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Rheological Properties of Low-calorie Red Deer Meat Pâté

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Authors' contributions

This work was carried out in collaboration between all authors. Authors EO, MR, ZY and MS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DT, PS and TB managed the analyses of the study. Authors OV and TS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Background: The formulation of new meat products requires evaluation of the effect of different ingredients on physical-chemical and rheological properties of meat batters.
Objective: In this study, the yield stress properties of three low-calorie meat pâté recipes were evaluated under different conditions. Changes in physical properties associated with the addition of a protein fortifier (PF) and ground boiled bean (GBB) to red deer meat pâté recipes were measured.
Materials and Methods: Three formulations of meat pâté were developed that included different

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amounts of PF and GBB as follows: the first recipe contained no PF or GBB; the second recipe contained 15% PF and 20% GBB; and the last recipe contained 25% PF and 10% GBB. Proximate composition, water-binding capacity (WBC), and pH were measured using standard methods. Yield stress was measured using a cone penetrometer.

Results: The addition of PF and GBB increased yield stress, WBC, and pH. Increasing the temperature from 12 to 25°C significantly lowered yield stress. In addition, temperatures ranging from 0-5°C increased yield stress, with a holding time of up to 11 hours for all recipes. However, at 25 hours, the yield stress deceased up to at least 50 hours after.

Conclusion: Enrichment of meat pâté with protein fortifier and beans enhanced nutritional composition but did not significantly change rheological properties.

Keywords: Yield stress; pâté; temperature; composition; maral meat; batter.

1. INTRODUCTION

Meat products comprise different ingredients, including raw materials from plants and animals, fillers, bioactive compounds, and spices. Addition of these ingredients changes the structure, consistency, and physical and chemical characteristics of meat batters [1]. Meat and meat products hold an important place in nutrition; however, overconsumption of meat increases fat in the diet, which could be detrimental to health [2,3].

One way to adequately balance nutrition, while limiting calorie intake, is to develop dietary foods that consist of a mixture of traditional (beef, pork, poultry, and lamb),non-traditional (horse, deer, and rabbit) meat, and/or additives such as vegetable supplements [4]. Meat pâté is a widely consumed meat product. Various other types of food supplement and brine, including various protein additives of different origins, polysaccharides, vitamins, and essential elements, are also widely used in meat technology. In addition, protein-fat emulsions are used during processing to improve appearance, or the customer appeal, of the products [5-7]. Due to its low cost and high nutritive value, meat pâté is now reaching a wide base of consumers.

The quality of meat pâtés can be assessed based on physical properties which reflect the structural, biological, and chemical composition of the food. In fact, small changes in these properties can change structural-mechanical properties [8]. Basic rheology parameters include shear stress, deformation, shear rate, and viscosity, whilst moisture content, fat, protein, carbohydrate, and salt contents can affect these parameters in food products [9]. The consistency of meat products is the most important quality indicator; however, appearance, colour and taste are also important [10]. Meat consistency can be assessed by evaluating rheology parameters or through sensory evaluation. The consistency of a given meat product is dependent on how it flows or deforms under shear stress and shear rates [11]. Yield stress, plastic and apparent viscosity, and relaxation time are all shear properties that describe the quality, as well as the degree or depth, of processing. The best sensory characteristics of meat pâtés are s oftness and juiciness.

In developing new meat product recipes, rheological properties are judged based on yield stress determination. Yield stress is classically defined as the threshold stress required to initiate flow; thus, yield stresses is a material property that denotes the transition to pseudo-solid and pseudo-liquid states [12,13]. Mineimum shears stress is used as evidence to flow due to the transition from elastic to viscous deformations, a non-Newtonian effect [14,15].When shear stress is higher than yield stress, the structure of the food is destroyed and the body flows as a Newtonian fluid; the structure can also rebound. Measuring yield stress in foods has several practical implications as it can guide process calculations for product development, as well as composition and processing conditions that can affect product texture [13,16,17].

The rheological behaviour of food products cannot be predicted theoretically due to a complex array of physical, chemical, and biological factors that would otherwise have to be taken into account in such predictions; in addition, the rheological properties of yield stress and viscosity can be affected by various factors including temperature, pH, water-binding capacity (WBC), and holding time [9]. Measurements of the rheological profile of the meat batters and ready-to-eat meat products aid in determining technological processes, the output, and the quality of the end product [18].

The purpose of this study was to evaluate the effect of a protein fortifier and bean recipe on the physical-chemical properties and yield stress of low-calorie meat pâtés under different conditions.

2. MATERIALS AND METHODS

2.1 Meat Sampling

Maral (red deer) meat was obtained from the local trade market in the Ulan settlement and from the market located in Ust-Kamenogorsk city. Both markets are within the East Kazakhstan region. Cattle rumen and horse-rendered fat were purchased from a local market 24 h postmortem and blood was obtained from the local meat processing plant. All samples were stored separately at 2-3˚C prior to pâté preparations.

2.2 Preparation of the Protein Fortifier

Cattle rumen (following preliminary technological treatment) and horse-rendered fat, as well as blood, salt, garlic, nitrite, black powdered pepper, and bacterial ferment (BF), were used to produce the protein-enriching additive. The protein additive was prepared in two stages.

The first stage consisted of preparing the protein-fat emulsion (PFE). Cattle rumen was boiled for 1 hour. Then, the broth obtained was mixed with the horse-rendered fat and blood in the following proportions: 75%, 15%, and 10%, respectively. These ingredients were mixed for 10 to 12 minutes. The composition of the emulsion was as follows: protein: 10.26%; fat: 13.68%; residue on drying: 14.07%;and ash: 0.95%.

The second stage consisted of boiling the cattle rumen for 1.5 to 2 h using a rumen/water ratio of 1:3. The cooked rumen was ground and mixed with PFE at a ratio of 2:1 and 3% salt was added. The product was mixed for 5 to 7 min. At the end of the mixing process, 5 to 10% of bacterial starter (including *Str. Lactis, Str. Diacetilactis*, and *Str. Cremoris*) was added. Mixing continued for 2 to 3 min. A stable protein fortifier color was obtained because bacterial starter and blood were used during preparation. The protein-enriching additive was stored for 6-12 hours at 4 °C. The composition of the protein fortifier was as follows: protein: 16.80%; fat: 4.80%; and ash: 1.27%.

2.3 Preparation of the Pâté

The pâté was made from ground maral meat, protein fortifier, boiled ground beans, rumen broth, boiled carrot, onion, wheat flour, salt, black powdered pepper, and spices. The pâtés were manufactured using three formulations with different proportions of protein-enriching additive and beans. The first formulation included 85% of maral meat without protein-enriching additive and beans. The second formulation consisted of 15% of protein-enriching additive and 20% of ground boiled bean. The third formulation included 25% of protein additive and 10% of ground boiled beans. The formulations are shown in Table 1.

The maral meat was washed and cut into small pieces (100-150 g each) and then blanched in water for 30 minutes (90-95 0C) using a meat/water ratio of 1:3.Beans were washed and boiled in water for 45-60 minutes. The boiled beans were then processed to obtained ground beans. Fresh carrots were cleaned and cut in small pieces and then boiled until softened. The onions were peeled, cut, and sautéed in vegetable oil for 10-15 minutes. Onions were then weighted and cut into small pieces.

Table 1. Maral pâté recipes

Ingredient	Mass part (%)		
	Recipe 1	Recipe 2	Recipe 3
Ground maral meat	85	50	50
Protein fortifier	-	15	25
Boiled ground beans	-	20	10
Rumen broth	7	7	7
Boiled carrots	4	4	4
Onions (sautéed)	1	1	1
Wheat flour	2	2	2
Salt	1	1	1
Black pepper	0.1	0.1	0.1
Spices	<0.1	<0.1	<0.1

Patties were made in a cutter machine at 6-8°C. The ground maral meat, protein fortifier, onions, wheat flour, salt, pepper and spices (to taste) were gradually added. Then, at the mixing stage, beans, carrots, and rumen broth were added, a small quantity at a time. Following the mixing stage, the prepared meat batter was stored at -2 to-4°C.

2.4 Proximate Composition

Determination of the proximate composition of meat was based on the following constituents: moisture (by drying at 150°C to constant weight), fat (by extraction with ethylic ether), ash (by incineration at 550°C), and protein (by Kjeldahl method: acid digestion of meat sample, distillation and titration) [4].

2.5 Yield stress Measurements

Yield stress was measured using a cone penetrometer "Structurometer" ("Radius" Company, Russia). This technique is used to measure rheological parameters of food in the food industry. The cone penetrometer container was first filled with a sample. Then, the sample was gently pressed, such that the surface was leveled and the temperature was adjusted using a water bath. Tests were conducted at temperatures between 12 and 25°C. For each temperature tested, the uncertainty was ±0.5°C. Each measurement was performed in accordance with the operational instructions of the device and the principles of the test.

The "Structurometer" displays the value of penetrating load. Yield stress was calculated using Equation *f*:

$$\theta_0 = K \cdot \frac{P \cdot 9{,}81 \cdot 10^3}{h^2}, \text{ Pa} \qquad (f)$$

where, P: penetrating load g; h: immersion depth of cone, mm; K:calculated using eq. *g*.

The constant K, as it applies to the cone of the device, is obtained as follows:

$$K = \frac{\cos^2(\alpha/2)}{\pi \cdot tg(\alpha/2)}, \qquad (g)$$

where, α: angle at the vertex of the cone (α=45° or α=60°); *tg:* tangent of angle

As multiple measurements were taken, the arithmetic mean of yield stress data, obtained according to Equation *h*, was used to report the results.

$$\theta_0 = \frac{\sum \theta_i}{i}, \qquad (h)$$

where, *i*:number of measurements

Standard uncertainty was calculated using Equation *i*

$$U = \frac{s}{\sqrt{i}}, \qquad (i)$$

where, *i*: is the number of measurements*;* *s:*standard deviation

2.6 pH Measurements

Active acidity (pH) was determined using the potentiometer method. A pH-tester 340 (Infraspak-Analit, Russia) was used to obtain the measurements by dipping the two electrodes into the test solution and taking a reading. The solution was prepared as follows: the meat sample was minced and mixed with water (distilled-deionized water in the ratio 1 part of meat:10 parts water). The pH reading was obtained after 30 minutes of infusion at 20˚C.

2.7 WBC Measurements

The method used to determine WBC of the samples is based on exudation of moisture to a filter paper through the application of pressure. The moisture absorbed by the filter paper is evaluated based on the spot area on the filter paper. Specifically, for each sample, 0.3 g of minced meat was placed on a 15-20mm-diameter disk plate on a Mettler Toledo electronic balance (Mettler Toledo, Switzerland). The meat was then transferred onto an ash-free filter (Munktell Filter AB, Sweden) and placed on a glass or plexiglass plate. The sample was covered with the same filter before a 1 kg load was carefully placed on top of the meat. The weight was left for 10min. Once removed, the top filter was pulled off and bound water was calculated, as described (see Equation *g* and *k*). The filter was scanned using an Xpress M2070 scanner (SAMSUNG, Japan) after the contour of the wet spot was traced on the filter. The area was calculated using the «Compas-3D V-10» software [19]:

$$X_1 = (A-8,4B)\cdot 100/m_0, \quad (g)$$

$$X_2 = (A-8,4B)\cdot 100/A; \quad (k)$$

where, X_1:bound water content, expressed as % of sample; X_2:bound water content, expressed as % to total water; B: wet spot area, cm^2; m_0: sample weight; mg; A: total content moisture in the sample, mg.

2.8 Energy Value Calculation

The energy value of meat pates was calculated based on the contents, expressed as a percentage, of three major nutrients – protein (P), fat (F), and carbohydrates. In Equation *l*, the energy value (EV) of the product is given in kcal/100g.

$$EV = (4P + 9F + 3.8C) \quad (l)$$

where, *4, 9,* and *3.8*arecoefficients of energy value of protein, fat, and carbohydrates (kcal/100 g), respectively.

2.9 Statistical Analysis

Statistical analysis was performed using Statistica 12.0 (STATISTICA, 2014; StatSoft Inc., Tulsa, OK, USA). The differences between meat pâté samples with different recipeswere evaluated using a one-way ANOVA. Differences were considered to be statistically significant at $p \le 0.05$.

3. RESULTS AND DISCUSSION

Yield stresses were determined for 3 formulations of pâtés [20]. In brief, the protein contents of recipes 1, 2, and 3 were 17.76±0.20%, 18.78±0.11%, and 19.61±0.15%, respectively, whereas the lipid contents of recipes 1, 2, and 3 were 3.21±0.05%, 2.32±0.01%, and 2.94±0.02%, respectively. Lipid content was largely driven by the addition of the protein fortifier (with a lipid content of 8.0%) and rumen broth (with a lipid content of 14.3%). The carbohydrate content for recipes 2 and 3 was1.38% and 0.95%, respectively; there were no carbohydrates in recipe 1. The combination of different ingredients in pâté recipes changed the total energy value. The highest caloric value was obtained in recipe 3 (108.7 kcal/100 g), while recipes 1 and 2 were very similar, at 99.9 kcal/100 g and 101.5 kcal/100 g, respectively (Table 2).

The main factors governing the ability of minced meat to bind and hold water include meat-grinding size, connective tissue content, salt content, and food-bound components such as flour and eggs. The WBC of such products has a direct impact on rheological characteristics (viscosity, adhesiveness, and cohesion), sensory properties (juiciness, consistency, and appearance), and structural-mechanical parameters (plasticity, shear stress, and yield stress). The rheological properties of ground meat rely on the balance between strongly-bound and weakly-bound water. The strongly-bound water is in the form of solvation spheres, created around the disperse particles. With the insufficient capacity of ground meat to strongly bound the water, the quantity of weakly-bound water is increased and excessive.

Proteins are the basis of meat structure and, accordingly, have an impact on rheological characteristics such as tenderness, hardness, and elasticity. Proteins also influence WBC; for example, the WBC in recipe 2 and 3 was higher than in recipe 1 (Table 2), due to the addition of a protein fortifier and a bean additive. The protein fortifier has a WBC of 70% and its addition to recipes 2 and 3, in different proportions, had an effect on the final WBC. In recipe 3, with its 25% of protein fortifier content, the WBC was higher than in recipe 2 with its 15% protein fortifier content. Ground boiled beans have a high water-absorbing ability, tightly binding the otherwise weakly-bound water of the meat and PF.

Based on WBC, it was estimated that the yield stress of the pâtés with PF and bean (recipes 2 and 3) would be higher than for recipe 1. In fact, the yield stress of recipe 2 (1868.95±48.38 Pa) was higher than the yield stress value of recipe 1 (1815.07±61.44 Pa) (Table 3). Recipe 2 included

Table 2. Calculated energy value, WBC, and pH for each recipe

Index	Recipe 1	Recipe 2	Recipe 3
Energy value(kcal/100 g)	99.9	101.5	108.7
WBC(%)	68.25±1.28	71.48*±0.41	78.15*±0.45
pH	5.93±0.13	6.12±0.03	6.20±0.03

*P<0.05**

15% PF and 20% of ground boiled beans. The addition of 25% PF and 10% ground boiled bean to recipe 3 also increased the yield stress (1851.88±59.67 Pa) compared to recipe 1. These changes in yield stress indicate that the additions had no detrimental effect on the consistency of the pâté.

We observed that the yield stress of minced meat pâté changed with holding time in the range 2-4°C. Based on the data shown in Table 3, yield stress peaked after a holding time of approximately 11h. This was likely due to the spontaneous hardening of the minced meat which peaks when the water is completely bound and has satiated all bonds [21]. Thereafter, there was a rapid reduction of occurrences such that, at 50 hours, the yield stress was approximately 40% of its value at the start point. Holding for prolonged periods of time periods causes yield stress values to decrease due to the weakening of the minced meat structure under the influence of microbiological and biochemical processes [21]. The same observations held true for all three recipes tested.

In all tested pâté recipes (Table 4), yield stress decreased considerably with temperature. With increasing temperature, water-protein-salt bonds weaken as a result of increased molecular movement, which leads to structure itself becoming weaker [22]. These results indicate that pâté maybe more palatable when consumed shortly after being taken out of the refrigerator.

We performed a literature search and found several studies on pâté development in which different additives were used to enhance nutritive value. Table 5 shows how reported recipes, energy values, and yield stress compare with the results from our study.

Meat pâté recipes are first described in terms of energy value as they are formulated to meet the needs of nutritious low-calorie foods for overweight and obese people. Based on our review, the energy values of those pâtés fall within the 128 to 371-kcal/100g range. In high-fat content (≥250 kcal/100g) recipes, the formulations include either protein-fat emulsions, fat (pork fat, or horse fat), fatty meat, or different protein supplements that contain fat. Low-calorie recipes (<200 kcal/100g) typically include poultry meat, lean meat, vegetable additives, and lean meat-by products. The three recipes evaluated in this study are thus considered low-calorie pâtés.

Only one report on yield stress was found in the literature that analysed a high-fat pâté recipe (≥250 kcal/100g);this particular pâté, at 254.6kcal/100g, had a low yield stress of only 1400 Pa [30]. In moderate fat-content recipes (≥200 to <250 kcal/100g), yield stress was 1800 Pa for a 244.7kcal/100gpâté [29] and 3420 Pa for a 208.8kcal/100g pâté [27]. Finally, within the low-fat category (<200 kcal/100g), yield stress was 2780 Pa for a 193.3kcal/100g pâté [26]. Recipe 2, with a yield stress of 1869 Pa and an energy content of 101.5 kcal/100g, seems comparable with other pâté formulations.

Table 3. Yield stress as a function of holding time (T=2-4°C), Pa

Treatment	Holding time, h				
	0	7	11	25	50
Recipe 1	1815.07±68.96	1893.12±51.89	2137.24±73.50*	1305.04±52.50*	649.43±19.39*
Recipe 2	1868.95±62.47	1949.31±58.09	2200.69±87.53*	1343.78±54.12**	668.71±23.06*
Recipe 3	1851.88±76.71	1931.51±82.45	2180.59±35.46**	1331.50±43.79**	662.60±21.07*

$*p<0.05$, $**p<0.02$

Table 4. Change in yield stress as a function of temperature, Pa

Name	Temperature(˚C)		
	12	18	25
Recipe 1	1815.07±61.44	907.54±19.72*	332.76±7.56*
Recipe 2	1868.95±48.38	934.48±30.86*	342.64±9.13*
Recipe 3	1851.88±59.67	925.94±20.18*	339.51±10.09*

$*p<0.05$

Table 5. Literature comparison

Reference	Pâté recipe	Energy value	Yield stress, pa
This study (recipe 2)	Red deer meat; protein fortifier; boiled ground beans; rumen broth; carrots; onions; wheat flour; salt; species	101.52 kcal/100g (p: 18.78%; f: 2.32%; c: 1.38%)	1869
Lazhenceva et al. (2010) [23]	Minced hydrobionts; water-binding agent (rice, peas, beans); milk-fat emulsion	128.32 kcal/100g (p: 13.2%;f: 6.0%; c: 5.38%)	-
Antipova and Polyanskih, (2003) [24]	Poultry meat; chicken liver; chicken hearts; chicken stomach; food hydrolysate; chicken fat; carrots; onions; chicken broth; species	178.5kcal/100g (p: 16.5%; f: 12.5%)	-
Andreeva, (2011) [25]	Lean lamb; poultry meat (breast); pork fat; flaxseed oil; dietary supplement; pumpkin seed powder; water; sodium alginate gelatin	179.1 kcal/100g (p: 18.0%; f: 11.9%)	-
Kalinovskiy, (2005) [26]	Beef or pork liver; fatty pork; lung; spleen; flour; water; spices	193.3 kcal/100g (p: 16.49%; f: 13.38%; c: 1.73%)	2780
Agalarova, (2000) [27]	Beef liver; pork trimmings; pork stomach; soybean protein isolate; protein-carbohydrate supplement from pea powder	208.8kcal/100 g (p: 14.22%; f: 14.48%; c: 5.41%)	3420
Nekrasov, (2002) [28]	Fatty pork; pork skin; pork liver; salt; sodium nitrite; complex compounds for pâté	224.0 kcal/100 g (p: 11%; f: 20%)	-
Zhmurina, (2014) [29]	Beef liver; iodine protein-fat compound; carrots; milk; pork back fat; onion	244.7 kcal/100g (p: 11.7%; f:21.1%; c: 2.0%)	1800
Kakimov, (2007) [30]	Beef liver; semi-fat pork; horse trimmings; protein complex, egg mélange; protein-fat emulsion; species	254.6 kcal/100g (p: 18.2%; f:20.2%)	1400
Amaral et al. (2015) [31]	Liver; lamb meat; blood; lard; water; ingredients	273.8 kcal/100g (p: 14.92%; f: 23.79%)	-
Terrasa et al. (2016) [32]	Pork back fat, chicken breast and liver; sunflower oil; sodium caseinate; sodium chloride; sodium phosphate; sodium nitrite; ascorbic acid	371.8 kcal/100g (p: 8.79%; f: 37.4%)	-

4. CONCLUSION

The results of this study indicate that the addition of protein fortifier and ground boiled beans significantly changed the proximate composition, WBC, and yield stress of the pâté recipes. The effect of temperature on yield stress was significantly reduced, by approximately 80%, from 12°C to 25°C. In addition, storing meat pâtés up to 11 h at 2-4°C increased yield stress. However, following 25 and 50 hour holding times, yield stress values were found to be decreased. Overall, addition of a protein fortifier and ground boiled beans did not significantly change yield stress in red deer meat pâtés. However, enrichment of these pâtés with protein fortifier and bean enhanced their nutritional composition.

CONSENT

It is not applicable.

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the author.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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