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Rheological behavior of some berry milk-based beverages with enhanced functionality

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Abstract

The main goal of this study was to obtain and characterize in terms of rheological behavior two berry milk-based beverages. In the recipe of these beverages it was used milk, 10% berry mixture (blueberry, blackberry and raspberry), as well as, 2% sugar, respectively honey. The berry mixture used in recipe provides bioactive compounds, especially polyphenols and vitamin C. It was characterized from rheological point of view milk and mixtures sugar-milk and honey-milk in the range of temperature 5-25°C. These products present non-Newtonian behavior (pseudoplastic) at all investigated temperatures. The best model that can be applied to the experimental dependencies was Oswald model (Power Law). For both berry milkshakes (with sugar and honey), the values of flow behavior index (n) are smaller than 1, so all these fluids are pseudoplastic ones (the viscosity decreases with shear rate). There were no recorded changes in the rheological character of the studied fluids at all temperature, in the range 5-25°C.

Keywords: berry milk-based beverages, rheological characteristics, non-Newtonian behavior, viscosity, rheogram, Oswald model (Power Law).

1. Introduction

Nowadays, various berries have been proven to provide considerable health benefits because of their high content of bioactive compounds, minerals, fiber, etc. In addition to fresh consumption, this kind of fruits was widely used to obtain different beverages, milkshakes, gelled products, yogurt, ice cream, smoothies, and many other value-added food products for health promotion. Also, the demand for minimally processed foods has increased during the last decade.

Berry milk-based beverages are very attractive and have also large potential to provide a wide range of bioactive compounds in human diet [1]. This was the main reason why we have focused our attention to this study. Milk beverages are popular because of their high nutritional value, and milk products that are enhanced with various fruit flavors are especially in high demand. Also, many published data about nutritional properties of fruit milk-based beverages are available, but there is a lack of evidence regarding the rheological behavior of these products [2, 3]. The rheological characteristics of fruit milk-based beverages is rather defined using more subjective descriptive expressions based on comparisons with other foods, or due to theirs consistency. The effects of the addition of different types of sweeteners (sugar and honey) on the flow

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behavior of various beverages model systems were studied from rheological point of view [4].

The rheological characterization of a fluid can be described using the relationship between shear stress (σ) and share rate (γ) in a steady laminar flow. Milk is a colloidal suspension in which the solid compounds dissolve or disperse in a continuous water phase. Knowledge of the flow behavior of milk is important to the design and operation of the milk products processing equipments involved in mixing, storage and pumping. Rheological properties of milk are closely correlated with sensory perception of texture [5-7].

Following the increasing trends of consumer to require healthy food, the main objective of this study was to obtain and assess in terms of rheology and fluid dynamics of a berry milk-based beverage with enhanced functionality, usually called berry milkshake, easy to prepare, using a mixture of three forest berries. We hope that, this study will deliver relevant results for both specific industry and scientific field.

2. Material and methods

Ingredients and recipe for milkshake preparation

Berries. Wild berry such as blueberry (*Vaccinium myrtillus*), blackberry (*Rubus fruticosus*) and raspberry (*Rubus idaeus*) were used in milkshake preparation following a specific recipe. Fruits were harvested from mountain region of western Romania, at full ripening stage. Berries were analyzed in terms of bioactive compounds and color quality fresh, prior using in milkshake preparation. In the period between harvesting and analysis, berries were kept in refrigeration conditions 4-6°C for 24 h).

Milkshake preparation. The recipe used to obtain milkshake was a simple one: milk (1.8% fat), 10% fruits (berry mixture) and 2% sugar or honey. We prepared two kinds of milkshake, one with sugar and one with honey. Berry mixture consists of 30% (w/w) blueberry, 30% blackberry and 40% raspberry.

Analytical procedures

Obtaining the extracts used in analysis. For analysis of bioactive compounds from berry, the extracts were obtained according to Kalt *et al.* (1999) [8]. The extracts used for quantificationof total anthocyanins and antioxidant capacity were obtained using 95% (v/v) ethanol acidified with HCl (0.1%, v/v), while for analysis of total phenolics and Viotamin C, the extracts were prepared with 95% (v/v) ethanol.

Total antioxidant activity was evaluated on the base of FRAP (ferric reducing antioxidant power) assay using the analytical procedure reported by Benzie and Strain [9]. This method involves the reduction of Fe^{+3} to Fe^{+2}, which forms a blue-colored complex with 2,4,6-tripirydylo-s-triazine (TPTZ). The reduction was monitored on the base of change in the absorption intensity at 595 nm, being in relation with antioxidant concentration. FRAP values were expressed as mM of Fe^{2+} equivalents per 100 g FW. All measurements of mentioned parameters were done in triplicate.

Total phenolic content was evaluated by Folin-Ciocalteu colorimetric assay according to Singleton *et al.* (1999) [10]. The samples were kept for 2 h in the dark at room temperature and then, the absorbance at 750 nm was read using the UV-VIS spectrophotometer (Analytic Jena Specord 205). Quantification of the data was done using the calibration curve generated using gallic acid as a standard. The results were expressed as mg GAE per 100 g FW.

Vitamin C content was determined by titration with 2,6-dichlorophenolindophenol sodium salt solution, according to AOAC [11]. Results were expressed in mg L-AsAc equivalent per 100 g FW.

Total anthocyanins content of berry were assessed on the base of pH-differential method [12]. Samples were diluted with 0.025 M potassium chloride buffer (pH=1.0) and 0.4 M sodium acetate buffer (pH=4.5). The absorbance was measured using the UV-VIS spectrophotometer at 520 and 700 nm after 15 min of incubation at 20°C. The content of total anthocyanins was reported as mg cyandin-3-glucoside equivalents per 100 g FW.

Color quality of berry, appreciated on the base of color density, polymeric color and percentage of polymeric color, was determined using the bisulfite bleaching method [12]. Polymeric color (%), expressed as ratio between polymeric color and color density, represents the percentage of color that is contributed by polymerized material [13].

Total soluble solids of berry was determined at 20°C using the refractometer DR301-95 (KRÜSS, Germany) according to standard method described by AOAC [14]. The values were done in °Brix.

Rheological measurements were made with a Brookfield LVDV III Ultra rheometer equipped with a control temperature device. For measurements it was used a coaxial cylinders geometry (DIN-86) for milk and mixes milk-sugar and milk-honey. For berries milkshake it was used a DIN-87 geometry. The determinations were realized in a Brookfield type, based on torque measurements when a spindle of various sizes rotates in a container where water can be recycled to ensure thermostating. In the container were introduced analyzed samples (2-7 mL), regarding the used geometry. Temperature control was ensured (±0.1ºC) by a Julabo recycling water bath. Rheological measurements for milk, milk-sugar, milk-honey were made at temperatures in the range 5-25°C, as follows: 5, 10, 15, 20 and 25°C. For the rest of the samples, rheological measurements were made at increasing temperatures from the same temperature range, as follows 5; 7.5; 10; 12.5; 15; 17.5; 20; 22.5; 25. All measurements were made at increasing share rate. There have been considered only the measurements from torsion range 10-100%. Rheometer computerized control was realized with BEVIST program. All these rheograms were registered at 5, 10, 15, 20, 25^{o}C and a share rate between 60 and 240 s^{-1}. The three most common mathematical models for non-Newtonian fluids: Herschel Bulkley model, Ostwald model (Power Law) and Bingham model, were applied in order to transform rheogram data values to the rheological behaviour of the fluids. Flow behavior index (n) and consistency index (K) were studied.

3. Results and discussion

Chemical parameters of fresh forest berries used in this study for milkshake preparation were reported in Table 1. These characteristics are very important because they provide data about bioactive compounds and associated antioxidant properties, in a close connection with health benefits, of obtained milkshake.

The berry mixture used for milkshake preparation provides bioactive compounds belonging to the polyphenols class, the most important from them being monomeric anthocyanins, as can be seen from data reported in Table 1. Additionally, these berries contain vitamin C, an important compound with antioxidant properties.

For all species of berry, percentage of polymeric color have recorded values lesser than 5%, thus, the polymerized anthocyanins contributed in a small extent to the color of berry. In this case, total monomeric anthocyanins, with proven antioxidant properties, were the main contributors of berry color. In addition to bioactive compounds with antioxidant characteristics, the berry mixture brings along other soluble substances that improve both, the rheological parameters and nutritional properties of berry milk-based beverages obtained in this study.

The first part of rheological studies covered the influence of temperature on milk, mixes milk-sugar, milk-honey flowing character. Figures 1-3 shows the rheograms for milk, mixes milk-sugar, milk-honey. All these rheograms were registered at 5, 10, 15, 20, 25°C and share rate in the range 60-240 s^{-1}.

Graphical representation of rheograms is straight lines passing through the origin of axes, so these 3 fluids have a Newtonian behavior. From the slopes of the linear regression of these rheograms was calculated viscosity of the three fluids.

The values of these viscosities are presented in the Table 2 and the Figure 4 presents viscosities graphical descending with temperature increasing. A viscosity analysis shows, as expected, a viscosity increasing with sugar and honey addition. The increase of viscosity was higher for sugar samples than the ones with honey. This can be explained in two ways: (1) unlike sugar, honey has higher water content, up to 20% and (2) carbohydrates in honey are different from sucrose.

Table 1. Chemical characteristics of fresh berry used in milkshake preparation

Component (Units)	blueberry	raspberry	blackberry
Total phenolics (mg GAE/100g FW)	557.14±19.21	217.58±8.49	361.3±13.45
Total anthocyanins (mg/100g FW)	211.27±15.75	52.31±3.86	189.51±9.29
FRAP (mM Fe^{2+}/100g FW)	5.18±0.42	3.51±0.42	4.58±0.37
Vitamin C (mg/100g FW)	15.19±1.07	32.41±2.28	12.87 ± 0.8
Color density	11.73±0.82	6.71±0.54	10.21±0.6
Polymeric color	0.39±0.02	0.33±0.03	0.47±0.03
(%) of polymeric color	3.32±0.27	4.91±0.42	4.60±0.38
Total soluble solids (°Brix)	11.34±0.80	10.73±0.70	12.56±0.85

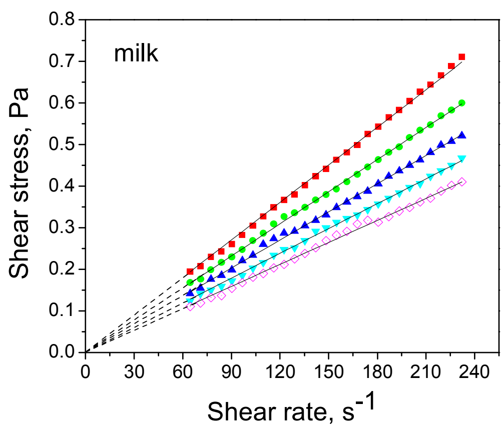

Figure 1. Temperature influence on milk rheogram
Legend: ■ 5°C; ● 10°C; ▲ 15°C; ▼ 20°C; ◊ 25°C

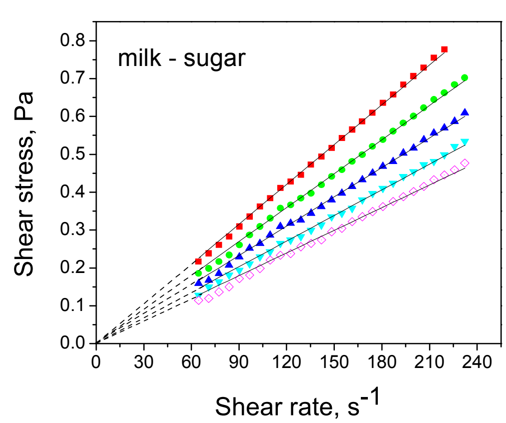

Figure 2. Temperature influence on milk-sugar rheogram
Legend: ■ 5°C; ● 10°C; ▲ 15°C; ▼ 20°C; ◊ 25°C;

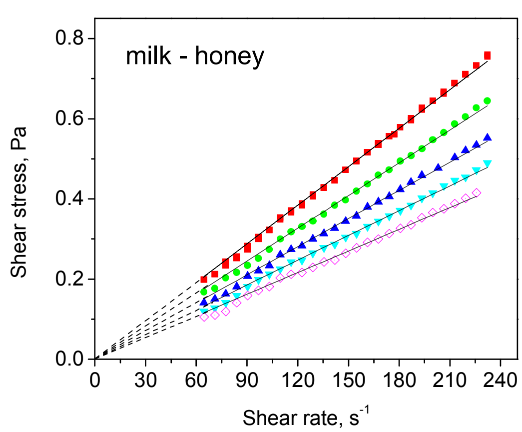

Figure 3. Temperature influence on milk-honey rheogram
Legend: ■ 5°C; ● 10°C; ▲ 15°C; ▼ 20°C; ◊ 25°C.

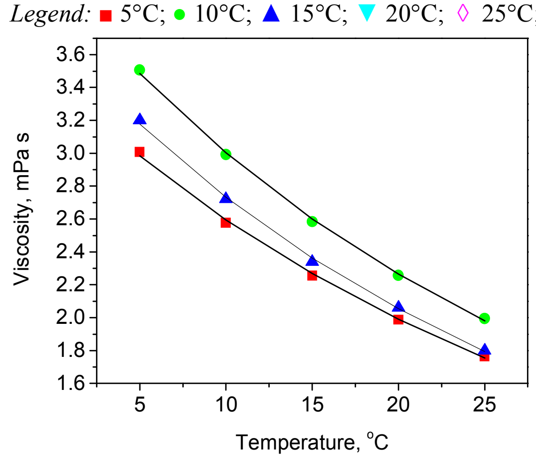

Figure 4. Temperature effect on milk, milk-sugar, milk-honey viscosity
Legend: ■ milk; ● milk-sugar; ▲ milk-honey

Table 2. Temperature influence on milk, milk-sugar, milk-honey

T(°C)	Viscosities (mPa · s)		
	Milk	Milk-sugar	Milk-honey
5	3.008±0.008	3.507±0.008	3.201±0.007
10	2.577±0.005	2.993±0.009	2.722±0.009
15	2.256±0.006	2.584±0.008	2.34±0.007
20	1.988±0.005	2.257±0.009	2.06±0.008
25	1.765±0.007	1.995±0.0011	1.801± 0.009

Table 3. Temperature influence on rheological characteristics of sugar and berry milkshake

T(°C)	K (mPa · s^n)	SD	n	SD	R^2
5	1209.2	19.50	0.331	0.004	0.997535
7.5	713.35	10.67	0.408	0.004	0.998753
10	498.97	11.63	0.453	0.006	0.997815
12.5	396.27	6.72	0.466	0.004	0.998964
15	281.24	6.51	0.513	0.005	0.998396
17.5	237.05	2.72	0.521	0.003	0.999616
20	190.54	2.32	0.540	0.003	0.999621
22.5	151.08	2.10	0.563	0.003	0.999572
25	130.36	1.76	0.572	0.003	0.999645

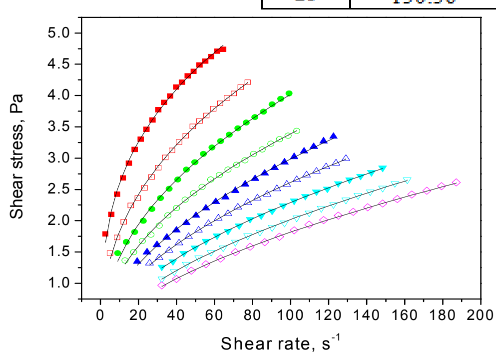

Figure 5. Temperature influence on sugar milkshake
Legend: ■ 5°C; □ 7.5°C; ● 10°C; ○ 12.5°C; ▲ 15°C; Δ 17.5°C; ▼ 20°C; ▽ 22.5°C; ◊ 25°C. The continuous lines are the calculated rheograms.

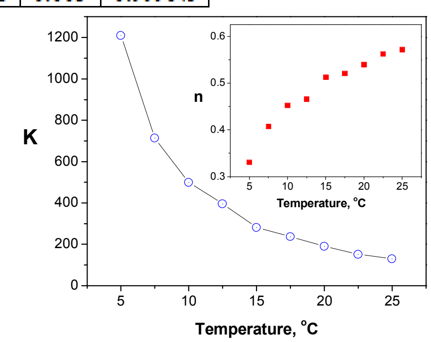

Figure 6. Temperature influence on rheological characteristics of sugar and berry milkshake

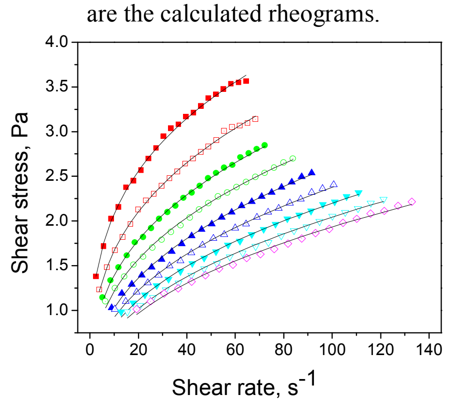

Figure 7. Temperature effect on honey and berries milkshake rheograms
Legend: ■ 5°C; □ 7.5°C; ● 10°C; ○ 12.5°C; ▲ 15°C; Δ 17.5°C; ▼ 20°C; ▽ 22.5°C; ◊ 25°C. The continuous lines are the calculated rheograms.

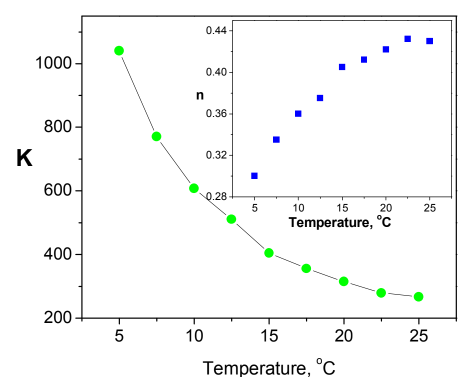

Figure 8. Temperature effect on rheological characteristics of honey and berries milkshake

Table 4. Temperature influence on honey and berries milkshake rheological characteristics

T (°C)	K (mPa · s^n)	SD	n	SD	R^2
5	1040.61	14.56	0.300	0.004	0.997693
7.5	770.44	9.23	0.335	0.003	0.998671
10	607.33	8.49	0.360	0.004	0.998467
12.5	510.75	9.60	0.375	0.005	0.997623
15	404.62	6.91	0.405	0.004	0.998381
17.5	356.26	8.58	0.412	0.006	0.997030
20	314.82	6.51	0.422	0.005	0.997992
22.5	279.47	7.78	0.432	0.006	0.996622
25	266.83	8.96	0.430	0.008	0.995141

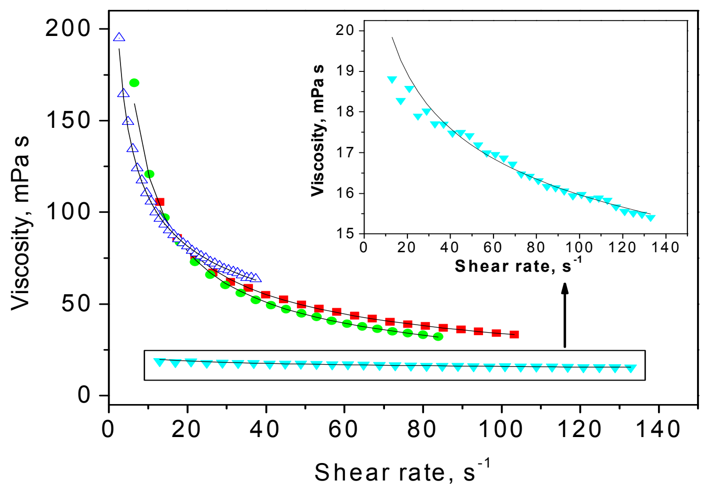

***Figure* 9.** Apparent viscosity

Figures 5-8 presents the calculated rheograms. These rheograms were calculated with the aid of viscosity (Table 2) at all expressed share rates.

The rheograms for milkshake with sugar, honey and berries, Figures 5-8, were registered for the same temperatures as the others milkshakes. It could be observed non-Newtonian character of these products, in the case of these products the best model being the Ostwald model (Power Law).

Rheological characteristics for this model were calculated through linear regresion and are presented in Tables 3 and 4.

There were calculated theoretical rheograms, by using of rheological characteristics from these tables and law power, being observed a very good overlap of calculated rheograms on the experimental ones.

As regards the berries milkshake samples, both with sugar and honey, the values obtained for flow behavior index (n) are smaller than 1, so all these fluids are pseudoplastic ones.

Thus, the viscosity decreases with shear rate (Figure 9), in the same way for both samples of milkshake.

4. Conclusion

The berry mixture used for milkshake preparation provides bioactive compounds belonging to the polyphenols class. Additionally, these berries contain vitamin C, an important compound with antioxidant properties. The polymerized anthocyanins contributed in a small extent to the color of berry, thus, the monomeric anthocyanins, were the main contributors of berry color. It was characterized from rheological point of view milk as raw material and mixtures sugar-milk, honey-milk, where weight ratio milk/sugar and milk/honey is identical with technology. These products have non-Newtonian behavior (pseudoplastic) at all studied temperatures. The best model that can be applied to the experimental dependencies was Ostwald model (Power Law). For obtained berry milkshake (with sugar or honey), the values obtained for flow behavior index (n) are smaller than 1. Thus, these fluids are pseudoplastic ones (the viscosity decreases with shear rate). In the temperature studied range (5-25^{0}C), rheological character of these fluids (pseudoplastic) didn't record any change.

Abbreviations

FRAP: Ferric reducing antioxidant power; GAE: Gallic acid equivalent; FW: Fresh weight; σ: shear stress; γ: share rate; K: consistency coefficient; n: the flow behavior index; SD – standard deviation; R^2: coefficient of determination.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human / or animal subjects (if exist) respect the specific regulation and standards.

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