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RHEOLOGICAL CHARACTERISTICS OF BEEF FILLING MIXTURE WITH VEGETABLE OILS

CRISTIAN TUDOSE[a], LIVIA PATRASCU[a]*, PETRU ALEXE[a]

ABSTRACT. In this study, two vegetable oils have been characterized from the rheological point of view (olive and palm). The resulting emulsion from these two oils and also a meat mixture obtained by replacing animal fat with vegetable fats were rheologically analysed in order to observe structure changes caused by totally replacing animal fat with vegetable ones. Experimental data have shown that an emulsion from these two oils could be appropriate for using in meat industry but at a higher rate of olive oil. The emulsified mixture from beef and oils behaved rheologically as a solid material, temperature ramp test demonstrating that it could be used on a large scale in meat industry in order to obtain a dietetic product.

***Key words**: beef; emulsion; olive oil, palm oil, rheology, viscosity.*

INTRODUCTION

During this period researchers are seeking an ideal formula resulting from the combination of fats with superior nutritional characteristics, formula that will lead to the development of new types of foods which are balanced in nutritional and biological values [1-3].

Vegetable oil fats in comparison to animal fats are better in terms of nutrition composition due to the presence of unsaturated fatty acids, but may affect product organoleptic properties, when referring to meat and products manufactured from chopped or restructured meat. However there is considered that meat industry is the branch of the food industry where animal fat can be successfully replaced with vegetable oils without changing quality properties. JIMENEZ-COLMENERO et al., [4] have replaced pork back fat with vegetable oils, especially olive oil, in frankfurters and they obtained a new meat product

[a] *Department of Biochemistry, Faculty of Food Science and Engineering, Dunarea de Jos University, 111 Domneasca Street, 800201 Galati, Romania.*
**Corresponding author: Tel:+40743261889; e-mail: livia.mantoc@ugal.ro*

which had a reasonable level of flavour and juicy and overall the product was very close to a standard one, without changes in terms of organoleptic characteristics. Also, according to BABJI et al., [5] and TAN et al., [6] palm oil in meat products enhances the sensory qualities of the product.

It should be also recalled the key role which plays antioxidants, compounds that protect against degradation due to free radical reactions. The most important nutritional antioxidants mention vitamin E, carotenoids, tocopherols, polyphenols and vitamin C [9, 10].

Biological value of fats depends on the fatty acids they contain, the number and position of double bonds and stereochemical configuration of the molecule ("cis" and "trans" isomers) [11]. Fatty acids composition in foods is important, but must be in connection with the role of phospholipids, sterols and fat-soluble vitamins which contributes substantially to the biological action of fat [12]. From nutritional point of view the optimal ratio for fatty acids is: 33 % of saturated and unsaturated fats, 34 % of oleic acid (Omega-9), 27.5 % of linoleic acid (Omega-6) and 5.5 % of linolenic acid (Omega-3) [13, 14]. Because in animal fats there are no unsaturated fatty acids Omega-3 and Omega-6, in order to ensure optimal ratio mentioned above we need to replace these animal fats with vegetable fats partially containing these PUFAs [15]. A dietary product must have selected qualities in order to be suitable for human health. To obtain a dietetic product animal fat (which has a high content of saturated fatty acids and cholesterol) can be replaced with vegetable fats rich in unsaturated fatty acids (Omega-3 and Omega-6), antioxidants and cholesterol [19, 20].

According to a recent research addition of palm oil in meat products enhanced its sensory qualities [19]. However vegetable oils from various sources have been reported to differ significantly from physical point of view, thus when added to meat products, some quality characteristics could be affected [21, 22]. When incorporating fats that are difficult to stabilize, pre-emulsion is generally used (oil in- water emulsion with an emulsifier, typically a protein of non-meat origin) [1]. Taking into account that there are many factors that can affect stability of such a product knowing rheological characteristics in different conditions is a requisite. CHOI et al., [22] concluded that the replacement of up to 50% pork backfat with pre-emulsified vegetable oil in meat batter formulations significantly affected rheological and composition of unheated meat batters.

Given the increasing demand for meat products with improved nutritional qualities and because fats play a very important role in the organoleptic qualities of meat products we aimed to substitute all animal fat from a meat based foodstuff with a pre-emulsion obtained from vegetable oils. Concerning utilization of olive and palm oils in meat industry most of the existed studies focused on single oil types. Olive oil was investigated as a possible animal fat replacement by LURNENA-MARTINEZ et al., [3], VUARL et al., [4], PAPPA et al., [22]. Regarding palm oil, there are also many researches [18, 23, 24, 25]. However, given the structure difference between olive and palm oils, no study investigated the possibility of coupling these two oils in order to obtain a stable pre-emulsion. Thus, the aim of this study was to identify a suitable vegetable oil emulsion from rheological standpoint that could be suitable for replacing animal fat in meat products based on minced meat.

RESULTS AND DISCUSSION

Physico-chemical characteristics of extra virgin olive oil and palm oil

Physico-chemical analysis results showed that both oils had very good characteristics and complied with the regulations (Table 1).

Table 1. Physico-chemical characteristics of studied oils

Quality characteristics	Extra virgin olive oil		Palm oil	
	Bulletin	Test	Bulletin	Test
Acidity value (mg NaOH /g)	0.43	0.56±0.02	0.10	0.23±0.02
Peroxide value (ml sodium thiosulfate 0.01n /g)	12.60	11.78±0.02	9.20	10.10±0.02
TBA value (mg malon aldehyde /kg)	-	1.085±0.01	-	0.235±0.02
Humidity (%)	-	0.02±0.04	-	0.01±0.04

Values represent means of three replicates± Standard Deviation

Rheological behaviour of olive oil

Figure 1 presents results obtained for oscillatory and flow tests describing olive oil rheological characteristics. Regarding oscillatory tests it can be seen the existence of the viscous or terminal region until 4 Hz were G`` predominates and the viscous (flow) behaviour prevails [26]. The crossover frequency at which G` = G`` (a measure of the longest relaxation time), was registered at 5 Hz (G`= 1.289 Pa and G`` = 1.065 Pa), after which elastic behaviour dominated. This means that when applying low strain values (0.5%) for longer times tested oil will respond as a viscous material and will begin to flow. Shift angle (δ) values confirmed that at longer times olive oil will behave as a perfect liquid (90°), heading to solid (elastic) behaviour at short times, higher frequencies respectively.

When subjected to flow, over the range of 0.1-100 s^{-1} olive oil presented a Newtonian behaviour, like the majority of edible oils [27]. The rate index determined by applying Power Low equation was 0.99 when increasing shear rate and 1.00 when decreasing shear rate and the overall viscosity was 0.03805 Pa*s. At a constant temperature of 25 °C the resulted shear stress values formed a line whose slope was a measure of viscosity not showing any thixotropy phenomenon, and viscosity values remaining constant throughout experiment.

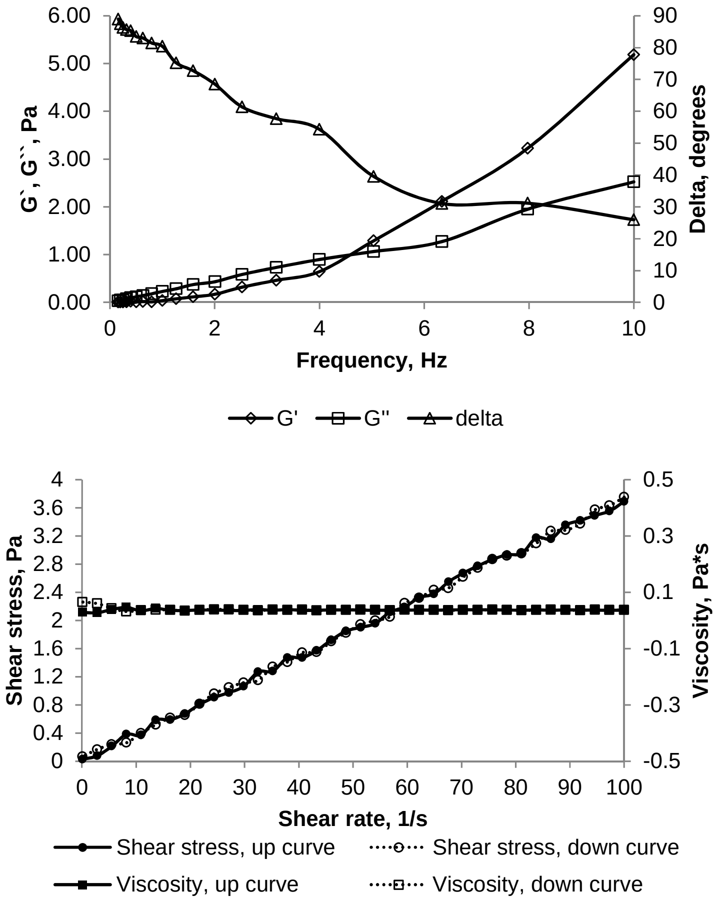

Figure 1. Rheological behaviour of extra virgin olive oil under frequency sweep and flow tests

Rheological behaviour of palm oil

Palm oil rheological characteristics are presented in figure 2. It can be seen that unlike olive oil, at longer times (lower frequency) it presented an elastic behaviour.

The cross over point (G` = G``) was registered similar to olive oil at the same frequency domain. Also higher values for both G` and G`` were recorded for palm oil comparing to olive one (278 Pa at crossover point). Delta values confirmed the elastic (solid) behaviour of palm oil, rising from 30° to 50° throughout the experiment. KALOGIANNI et al., [27] had investigated different oils for rheological characterisation and identified palm oil to have a Newtonian behaviour, however their analysis had been performed at a higher temperature of 50°C.

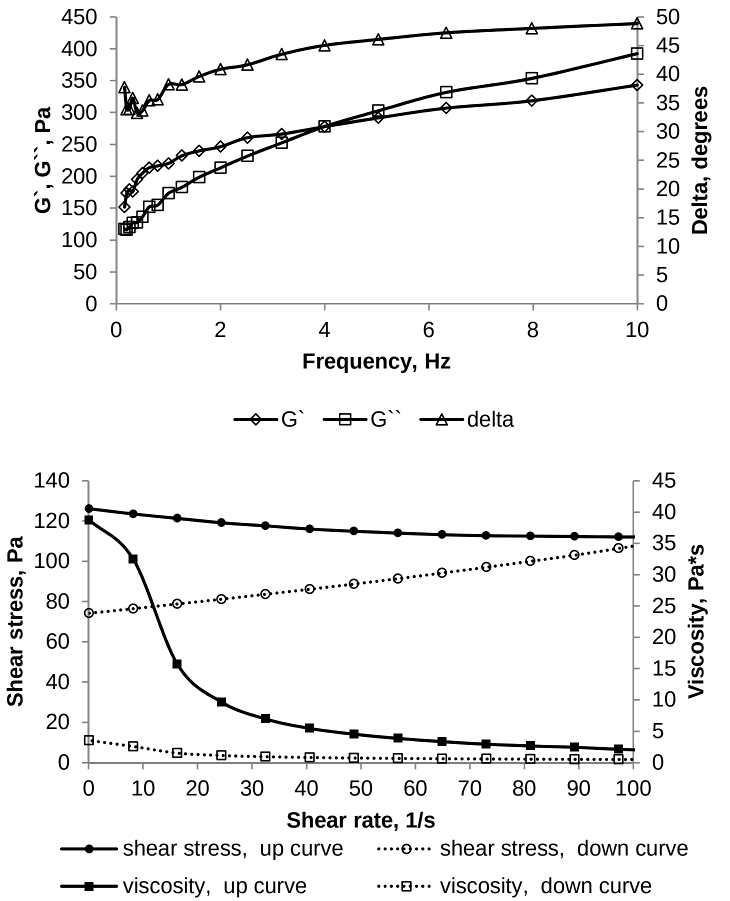

Figure 2. Rheological behaviour of palm oil under frequency sweep and flow tests

Besides shear thinning behaviour (decreasing viscosity when subjected to increasing shear rates), data recorded for flow conditions reported an unstable structure, it being unable to recover when shear rate was decreased to initial $0.1s^{-1}$. By applying Power Low equation, a hysteresis area of 31930 Pa/s was calculated. More, rate index for the up curve was 4.83×10^{-8} increasing till 0.6243 for the down curve, so according to rate index values we can conclude that palm oil in tested conditions presented a shear thinning behaviour. Viscosity values for tested palm oil presented significantly different values ($p<0.05$) for up and down curves, as shown by Power Low equation, namely 170.9 Pa*s versus 2.88 Pa*s. The beginning of flow required a rather high yield stress which resulted to be 235.9 Pa, calculated with Bingham equation.

Rheological behaviour of pork backfat

In order to compare oils rheological behaviour to usually used animal fat in meat technology, minced pork backfat (80μm particle size) was subjected to same conditions of testing. From figure 3 it can be seen that despite vegetable oils, animal fat did not present a crossover point, material being more elastic like.

G` values overcome those of vegetable oils, beginning from 2386 Pa till 6527 Pa at the end of the experiment.

A shear thinning behaviour was observed when subjected to flow (rate index = 1.86×10^{-8} for the up curve and 0.037 for the down curve). However, despite palm oil, animal fat had a more stable structure, viscosity values having a reversible tendency when decreasing shear rate, with a lower hysteresis area (12410 Pa/s). As indicated by the Power Low equation, viscosity value was 227.8 Pa*s for the up curve and 90.80 Pa*s for the down curve. The beginning of flow in case of animal fat required a yield stress of 227.3 Pa, calculated with Bingham equation. Viscosity Similar to our findings ALVAREZ et al., [28] also reported for frankfurters made with backfat a higher consistency and lower resistance to structure failure than vegetable oil emulsions.

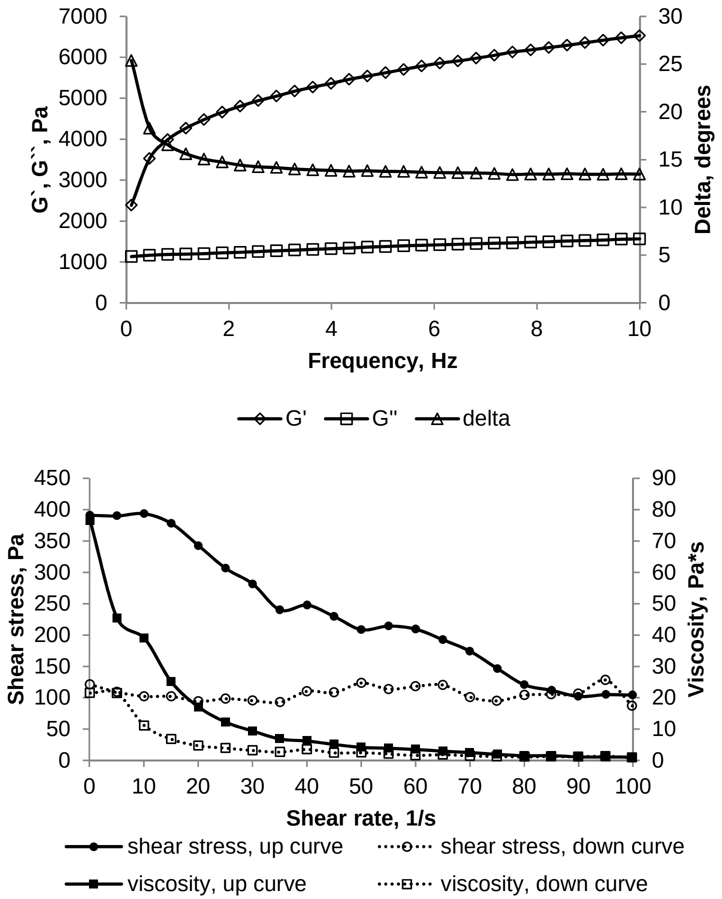

Figure 3. Rheological behaviour of pork backfat under frequency sweep and flow tests

Rheological behaviour of olive-palm oil pre-emulsion

The ideal combination between extra virgin olive oil and palm oil for a more stabilized emulsion was observed to be at a higher percentage of extra virgin olive oil (70/30). Because palm oil present solid characteristics up to a temperature of over 20 ^{o}C it can give instability to emulsion, therefore palm oil must be added carefully as the last piece. Rheological characteristics during flow and oscillatory tests were represented in figure4.

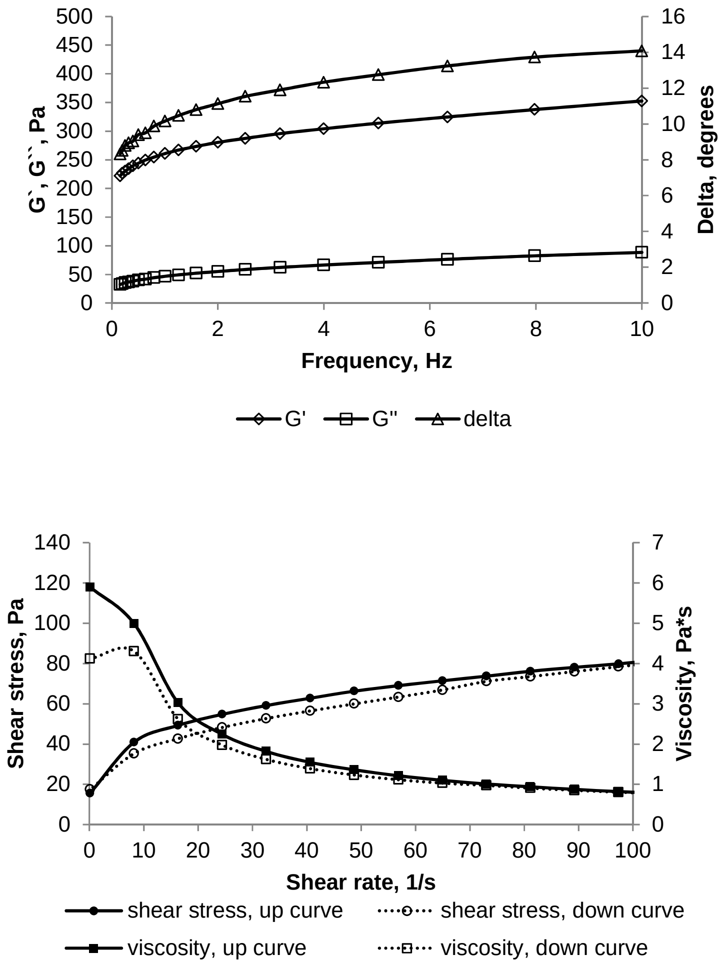

Figure 4. Rheological behaviour of the olive - palm oil pre-emulsion under frequency sweep and flow test

Oscillatory test of frequency sweep presented a solid like behaviour for the analysed emulsion similar to pork backfat. Shift angle had an increasing tendency over the tested frequency range similar to palm oil, with values ranging from 8 to 14^{o}. Besides a higher G` modulus for the entire test, values were lower than those registered for animal fat, being closer to those of palm oil.

The stability of the obtained pre-emulsion could be observed during flow test. The hysteresis loop of shear stress had a rather low value, of only 320.0 Pa/s and the yield stress, given by Bingham equation, at which the emulsion began to flow had the value of only 50.88 Pa. Viscosity values for the up and down curves given by Power Low equation had much closer values in comparison with pork backfat or palm oil, namely 20.71 versus 16.01 Pa*s. Given the results we could appreciate that this pre-emulsion would have the adequate stability in a meat matrix in order to resist a technological process.

Rheological characteristics of meat - oil matrix

The most important objective of the experiment was to maintain the main properties of the meat emulsion by replacing pork backfat with a vegetable oil pre-emulsion. In order to do that, meat–oil rheological characteristics (Figure 6) were compared with a standard meat–animal fat mixture (Figure 5). Similar to olive–palm oil pre-emulsion, meat composition obtained with pork backfat showed elastic behaviour when subjected to frequency sweep test with G` > G`` for the entire tested frequency range.

Rheological tests of temperature sweep are usually used for observing material behaviour during heat treatment, one being able to determine proteins` nature without destroying the colloidal system [29]. The inflection point, were there is supposed myosin denaturation occurs was recorded near 46 °C, at G` = 1018 Pa, after which, the elasticity continued to rise progressively until the end of the heat treatment. For both moduli (G` and G``) the shoulder peak was recorded around 60 °C, after which elastic modulus increased rapidly highlighting the transformation from a viscous sol to an elastic gel network. Samples` solid like structure was confirmed also by delta values, which decreased from 15 to 9° at the end of the temperature ramp test. PATRASCU et al., [30] stated that meat emulsified systems containing animal fat and carrageenan showed a solid like behaviour and when subjected to temperature ramp test, inflexion point of protein denaturation started just after 40 °C till 60 °C. ÁLVAREZ, et al., [28] stated that the exact magnitude of G′ rheograms, especially at around 60 °C and at the end of heating, was influenced by the fat type and the specific ingredient added.

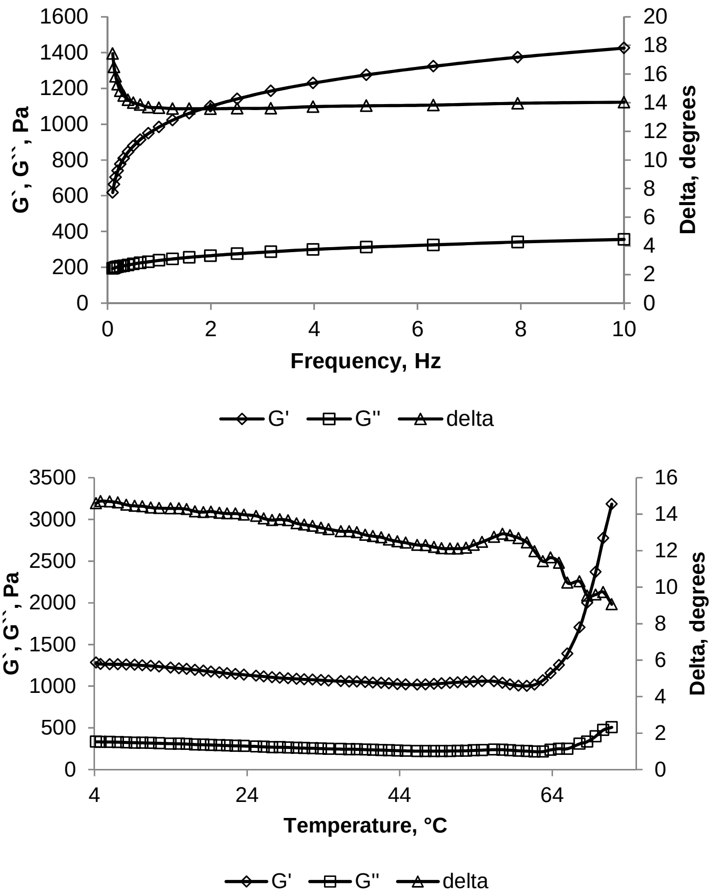

Figure 5. Rheological characteristics of control (meat-pork backfat) emulsified system

As one can see from figure 5 and 6 there are a lot of similarities between behaviour of beef mixture with pork backfat and beef mixture with vegetable oils pre-emulsion, the only difference being viscoelasticity values, much lower than in first case.

Although for G` were recorded values under 150 Pa, shift angle (δ), fitted under 30° for frequency sweep test and beneath 20° for temperature ramp test confirming that our mixture had a solid like behaviour. Thus there must be mentioned that during temperature rising beef composition with vegetable oil did not expel technological water added to the system, mixture remained stable and formed a nice slice of frankfurter at the end of the test.

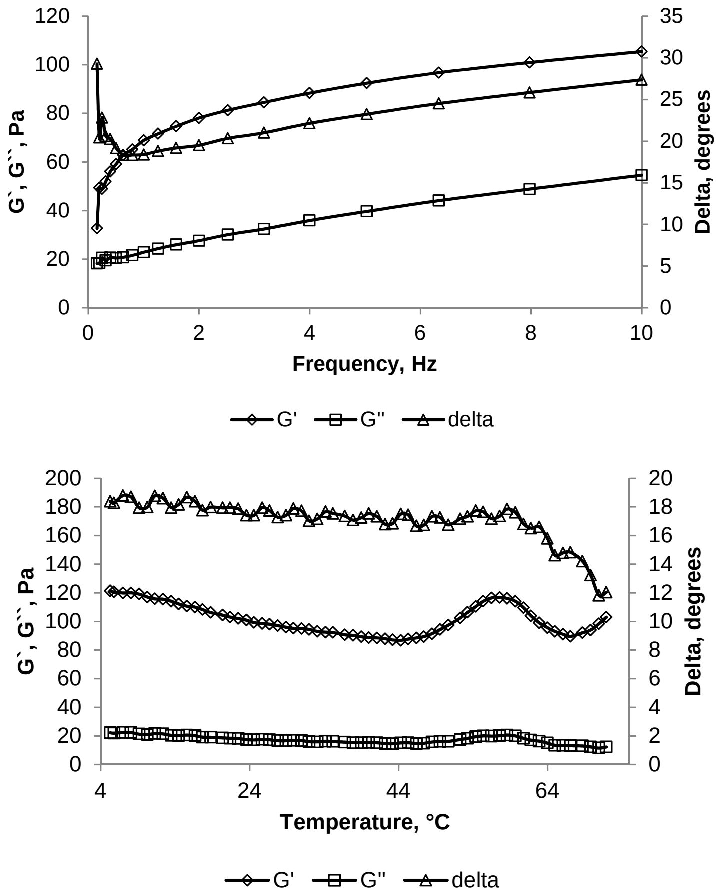

Figure 6. Rheological characteristics of meat–oil emulsified system

CONCLUSIONS

Our objective was to investigate the possibility of obtaining new meat products with improved nutritional qualities by using new advanced technologies with standard organoleptic properties.

After analysing both oils rheological parameters, we could conclude that the selected pre-emulsion of two vegetable oils (70/30 olive and palm) have features that are appropriate for partial or total replacement of animal fat in meat products and obtaining a meat product with superior nutritional qualities. Results demonstrated that the new meat matrix had similar rheological properties to a standard product (meat emulsion with animal fat) even after the heat treatment. Thus, a meat product (frankfurter like) with total replacement of animal fat can be a possible dietetic one produced on large scale (meat industry).

Further analyses are however needed in order to observe final product stability and sensorial characteristics.

EXPERIMENTAL SECTION

Frozen beef (a mixture of *Adductor*, *Biceps femoris* and *Gracilis* muscles) was taken from a local meat distributor. Beef was slowly thawed in refrigerated conditions at +4 ^{o}C for 24 hours. Two types of oil were used in this study: palm oil (Indochina) and extra virgin olive oil (Emilio Vallejo, Spain). Extra virgin olive oil and palm oil were tested in order to confirm the analysis bulletins results.

Preparation of oil-in-water emulsion

In this study five different proportions of oil/palm oils were considered for obtaining a stable pre-emulsion at the following ratios of extra virgin olive oil and palm oil: 30/70; 40/60; 50/50; 60/40 and 70/30. For stabilizing the composition 15% of soy protein isolate was added to each sample (91% protein concentration) (Supro EX37–Solae Europe Belgium).

Pre-emulsions stability was observed over a period of 4 hours at +4^{o}C in resting conditions. Thus, only one version presented emulsion stability at the end of the resting period, namely the pre-emulsion obtained from 70% of extra virgin olive oil with 30% olive oil. It`s rheological characteristics were further analysed and discussed in the results section. Also the mentioned oils ratio was incorporated in meat system in order to investigate the possibility of obtaining a functional product.

Experiment design and mixture preparation

For technological samples, thawed beef (Dry matter = 25.7%) was coarse chopped in a mincing devise (Wolf) up to 3 mm particle size than mixed with sodium chloride (1.8 kg/100 kg meat), sodium nitrate (15 g/100 kg meat) and ice (10 kg/100 kg meat), after which the composition was let to age for 24 hours at +5 ^{o}C.

After 24 hours the composition was further chopped in a cutter (3000 rot/min) for 4 minutes. In the same time progressively were added sodium tripolyphosphate (0.4 kg/100 kg meat) and the oil pre-emulsion (70/30 ratio of extra virgin olive oil and palm oil) at +2 ^{o}C, in proportion of 30%). The temperature was maintained by adding ice (10 kg/100 kg composition). At last spices were added (pepper, nutmeg, garlic). The final proximate composition of the recipe per 100 kg was: 58.33 kg beef; 25 kg oil pre-emulsion; 16.66 kg water.

The technological scheme applied is shown in figure 7:

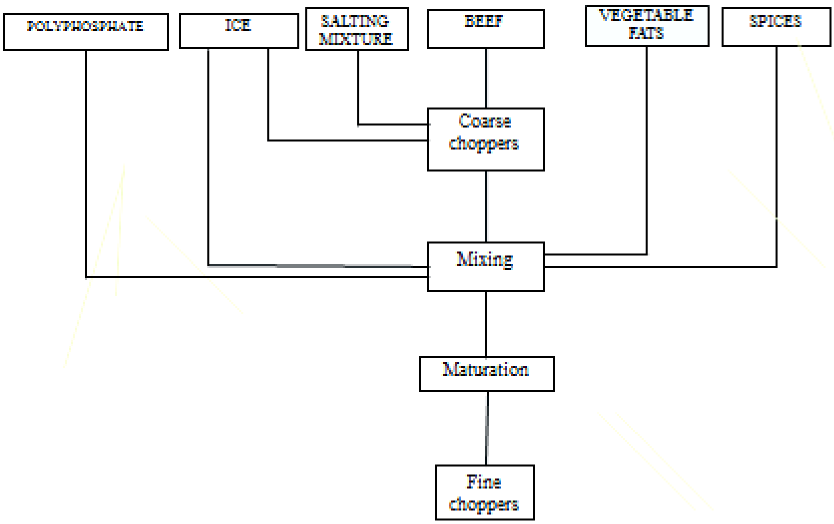

Figure 7. Technological scheme for obtaining a meat mixture with vegetable fats

Rheological analysis

Rheological characteristics were determined with an AR2000ex rheometer (TA Instruments, Ltd). Analyses were performed using a cone - plate geometry with 40 mm in diameter and 2^{o} cone angle. A gap of 1500 µm was used. Oscillatory tests were used for analysing samples rheological characteristics. First a strain sweep test was used in order to determine the viscoelastic domain, after which all following tests were performed at a controlled strain of 0.5%. Then, a frequency sweep step was applied, increasing oscillation frequency from 0.1 to 10 Hz in order to observe the behaviour of viscoelastic modulus G\` and G\`\`, together with shift angle (δ).

When the material is completely elastic the phase angle δ will be close to 0^o and when is completely viscous the phase angle δ will be 90 ^{o}C. A good emulsion must have a proportional change of G' and G'' moduli [5].

Structure changes of meat-oil mixture during technological heat treatment was studied by applying a temperature ramp test were temperature was increased from 10 to 72 ^{o}C controlled with a Peltier plate system.

In order to observe flow behaviour of tested oils, pork backfat and oil emulsions, a stepped flow step was applied and shear rate was increased from 0.1 to 100s^{-1}, and then decreased back to 0.1s^{-1}. Temperature was set to +25 ^{o}C observed to be the lowest temperature at which palm oil had a suitable consistency in order to be able to flow, more it is commonly considered for product utilization as a foodstuff [1]. Tests were performed in triplicate and mean values were represented in graphs. After every test a new sample was used. Data were analysed using TA Rheology Advantage Data Analysis Software V 4.8.3 and the mathematical models of Power Low and Bingham equations were used when necessary.

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