Study of the rheological properties of meat-vegetable minces

S P Merenkova¹, O V Zinina¹, M F Khayrullin², T S Bychkova² and L A Moskvina³
¹South Ural State University (National Research University), 75 Lenin Avenue, Chelyabinsk, Russian Federation
²K G Razumovsky Moscow State University of Technologies and Management (the First Cossack University), 73 Zemlyanoy Val, Moscow, Russian Federation
³Yaroslav-the-Wise Novgorod State University, 41, ul. B. St.-Petersburgskaya, Veliky Novgorod, Russian Federation

E-mail: pbio@ya.ru

Abstract. To adjust the nutritive and biological value of food products, it is advisable to combine meat and vegetable raw materials. The paper presents the results of study of the rheological and microstructural parameters of combined meat-vegetable minces. The mince includes beef trimming, hemp protein and flaxseed flour. The study results showed the minimum values of shear stress and viscosity of the mince system and increased indicators of total and plastic deformation in the samples of minced meat containing linseed flour in an amount of 10–15%. Samples of the meat-vegetable mince that contained 15% of hemp protein and not more than 5% of flax flour exhibited high stability of the meat system. Microstructural studies of combined minced meat revealed the presence of friable vegetable mass, starch grains and fragments of hemp and flax fiber. Samples with a predominance of hemp protein showed a denser and more uniform structure. Thus, the rheological properties of meat-vegetable mince systems depend significantly on the type and amount of vegetable materials introduced.

1. Introduction
The study of the rheological properties of food systems is important for controlling the parameters of the technological process during formation of optimal properties of the final product. Nonlinear mechanical properties of processed materials in the food industry are due to the multicomponent composition of the dispersed composition [1–5]. In recent years, comprehensive studies of combined foods with complex raw materials have been underway [6–10]. A combination of raw materials of vegetable and animal origin enables fabrication of a nutritionally balanced product [11–16].

The rheological properties of food systems correlate with the structural composition of the material. Many authors conduct research to analyze the viscoelastic properties of emulsions in order to establish the relationship between rheological properties and the system composition [17].

Meat is a source of high grade protein, but it contains animal fat that negatively affects human health [18]. The combination of meat and vegetable components enriches the meat system with vegetable protein, dietary fiber, vitamins and minerals [19–21]. Promising sources of vegetable protein for combined systems are processed products of flax and hemp seeds. Hemp seed products are of high nutritional and biological value, they contain essential amino acids, polyunsaturated fatty acids and other bioactive components [22–24]. Seeds of brown and yellow-seed flax also contain protein and fat of excellent quality. Flax seeds are a good choice to ensure a balanced lipid profile [25].
Inclusion of vegetable components in the composition of minced meat can decrease quality indicators, in particular the stability of the emulsion and structural and mechanical properties [26]. Therefore, evaluation of the rheological parameters of combined food systems is highly relevant.

The aim of the study is to establish the effect of vegetable components on rheological and microstructural parameters of combined meat-vegetable systems.

2. Material and methods

2.1. Experimental sample fabrication

The object of the study was meat-vegetable mince. The basic components of minced meat were beef trimming (90/10), flaxseed flour, hemp protein, and water.

Flaxseed flour (9.1% moisture, 39.3% protein, 21.1% fat) was made from flax seeds of the Ratsiol variety by Medal company (Chelyabinsk, Russia).

Hemp protein (9.8% moisture, 56.1% protein, 23.4% fat) was produced from seeds of industrial hemp varieties Nadezhda by Medal company (Chelyabinsk, Russia).

Beef trimming was ground in a meat grinder to a particle size of 2–3 mm. Hydrated (1:2) hemp protein and flaxseed flour were added to the ground beef trimming in accordance with the formulations presented in table 1.

| Component        | Amount of the component, kg per 100 kg of raw materials |
|------------------|--------------------------------------------------------|
|                  | formulation 1 (F1) | formulation 2 (F2) | formulation 3 (F3) | formulation 4 (F4) |
| Beef trimming    | 80                | 80                | 80                | 90                |
| Hemp protein     | 5                 | 10                | 15                | 5                 |
| Flax flour       | 15                | 10                | 5                 | 5                 |

The components were thoroughly mixed, and the mince samples were packaged in plastic bags and stored at 4 °C until testing.

2.2. The study of rheological parameters

Rheological parameters were measured using a rotary viscometer (Brookfield R/S SST). The viscometer determines the viscosity and shear stress by measuring the shear speed of the spindle immersed in the test sample of minced meat. Viscosity measurements and shear stress ranges were determined with regard to spindle speed, spindle size, and full-scale torque of the calibrated spring. The size of the selected spindle was 30/15, and the maximum torque was 80%. The values of viscosity and shear stress were calculated using coefficient 9. The rheological parameters (ultimate shear stress, effective viscosity) of the meat-vegetables mince were studied at 20 °C.

The deformation indices (plastic and elastic deformation) were determined using an ST-2 Struclometer texture analyzer (Quality Laboratory, Russia) through its compressing using a Ø36 Cylinder indenter (duralumin, weight 42.5 g). The mechanical tension created on the cylindrical indenter was analyzed in the following operating mode: contact force (Fc=7 g); strain rate (Vd=0.5 mm/s). Indentation lasted until the force Fmax became equal to 500 g.

2.3. Scanning Electron Microscopy

The microstructure of the samples of meat-vegetable minces was studied using a scanning electron microscope (SEM), JSM 7001F (JEOL, Japan). After freeze-drying, the minced meat samples were cut into 10×5×2 mm sections. The prepared samples were fixed on the aluminum plate of the holder using carbon adhesive tape. The sample surface was covered with a layer of electrically conductive material (platinum) with a thickness of about 10 nm. In the study, secondary electrons were recorded at accelerating voltage of the cathode of 5 kV.
2.4. Statistical analysis
Measurements were performed in five replicates. The results were expressed as mean values of five replications ± standard deviation. Probability values P ≤ 0.05 were taken to indicate statistical significance. Data were analyzed by means of one-way ANOVA and the Tukey HSD post-hoc test using software provided by Assaad et al. (2014) [27].

3. Results and discussion
Minced meat is a concentrated food emulsion with a structured matrix of protein molecules as the medium, and droplets of fat distributed in the matrix cells, soluble proteins and salts as the phase. Highly concentrated food emulsions belong to elastic viscous-plastic media with apparent yield strength, solid behavior at small deformations and non-Newtonian behavior at high shear stresses [28].

The study of the rheological parameters of the experimental samples showed that the ratio and amount of vegetable materials in the formulation significantly affect the strength and viscosity of combined meat-vegetable systems. The minimum values of the ultimate shear stress and viscosity of combined minces can be observed when the amount of flax flour is 10–15% (F1 and F2) (P <0.05).

The data obtained are due to the significant amount of non-starchy polysaccharides – cellulose and hemicellulose – in flaxseed flour, which are distinguished by a pronounced water- and fat-binding capacity. A large number of water and fat molecules in the mince matrix weaken the bonds between the protein molecules, which form the structural network, and decrease density and viscosity.

The ultimate shear stress and viscosity are associated with the stability of intermolecular interactions in the protein matrix. The use of components that exhibit surface-active properties provides formation of an adsorption layer with elasticity and high structural strength on the interphase boundary [29].

Thus, samples F3 and F4 show stronger intermolecular interactions and high stability of the disperse system. Indicators of the ultimate shear stress and viscosity attain maximum values in samples containing 15% of hemp protein in the formulation (F3) (P <0.05).

Addition of hemp protein containing proteins of globular nature with surfactant properties improved the stability and uniformity of the highly concentrated meat emulsion and facilitated formation of the stable combined food system with a strong structure (figures 1, 2).

![Figure 1](image-url)  
**Figure 1.** Dynamics of ultimate shear stress of the combined meat-vegetable minces depending on the shear speed.
Designation of samples: F1, F2, F3, F4 are the combined meat-vegetable minces produced according to formulations 1, 2, 3 and 4, respectively.

**Figure 2.** Dynamics of viscosity of the combined meat-vegetable minces depending on the shear speed.

The changes observed are characteristic of protein stabilized emulsions. Chattong and Apichartsrangkoon (2009) stated that viscoelastic gels with a certain cross-link density exhibit similar behavior during rheological evaluation [30].

The change in deformation parameters of combined meat-vegetable minces correlated with the data obtained for viscosity and ultimate shear stress. Thus, the highest values of total, plastic, and elastic deformation were found in samples with the lowest shear stress and viscosity – F1 and F2 (figure 3).

**Figure 3.** Deformation parameters of the combined meat-vegetable minces.

Designation of samples: F1, F2, F3, F4 are the combined minces samples produced according to formulations 1, 2, 3 and 4, respectively.
The combined mince that contained more than 10% of flax flour was characterized by a more plastic structure and a lower Young's modulus (for F1, total and plastic deformation amounted to 4.3 and 2.1 mm; for F2, these values were 3.9 and 1.9 mm, respectively). At the same time, mince containing 15% of hemp protein (F3) and mince containing 90% of meat components (F4) were more resistant to deformation loads.

Figure 4 illustrates the microstructure of meat-vegetable minces. The structures of the mince samples showed the presence of friable vegetable mass, starch grains, and hemp and flax fiber fragments, which are similar in appearance to those described by Jiang et al. (2019) [31]. Vegetable fibers are uniformly distributed over the meat mass. In samples F3 and F4, a denser and more homogeneous structure and a compact arrangement of components were noted. In addition, high porosity was established in all mince structures. Figures 1–4 show insoluble dietary fibers in flaxseed and hemp protein. Similar inclusions were found in the study of the microstructure of meat sausages with addition of wheat and oat fibers by Barrett et al. (2015).

![Figure 4](image)

Figure 4. Scanning electron microscope (SEM) images of the combined meat-vegetable minces.

4. Conclusion
The results of rheological and microstructural studies show that the composition and amount of vegetable materials added to the formulation has a significant effect on the structure, strength and viscosity of combined minces.
Samples containing linseed flour in an amount of 10–15% exhibited the minimum values of shear stress and viscosity of the minced system, and increased indicators of total and plastic deformation. The meat-vegetable mince samples containing 15% of hemp protein with surfactant properties, revealed high stability of meat emulsion. The indicators of ultimate shear stress and viscosity attained maximum values, and the level of total and plastic deformation reduced significantly.

Microscopic analysis of cuts of combined meat-vegetable minces revealed friable vegetable mass, starch grains, and hemp and flax fiber fragments. A denser and more uniform structure and compact arrangement of the components could be observed in samples containing 15% of hemp protein and not more than 5% of flax flour.

Thus, the structure and ratio of vegetable components significantly affect the rheological parameters of meat-vegetable systems, which must be taken into account when choosing molding equipment and production modes.

Acknowledgments
The study was supported by the Government of the Russian Federation (Decree # 211 dated 16 March 2013) and funded by RFBR grant # 18-53-45015.

References
[1] Nesterenko A, Goushchin V, Koshchaev A, Kenijz N, Rebezov M and Khayrullin M 2020 Electromagnetic treatment of fresh sausage meat and starter cultures in summer sausage production International Journal of Advanced Science and Technology 29 (9S) 1173
[2] Vladimirovna Z O and Borisovich R M 2016 A biotechnological processing of collagen containing by-products of bovine animals Research Journal of Pharmaceutical, Biological and Chemical Sciences 7 (1) 1530–34
[3] Zhumanova G, Rebezov M, Assenova B and Okushanova E 2018 Prospects of using poultry by-products in the technology of chopped semi-finished products International Journal of Engineering and Technology (UAE) 7 (3.34) 495–98 DOI: 10.14419/ijet.v7i3.34.19367
[4] Nesterenko A, Koshchaev A, Kenijz N, Akopyan K, Rebezov M and Okushanova E 2018 Biomodification of meat for improving functional-technological properties of minced meat Research Journal of Pharmaceutical, Biological and Chemical Sciences 9 (6) 95–105 WOS: 000496307000013
[5] Kabulov B, Kassymov S, Moldabayeva Zh, Rebezov M, Zinina O, Chernyshenko Yu, Arduvanova F, Peshcherev G, Makarov S and Vasyukova O 2020 Developing the formulation and method of production of meat frankfurters with protein supplement from meat by-products Eurasian Journal of Biosciences 14 (1) 213–18 DOI: 10.31838/jcr.07.02.30
[6] Zinina O V, Borisovich R M and Vaiscrobova E S 2016 A microstructure of the modelling systems on the basis of the ferment raw material with a high collagen content Pakistan Journal of Nutrition 15 (3) 249–54 DOI: 10.3923/pjn.2016.249.254
[7] Kassymov S, Rebezov M, Ikonnikova A, Fedin I, Rodionov I, Rukhadze S and Bokuchava O 2020 Using of pumpkin and carrot powder in production of meat cutlets: effect on chemical and sensory properties International Journal of Psychosocial Rehabilitation 24 (4) 1663–70 DOI: 10.37200/IJPR/V24I4/PR201274
[8] Kazhibayeva G, Issaeva K, Mukhamejanova A, Khayrullin M, Kulikov D, Lebedeva N, Gribkova V and Rebezov M 2019 Development of formulation and production technology of fish pate for therapeutic and prophylactic purposes International Journal of Engineering and Advanced Technology 8 (5C) 1355–59 DOI: 10.35940/ijeat.E1193.0585C19
[9] Okuskhanova E, Smolnikova F, Kassymov S, Zinina O, Mustafayeva A, Rebezov M, Rebezov Y, Tazeddinova D, Galieva Z and Maksimiuk N 2017 Development of minced meat ball composition for population from the unfavorable ecological regions Annual Research &
[10] Kassymov S, Amirzhan T, Moldabayeva Zh, Rebezov M, Sharova T, Nikolaeva N, Gribkova V, Gaidarenko L and Karapetyan I 2020 Nutritional and biological value of bakery products with the addition of vegetable powders and milk whey *International Journal of Psychosocial Rehabilitation* **24** (7) 3985–89 DOI: 10.37200/IJPR/V24I7/PR270394

[11] Cócaro E S, Laurindo L F, Alcantara M, Martins I B A, Junior A A B and Deliza R 2020 The addition of golden flaxseed flour (*Linum usitatissimum* L.) in chicken burger: effects on technological, sensory, and nutritional aspects *Food Sci. Technol. Int.* **2** 105–12

[12] Bilek A E and Turhan S 2009 Enhancement of the nutritional status of beef patties by adding flaxseed flour *Meat Sci.* **82** 472–77

[13] Igenbayev A, Okuskhanova E, Nurgazezova A, Rebezov Ya, Kassymov S, Nurymkhan G, Tazeddinova D, Mironova I and Rebezov M 2019 Fatty acid composition of female turkey muscles in Kazakhstan *Journal of World's Poultry Research* **9** (2) 78–81 DOI: 10.36380/jwpr.2019.9

[14] Okuskhanova E, Assenova B, Rebezov M, Yessimbekov Zh, Kulushbayeva B, Zinina O and Stuart M 2016 Mineral composition of deer meat pâté *Pakistan Journal of Nutrition* **15** (3) 217–22 DOI: 10.3923/pjn.2016.217.222

[15] Okuskhanova E, Rebezov M, Yessimbekov Zh, Suychinov A, Semenova N, Rebezov Y, Gorelik O and Zinina O 2017 Study of water binding capacity, ph, chemical composition and microstructure of livestock meat and poultry *Annual Research & Review in Biology* **14** (3) 1–7 DOI: 10.9734/ARRB/2017/34413

[16] Okuskhanova E, Rebezov M, Yessimbekov Zh, Tazeddinova D, Shcherbakov P, Bezhinar T, Vagapova O, Shcherbakova T and Stuart M 2018 Rheological properties of low-calorie red deer meat pate *Journal of Pharmaceutical Research International* **23** (1) 1–9 DOI: 10.9734/JPRI/2018/42317

[17] Fischer P and Windhab E J 2011 Rheology of food materials *Curr. Opin. Colloid Interface Sci.* **16** 36–40

[18] Barretto A C S, Pacheco M T B and Pollonio M A R 2015 Effect of the addition of wheat fiber and partial pork back fat on the chemical composition, texture and sensory property of low-fat bologna sausage containing inulin and oat fiber *Food Sci. Technol., Campinas* **1** 100–7

[19] Okuskhanova E, Rebezov Y, Khayrullin M, Nesterenko A, Mironova I, Gazeev I, Nigmatyanov A and Goncharov A 2019 Low-calorie meat food for obesity prevention *International Journal of Pharmaceutical Research* **11** (1) 11589–92

[20] Zinina O, Merenkova S, Tazeddinova D, Rebezov M, Stuart M, Okuskhanova E, Yessimbekov Zh and Baryshnikova N 2019 Enrichment of meat products with dietary fibers: a review *Agronomy Research* **17** (4) 1808–22 DOI: 10.15155/AR.19.163

[21] Abilmazhinova B, Rebezov M, Fedoseeva N, Belookov A, Belookova O, Mironova I, Nigmatyanov A and Gizatova N 2020 Study chemical and vitamin composition of horsemeat cutlets with addition of pumpkin *International Journal of Psychosocial Rehabilitation* **24** (8) 7614–21 DOI: 10.37200/IJPR/V24I8/PR280773

[22] Frassinetti S, Moccia E, Caltavuturo L, Gabriele M, Longo V, Bellani L and Giorgetti L 2018 Nutraceutical potential of hemp (*Cannabis sativa L.* ) seeds and sprouts *Food Chem.* **262** 56–66

[23] Andre C M, Hausman J F and Guerriero G 2016 Cannabis sativa: the plant of the thousand and one molecules *Front. Recent Dev. Plant Sci.* **7** 1–17

[24] Mamone G, Picariello G, Ramondo A, Nicolai M A and Ferranti P 2019 Production, digestibility and allergenicity of hemp (*Cannabis sativa L.* ) protein isolates *Food Res. Int.* **115** 562–71.
[25] Nitrayová S, Brestenský M, Heger J, Patráš P, Rafay J and Sirotkin A 2014 Amino acids and fatty acids profile of chia (Salvia hispanica L.) and flax (Linum usitatissimum L.) seed Potravinarstvo 1 72–6

[26] Kumar Y, Tyagi S K, Vishwakarma R K and Kalia A 2017 Textural, microstructural, and dynamic rheological properties of low-fat meat emulsion containing aloe gel as potential fat replacer Int. J. Food Prop. 20 1132–44

[27] Assaad H, Zhou L, Carroll R J and Wu G 2014 Rapid publication-ready MS-Word tables for one-way ANOVA Springer Plus 3 p 474

[28] Derkach S R and Zotova K V 2012 Rheology of food emulsions Vestnik MGTU 1 84–95

[29] Izmailova V N, Yampol’skaya G P, Levachov S M, Derkach S R, Tulovskaya Z D and Voronko N G 2001 Bulk and interfacial sol-gel transitions in systems containing gelatin Food Colloids Fundamentals of Formation ed E Dickinson and R Miller (Cambridge UK: Royal Society of Chemistry) 376–83

[30] Chattong U and Apichartsrangkoon A 2009 Dynamic viscoelastic characterisation of ostrich-meat yor (Thai Sausage) following pressure, temperature and holding time regimes Meat Sci. 3 426–32

[31] Jiang Y, Lawrence M, Hussain A, Ansell M and Walker P 2019 Comparative moisture and heat sorption properties of fibre and shiv derived from hemp and flax Cellulose 26 823–43