickening of the system, giving it a thick consistency [13].

Dairy products such as milk give the system a creamy texture and rich flavour. Their structure is combined with the starch, further improving the product's creaminess. Dairy products contain emulsifiers, such as milk proteins, which help stabilize the system [19, 20]. They prevent the separation of the milk phase from the starch and keep the system homogeneous and stable.

Starch-milk systems generally have good heat resistance. They retain their properties and texture at different temperatures. These properties make them popular in preparing various foods and desserts [21].

3.1 Visual and microscopic observation of the structure of the obtained creams

In order to test the influence of starch as a thickener in a starch-milk dessert cream, parallel samples were made with five types of starches (corn, wheat, rice, tapioca and potato). The difference in the structure of the resulting creams was observed visually and under a microscope.

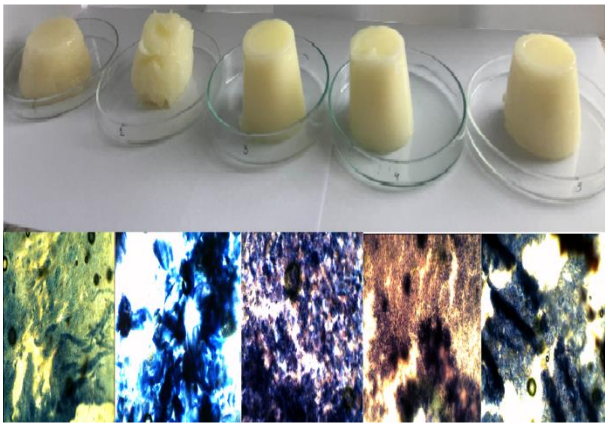

Figure 2. Photographic and microscopic images of starch-milk creams with A) tapioca, B) potato, C) corn, D) rice and E) wheat starch

After the visual analysis and the microscopic observation of the structure of the obtained creams, a similarity was established between the structure created by root starches and grain starches. In the samples with root starches, a weaker strength in the structure and poor preservation of the shape of the obtained starch gels was visible. On the second day after storage, liquid separation was also observed in the cream with potato starch, also visible in Fig. 3. Under the microscope, a thread-like structure can be observed in the resulting creams with potato and tapioca starch, and more granular in those with corn, rice and wheat starch.

3.2 Analysis of the stability of starch-milk creams (retrogradation of the used starch)

According to the indicated method for determining the stability of the system - by centrifuging the starch creams, the % separated water of the individual samples is calculated in relation to the days of storage. Based on the obtained data we can conclude which of the starch-milk dessert creams shows the lowest stability during long-term storage, which is also an indicator of the retrograde properties of the used starches (Fig. 3). Analyzing the data in Figure 3, it is found that after 24 hours, the potato starch released a significant amount of water, while the rice and corn starch showed stability in terms of the percentage of water released. Over time, as can be seen, the amount of water released for the potato starch continues to increase. A significant increase in the amount of water released over time has also been reported for the cream with tapioca starch. This would make the product non-durable and of lower quality. While the wheat and corn starches have the lowest values of the percentage of separated water and would be a suitable alternative.

3.3 Analysis of the rheological and thixotropic characteristics of starch-milk creams

The rheological properties of food products in a wide range of phase behaviour can be expressed in terms of viscous, elastic or viscoelastic functions. Most rheological studies have focused on the viscosity function and dynamic viscoelastic properties [22].

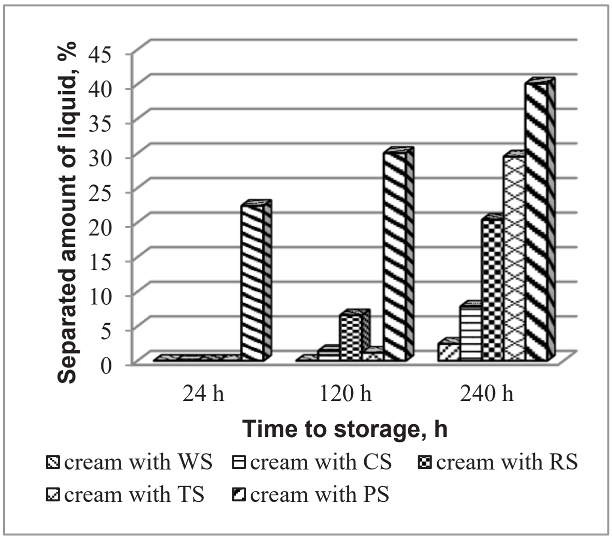

Figure 3. Stability of starch – milk dessert creams with corn, wheat, rice, tapioca and potato starch

Viscosity is defined as the primary rheological parameter that represents the internal friction of a fluid or the tendency to resist flow.

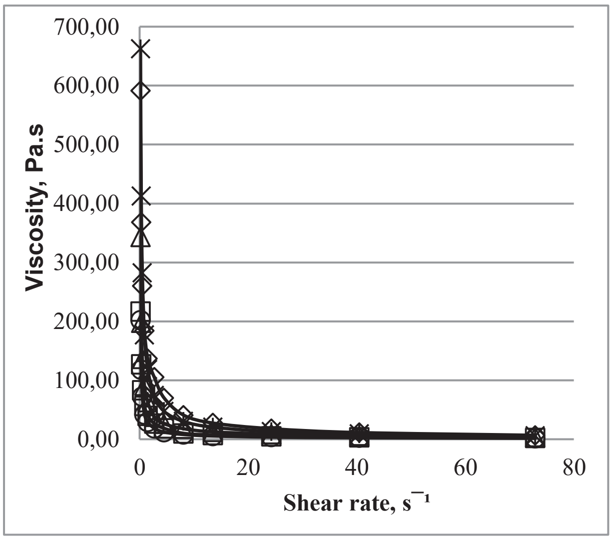

Figure 4. Viscosity of creams with corn (◊), wheat (□), rice (○), tapioca (×) and potato starch (Δ).

Fig. 4 shows the viscosity of creams with different types of starch depending on the shear rate (D). It is clear from the data that with an increase in the value of the velocity gradient, the viscosities decrease. As the shear rate varies in the low value range over a small interval, the relative decrease in viscosity is greater than in the high shear rate value range over a large interval. The close values of the relative decrease in viscosities indicate that the degrees of changes in the structures of the creams are close. Fluids with similar rheological behaviour are defined as non-Newtonian and have a so-called effective viscosity.

The smallest changes in viscosity when changing the velocity gradient according to the data in Figure 4 is the cream with rice starch, because its initial and final change points have the smallest distance compared to the other types of starches used, which means that it has undergone minor changes as the velocity gradient increases.

The initial viscosity of the samples was different, and the highest viscosity was the sample with tapioca starch. The initial viscosity of the creams with wheat and rice starch is close, it could be interchangeable. The shear rate increased from 0.17 to 72.9 s^{-1}, and the viscosity decreased. These facts showed that the starch suspensions were non-Newtonian fluids, and their viscosity variations were close. These samples had pseudoplastic properties because they flow with applying the external impact.

The rheological behaviour of the five types of creams with different types of starch was analyzed at a temperature of 50°C. A rheogram of the analyzed samples was constructed and presented accordingly in Figure 5.

From the graphically expressed dependence between the shear stress (τ) and the shear rate (D), it is seen that each of the starches used exhibits a different degree of structural destruction when applied to mechanical impact. The cream with corn starch shows the highest values of thixotropic properties, this is due to the increased destruction of the structure of the system with increasing tension. In thixotropic properties, viscosity decreases with time at a given velocity gradient.

Thixotropy is the area occupied by the ascending and descending curves of the tangential curve.

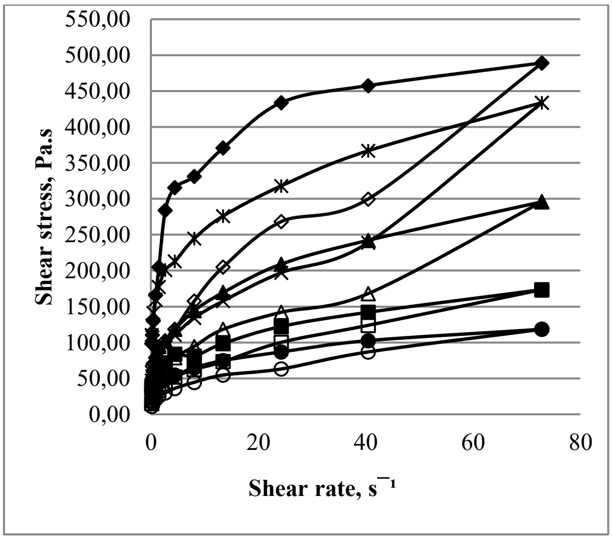

Figure 5. Rheograms of creams with corn (◊,♦), wheat (□, ■), rice (○, ●), tapioca (✳, ×), and potato (Δ,▲) starch.

The sample with rice starch shows the highest stability when increasing the tension and speed of mechanical impact, which means that it is more suitable for preparing the cream.

The power law model parameters for the samples are given in Table 1, along with coefficients of determination (R^2).

Herschel–Bulkley model, which is widely used in the analysis of various food systems [23].

The consistency coefficient (k) and flow behavior

Table 1. Parameters of Herschel–Bulkley models for flow curves of the systems

Type of starch	τ_0	k	n	R^2	τ_0	k	n	R^2	Hysteresis loop area [Pa. s^{-1}]
	Upward curve				Downward curve				
Corn	81.99± 1.23	173.64± 3.44	0.282± 0.03	0.9602± 0.0134	58.79± 0.68	79.22± 2.41	0.376± 0.03	0.9615± 0.0235	12087,67± 2.35
Rice	28.59± 0.87	42.87± 2.15	0.218± 0.02	0.9692± 0.0342	7.56± 0.36	21.91± 1.63	0.363± 0.04	0.9906± 0.0156	972,25± 3.56
Wheat	28.14± 1.05	53.18± 1.36	0.261± 0.06	0.9866± 0.0087	12.01± 1.24	29.60± 1.14	0.384± 0.02	0.9950± 0.0352	1297,35± 5.62
Potato	51.39± 0.56	84.05± 3.09	0.278± 0.04	0.9902± 0.0234	11.26± 0.64	46.52± 0.89	0.372± 0.06	0.9842± 0.0453	3567,05± 2.45
Tapioca	96.78± 1.78	161.13± 2.87	0.218± 0.02	0.9956± 0.0345	39.15± 1.52	74.36± 2.37	0.329± 0.01	0.9600± 0.0068	7817,59± 6.89

Flow curves for all the systems indicating similler changes in the structure of the samples on the shear applied.

The rheology of the studied starch milk creams can be satisfactorily modeled by considering that, after gelatinization and cooling, the polysaccharide polymers and swollen starch granules form network structures that are irreversibly disrupted by shear, leading to a shear-dependent change in the properties of the stream. The differences in viscosity and the changes in the structure under the action of mechanical impact are due to the different structures of the gel formed during cooling and to the different swelling characteristics of the granules of the different starches used.

The multiple correlation coefficients, R^2, reported in Table 1 informed about, generally, very good fitting of the index (n), obtained by fitting of the power law and Herschel–Bulkley models to the experimental shear stress-shear rate data are given in Table 1. Yield stress is an important characteristic. High values of yield stress, τ_0, from the Herschel–Bulkley model, pointed to a high stability of the structure of the samples [24]. The power law equation was found to be an adequate model to describe the flow behaviour of the samples in this study. Viscosity functions data showed that all of the systems under examination were Non-Newtonian fluids, since the values for flow behaviour index, n, were below 1, which was indicative of the pseudoplastic (shear thinning) nature [25]. The yield stress (τ_0) of the samples was from 7.56±0.36 to 96.78±1.78 (Pa). The sample with rice starch had the lowest value of τ_0. This results show that the highest stability of structure have rice starch [26]. The flow behaviour indices (n) are between 0.218±0.02 and

0.384±0.02 for the Herschel–Bulkley model. The smaller n values determine the greater departure from the Newtonian behaviour [27].

Consistency coefficient, k, from the Herschel–Bulkley model can also be used as a criterion of viscosity. It was from 21.91±0.04 to 173.64±1.36 (Pa). So the highest viscosity had the cream with corn and the lowest – with rice starch.

The hysteresis loop area data shown that the most narrow loops were found for the cream with rice starch (972.25±3.56). Thus, the structure of it was the strongest and shear-resistant. The thixotropic effect is described as a viscosity decrease with time at a constant shear rate [28].

Conclussion

It can be concluded that in terms of rheological characteristics and viscosity of five laboratory-produced starch-milk dessert creams withdifferent starches the sample with rice starch exhibit the greatest resistance and minimum changes. In the stability analysis, the cream with corn starch show the lowest percentage of water released, followed by wheat and rice starch. In this case, due to the advantages of rice starch such as granule size, resistance to mechanical impact and insignificant change in viscosity, it will be preferred over the other four types for making starch-milk dessert cream. In order to minimize the release of water, the product must be stored under suitable conditions and for a short time.

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