Short Note

Effects of heating temperature and ascorbyl palmitate on the oxidative stability of alimentary poultry fats

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The effects of high temperatures on frying fats are of major concern both for product quality and nutrition. The purpose of the study was to investigate the effects of temperature and ascorbyl palmitate addition on the quality parameters of alimentary chicken and turkey fats subjected to heating. Alimentary animal fats and 0.05% additivated fats were heated at varying temperatures (90, 120, 150, 180 and 210°C for 30 minutes) to follow quality alterations. Peroxide value (PV), thiobarbituric acid reactive substances test (TBARS), iodine value (IV), refractive index value (RIV), acid value (AV), saponification value (SV), and fatty acid (FA) content were determined to measure the degree of oxidative rancidity. Peroxide value was significantly (p <0.001) influenced by additivation and heating temperature. Thiobarbituric acid reactive substances values increased significantly (p <0.001) with heating temperature in all fats but were reduced by the addition of ascorbyl palmitate in the proportion of 0.05%. Strong positive correlations between PV and AV were found in chicken (r = 0.97; p <0.001) and turkey fat (r = 0.95; p <0.001). Total monounsaturated fatty acids (MUFA) was significantly affected by heating temperature both in chicken and turkey fat (to a greater extent in non-additivated fat). Statistical analysis of the data revealed that the development of rancidity in poultry fats subjected to heating at varying temperatures was significantly (p <0.01) reduced by the addition of ascorbyl palmitate in concentration of 0.05%.
Keywords: Chicken fat, turkey fat, antioxidant, heating, oxidation.

Keywords: Chicken fat. Turkey fat. Antioxidant. Heating. Hoxidation

1. INTRODUCTION

Frying is a popular method for the preparation of foods worldwide as it could be used for the fast preparation of products. Because of the large consumption of frying fats and oils, the effects of high temperatures on these fats are of major concern both for product quality and nutrition. Frying is delivering products with desirable sensory properties such as a crispy texture, golden crust, and unique fried food flavours in a short period of time [1]. However, at high frying temperatures, fats and oils are subjected to various chemical reactions which modify the flavour of the fried product and the quality of the remaining frying fat. Taste, flavour, shelf life, and consumer acceptance of fried food essentially depend on frying fat quality [2].
Alimentary animal fats are produced by melting raw material fats between a temperature range of 65-75°C, followed by filtration to remove solid impurities and water. In Romania, a major portion of these fats is used to cook and fry different foods.
There are nutritional reasons to use poultry fats in food preparation. Alimentary

animal fats are carriers of essential fatty acids and of the fat-soluble vitamins A, D, E and K. Fats also aid in the absorption of these vitamins and transport them and their precursors around the body. Dietary fats enhance the taste, smell, and texture of food, and they take longer to digest in the stomach than carbohydrates or proteins, thus causing a delay in the onset of hunger. In addition to providing energy, fats are the building blocks of phospholipids and glycolipids, which are essential components of cell membranes [3]. Several studies support the association between poultry fats consumption, within a balanced diet, and a reduction in the risk of developing cardiovascular diseases and their risk factors, such as overweight, insulin resistance, and tumours [4, 5].

Because of the high temperatures and atmospheric oxygen, reactions such as hydrolysis, oxidation, and polymerisation are produced. These reactions change and modify the chemical composition of the used frying fat, accelerating its degradation [6].

Animal fats are mostly saturated and monounsaturated fats, which means they stand up better to high heat and last longer than vegetable fats. Reduced oxidation in animal fats means they are less susceptible to the toxins and carcinogens generated by using vegetable oil. Because animal fats are more stable, foods cooked in them absorb less oil and less fat. It is well established that vegetable oils and foods containing unsaturated fatty acids are susceptible to atmospheric oxidation. As the concentration of highly unsaturated double bonds increases, the oil becomes more susceptible to oxidation and thermal degradation. Animal fats are safer and generate lowest amount of carcinogenic compounds than unsaturated oils [7].

In the thermal process, glycerides suffer partial hydrolysis, unsaturated fatty acids degrade by oxidation, and the glycerol is dehydrated and forms acrylic aldehyde. The hydrolysis derivatives, free fatty acids, mono- and diglycerides, present a higher speed of oxidation and reactivity than the original triacylglycerides, promoting alterations [8]. Oxidation of fats leads to the formation of aldehydes, ketones, free or oxidised fatty acids, dimerised triglycerides via oxygen bridges, etc. Oxidation is accelerated, in addition to temperature, by fat/air interface, the speed at which fat is absorbed by food, the presence of metals with a catalytic role and the type of fat [9, 10]. The cyclisation of fatty acid molecules is one of the main reactions produced due to intense thermal treatment. However, from a quantitative point of view, the most important group of alteration compounds are the dimers and the polymers of the triacylglycerides, and their formation is also catalysed by the high temperatures reached during the process [11]. During the autoxidation process, new changes appear such as organoleptic changes (flavour alteration, palatability, darkening), physical changes (increase in viscosity and scum formation), and chemical changes (formation of polymers, volatile compounds). The non-volatile compounds are retained in the fat, and therefore, the fried products absorb them, reaching the consumer [12].

The presence of antioxidants in frying fats can extend both the fry-life of the fats and the shelf-life of the fried products. A number of studies focused on the positive effects of the addition of plant extracts to frying fats and oils: oregano, rosemary, sage, tea, lavender and thyme [13 - 17]. Also, it has been reported that tocopherols show a rapid loss at frying temperatures due to their degradation, but α-tocopherol is less stable at high temperature than δ-tocopherol, while β- and ɣ-tocopherols degrade at an intermediate rate [12].

However, there is still a lack of systematic studies for evaluating the antioxidative activity of natural antioxidants in alimentary fried fats, and there are no studies regarding the effects of ascorbyl palmitate on the oxidative stability of chicken and turkey fats subjected to heating.

The purpose of this research was to investigate the effects of temperature and ascorbyl palmitate addition on the quality parameters of alimentary chicken and turkey fats subjected to heating. For the evaluation of fat stability and monitoring of deterioration during heating, methods used include peroxide value (PV), thiobarbituric acid reactive substances (TBARS), iodine value (IV), refractive index value (RIV), acid value (AV), saponification value (SV) and fatty acid (FA) content.

2. EXPERIMENTAL PART

2.1. MATERIALS

The research was conducted on two types of alimentary poultry fats: chicken and turkey fat. Chicken fat was collected from broilers, 10 weeks of age, male and female, from the Ross 308 breed and turkey fat was collected from poults, 28 weeks of age, male and female, from the Auburn Bronze breed. All birds were fed with a commercial protein diet, and from the third week, they also had access to vegetation. Poultry diets were based on corn and soybean meal, with small amounts of calcium, phosphorus, salt, vitamins, and trace minerals. The birds' diet was not supplemented with antioxidants or long-chain polyunsaturated fatty acids. Raw materials (abdominal fats) were collected immediately after slaughtering. A weight of approximately 500 g abdominal fat was cut into small pieces, heated at 65-75°C, centrifuged and filtered. Ascorbyl palmitate was dissolved in the melted fats (with up to 30 minutes stirring) in the same proportion of 0.05% (0.05 g/100 g of fat). Within each studied fat, one sample was used unheated. Approximately 50 g of fat were individually subjected to heating in an electric oven (FM11, Ariston, Fabriano, Italy) at 90, 120, 150, 180

and 210°C for 30 minutes. For each fat and heating temperature, we used glass vessels (90 cm^2 of exposure area with air). The cold samples were transferred to glass tubes and kept under refrigeration until analysis. For evaluation of fat stability and monitoring of deterioration during heating, methods included peroxide value (PV), thiobarbituric acid reactive substances (TBARS), iodine value (IV), refractive index value (RIV), acid value (AV), saponification value (SV) and fatty acid content. Three replications were carried out to examine each sample. All chemicals used were of analytical grade and obtained from Merck (Germany).

2.2. ANALYTICAL METHODS

2.2.1. Peroxide value (PV) determination

Peroxide value was determined using UV-VIS T60U spectrophotometer (Bibby Scientific, London, UK): operating temperature 5-45°C; field wavelength 190-1100 nm; wavelength accuracy 0.1 nm. This protocol was based on the spectrophotometer determination of ferric ions (Fe^{3+}) derived from the oxidation of ferrous ions (Fe^{2+}) by hydroperoxides, in the presence of ammonium thiocyanate (NH_4SCN). Thiocyanate ions (SCN^-) react with Fe^{3+} ions to give a red-violet homogeny that can be determined spectrophotometrically; the absorbance of each solution was read at 500 nm. To quantify PV, a calibration curve (absorbance at 500 nm vs. Fe^{3+} expressed in µg) was constructed. Peroxide value was expressed as meq O_2/kg fat [18].

2.2.2. Thiobarbituric acid reactive substances test (TBARS)

TBARS determination was carried out as follows: TBA Reagent (0.02 M 2-thiobarbituric acid in 90% glacial acetic acid) was prepared, then 1 g of fat sample was measured into a glass-stoppered test tube and 5 mL of TBA reagent was added. The tube was stoppered, and the contents were mixed. Then the tube was immersed in a boiling water bath for 35 minutes. A distilled water-TBA reagent blank was also prepared and treated like the sample. After heating, the sample was cooled in tap water for 10 minutes. A portion was transferred to a cuvette, and the optical density of the sample was read against the blank at a wavelength of 538 nm in a UV-VIS T60U model spectrophotometer. A standard curve was prepared by making appropriate dilutions of the 1×10^{-3} M 1,1,3,3-tetraethoxypropane standard solution, to give amounts ranging from 1×10^{-8} to 7×10^{-8} mol of malondialdehyde in 1 mL. These dilutions were reacted with TBA reagent and the optical densities were measured at the wavelength of 538 nm in the spectrophotometer. TBARS value was expressed as mg malondialdehyde (MDA)/kg fat [19].

2.2.3. Iodine value (IV) determination

Iodine value was determined according to the Hanus method. Approximately 0.5 g sample (dissolved in 15 mL CCl_4) was mixed with 25 mL Hanus solution (IBr) to halogenate the double bonds. After storing the mixture in the dark for 30 minutes, excess IBr was reduced to free I_2 in the presence of 20 mL of KI (100 g/L) and 100 mL distilled water. Free I_2 was measured by titration with 24.9 g/L $Na_2S_2O_3 \cdot 5H_2O$ using starch (1.0 g/100 mL) as an indicator. Iodine value was expressed as g I_2/100 g fat [18].

2.2.4. Refractive index value (RIV) determination

The values of the refractive index are conditioned by the nature and proportion of fatty acids. To determine the refractive index we used the PAL-RI (Tokyo, Japan) with the following technical characteristics: field: 1,3306-1,5284; resolution: 0.0001; accuracy: ±0.0003; measuring temperature: 5-45°C (resolution 1°C); measuring time: 3s; in accordance with the requirements of EMC Directive 93/68/EEC.

2.2.5. Acid value (AV) determination

The method consists in neutralising the fat acidity with 0.1 N sodium hydroxide using phenolphthalein as indicator. The acid value was expressed as g oleic acid/100 g fat [18].

2.2.6. Saponification value (SV) determination

Fifty millilitres of 4% KOH solution was added to approximately 5.0 g of fat and the mixture was gently boiled until the sample was completely saponified then was titrated with 0.5 N HCl in the presence of 1% phenolphthalein as indicator. Saponification value was expressed as mg KOH/g fat [18].

2.2.7. GC analysis

Fatty acid composition was determined using a Shimadzu GC-17 A gas chromatograph (Tokyo, Japan) coupled with a flame ionization detector. The gas chromatography column is Alltech AT-Wax, (60 mm × 0.32 mm × 0.5 µm), stationary phase (polyethylene); helium was used as a carrier gas at a pressure of 147 kPa, temperature of the injector and detector was set to 260°C. The oven program was the following: 70°C for 2 minutes, then the temperature was raised to 150°C with a gradient of 10°C/minute, a level of 3 minutes, and the temperature was raised to 235°C with a gradient of 4°C/minute. Identification and quantification of fatty acids (FA) were performed by comparison with standards. Results were expressed as g/100 g fat [18].

2.2.8. Statistical analysis

The effect of the heating temperature and antioxidant addition on peroxide value, thiobarbituric acid reactive substances, iodine value, refractive index value, acid value, saponification value, and fatty acid composition were analysed via factorial ANOVA using the General

Linear Model in Minitab 16.1.0 (LEAD Technologies, Inc., Charlotte, NC, USA). Three replications were carried out to examine each sample. Tukey's honest significance test was carried out at a 95% confidence level (p <0.05). Pearson's correlation (α=0.05) with two-tailed probability values was used to estimate the strength of association between chemical parameters.

3. RESULTS AND DISCUSSION

In the present study, the effect of ascorbyl palmitate added in concentration of 0.05%, on the oxidative stability and deterioration rates of two alimentary poultry fats (chicken and turkey) frequently utilised in Romania for culinary cooking, was determined under different heating temperatures (90, 120, 150, 180 and 210°C). Chemical analyses, such as, PV, TBARS, IV, RIV, AV, SV and fatty acid content were carried out to monitor fats quality. Chemical analysis results for animal fats and 0.05% additivated fats after subjected to heating are presented in Tables I-IV. Peroxide value is a measure of primary lipid oxidation, indicating the number of peroxides formed during oil oxidation. The products of lipid oxidation such as peroxides, free radicals, malonaldehyde, and other cholesterol oxidation products are reported to promote coronary heart disease and atherosclerosis [20].

Unheated animal fats showed lower values of the peroxide index. Peroxide value was significantly (p < 0.001) influenced by treatments: additivation and heating temperature (Tab. I). In chicken fat was found the highest level of PV (Tab. II) followed by the turkey fat (Tab. III). Regardless of the heating temperature, the highest PV level was found in non-additivated fat. The most intensive peroxide formation was found at 180°C, while over this temperature the decomposition was dominant.

The reason of this trend that peroxides are not heat-resistant, and high temperature lowers their concentration. During early heating, peroxides are characteristic, which are broken down at high temperatures. The decreasing tendency of PV in non-additivated animal fats due to the hydroperoxide generating effect of their melting pre-treatment, which was possibly broken down with heating temperature. According to Szabó *et al.* [21], the critical temperature at which peroxide decomposition occurs is about 190-200°C. Our results agree with this, as we found the most intensive peroxide formation at 180°C, while over this the decomposition was dominant.

Antioxidant application had a statistically significant (p < 0.001) effect on the PV of chicken and turkey fat samples. The results showed that turkey fat was more stable to heating, producing smaller amounts of peroxides. With higher heating temperatures, both fats become oxidised, with a higher degradation of polyunsaturated fatty acids and formation of oxidation compounds. The addition of ascorbyl palmitate in a proportion of 0.05% significantly retarded the development of oxidation products, but antioxidant activity decreased

Table I - Effects of fat type, additivation, and heating temperature on PV (meq O_2/kg fat), TBARS (mg MDA/kg fat), IV (g I_2/100 g fat), RIV (refractometric degrees), AV (g oleic acid/100 g fat), and SV (mg KOH/g fat)

Factor	PV	TBARS	IV	RIV	AV	SV
Type of fat						
Chicken fat	6.02^{a}	4.35^{a}	82.2^{b}	1.4609^{a}	0.57^{a}	197^{b}
Turkey fat	5.19^{b}	3.38^{b}	82.5^{a}	1.4579^{b}	0.50^{b}	199^{a}
p	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***
Additivation						
Non-additivated	5.80^{a}	4.23^{a}	82.0^{b}	1.4593^{a}	0.57^{a}	199^{a}
Additivated with 0.05% ascorbyl palmitate	5.40^{b}	3.50^{b}	82.7^{a}	1.4595^{a}	0.50^{b}	197^{b}
p	<0.001***	<0.001***	<0.001***	NS	<0.001***	< 0.001**
Heating temperature						
Unheated	1.95^{e}	0.98^{f}	84.9^{a}	1.4600^{ab}	0.22^{f}	195^{f}
90°C	3.00^{d}	1.67^{e}	84.2^{b}	1.4598^{ab}	0.33^{e}	196^{e}
120°C	5.08^{c}	2.78^{d}	83.3^{c}	1.4608^{a}	0.44^{d}	197^{d}
150°C	7.15^{b}	4.35^{c}	81.9^{d}	1.4590^{ab}	0.65^{c}	198^{c}
180°C	8.24^{a}	6.03^{b}	80.5^{e}	1.4586^{ab}	0.75^{b}	200^{b}
210°C	8.20^{a}	7.39^{a}	79.3^{f}	1.4582^{b}	0.83^{a}	202^{a}
p	<0.001***	<0.001***	<0.001***	< 0.05*	<0.001***	<0.001***

a) PV, peroxide value; TBARS, thiobarbituric acid reactive substances; IV, iodine value; RIV, refractive index value; AV, acid value; SV, saponification value.

b) Values are expressed as mean.

c) Different letters in the same column indicate statistically significant differences at p < 0.05 (Tukey's test). Significant differences are denoted by asterisks: $^{*}p$ < 0.05; $^{**}p$ < 0.01; $^{***}p$ < 0.001; $p \geq 0.05$, non-significant (NS).

Table II - Changes in quality parameters of chicken fat (non-additivated and additivated with 0.05% ascorbyl palmitate) subjected to heating at varying temperatures

Type of sample	Heating temperature	PV (meq O_2/kg fat)	TBARS (mg MDA/kg fat)	IV (g I_2/100 g fat)	RIV (refractometric degrees)	AV (g oleic acid/100 g fat)	SV (mg KOH/g fat)
Non-additivated	Unheated	2.16 ± 0.01^{i}	1.14 ± 0.02^{k}	85.4 ± 0.1^{a}	1.4615 ± 0.0001^{a}	0.24 ± 0.01^{h}	194 ± 0.0^{h}
	90°C	3.90 ± 0.73^{g}	2.62 ± 0.01^{i}	84.2 ± 0.1^{c}	1.4612 ± 0.0001^{a}	0.38 ± 0.02^{f}	195 ± 0.0^{f}
	120°C	5.86 ± 0.01^{e}	3.63 ± 0.02^{g}	82.8 ± 0.1^{e}	1.4608 ± 0.0071^{a}	0.52 ± 0.01^{e}	196 ± 0.0^{e}
	150°C	8.13 ± 0.02^{c}	5.42 ± 0.01^{e}	81.2 ± 0.1^{f}	1.4601 ± 0.0001^{a}	0.76 ± 0.01^{c}	198 ± 0.0^{c}
	180°C	9.23 ± 0.02^{a}	7.05 ± 0.01^{c}	79.6 ± 0.2^{g}	1.4596 ± 0.0001^{a}	0.83 ± 0.01^{b}	201 ± 0.0^{b}
	210°C	8.25 ± 0.02^{c}	8.54 ± 0.03^{a}	78.2 ± 0.1^{h}	1.4594 ± 0.0001^{a}	0.92 ± 0.01^{a}	203 ± 0.0^{a}
Additivated with 0.05% ascorbyl palmitate	Unheated	2.12 ± 0.02^{i}	1.11 ± 0.01^{k}	85.2 ± 0.1^{ab}	1.4615 ± 0.0001^{a}	0.22 ± 0.01^{h}	194 ± 0.0^{h}
	90°C	3.03 ± 0.01^{h}	1.85 ± 0.01^{j}	84.7 ± 0.1^{bc}	1.4612 ± 0.0001^{a}	0.31 ± 0.01^{g}	194 ± 0.0^{g}
	120°C	4.95 ± 0.02^{f}	2.74 ± 0.01^{h}	83.5 ± 0.2^{d}	1.4609 ± 0.0001^{a}	0.47 ± 0.02^{e}	195 ± 0.0^{e}
	150°C	7.11 ± 0.02^{d}	4.32 ± 0.02^{f}	82.2 ± 0.1^{e}	1.4604 ± 0.0001^{a}	0.62 ± 0.01^{d}	196 ± 0.0^{d}
	180°C	8.33 ± 0.01^{bc}	6.17 ± 0.02^{d}	80.8 ± 0.2^{f}	1.4601 ± 0.0001^{a}	0.77 ± 0.01^{c}	198 ± 0.0^{c}
	210°C	9.16 ± 0.01^{ab}	7.65 ± 0.01^{b}	79.3 ± 0.2^{g}	1.4597 ± 0.0001^{a}	0.83 ± 0.02^{b}	200 ± 0.0^{b}

a) PV, peroxide value; TBARS, thiobarbituric acid reactive substances; IV, iodine value; RIV, refractive index value; AV, acid value; SV, saponification value.
b) Values are expressed as mean ± standard deviation of three replicates for each parameter.
c) Different letters in the same column indicate statistically significant differences at $p < 0.05$ (Tukey's test).

Table III - Changes in quality parameters of turkey fat (non-additivated and additivated with 0.05% ascorbyl palmitate) subjected to heating at varying temperatures

Type of sample	Heating temperature	PV (meq O_2/kg fat)	TBARS (mg MDA/kg fat)	IV (g I_2/100 g fat)	RIV (refractometric degrees)	AV (g oleic acid/100 g fat)	SV (mg KOH/g fat)
Non-additivated	Unheated	1.77 ± 0.01^{j}	0.82 ± 0.01^{k}	84.7 ± 0.1^{a}	1.4587 ± 0.0001^{a}	0.22 ± 0.01^{h}	196 ± 0.0^{f}
	90°C	2.88 ± 0.02^{h}	1.23 ± 0.02^{i}	84.2 ± 0.1^{ab}	1.4585 ± 0.0000^{a}	0.34 ± 0.01^{fg}	197 ± 0.0^{e}
	120°C	5.14 ± 0.02^{f}	2.88 ± 0.01^{g}	83.3 ± 0.1^{bc}	1.4582 ± 0.0001^{a}	0.42 ± 0.01^{e}	199 ± 0.0^{d}
	150°C	7.24 ± 0.01^{c}	4.24 ± 0.02^{e}	81.7 ± 0.1^{de}	1.4576 ± 0.0001^{a}	0.66 ± 0.01^{c}	200 ± 0.0^{c}
	180°C	8.18 ± 0.02^{b}	5.97 ± 0.01^{c}	80.2 ± 0.1^{g}	1.4571 ± 0.0001^{a}	0.75 ± 0.02^{b}	202 ± 0.7^{b}
	210°C	6.93 ± 0.01^{d}	7.28 ± 0.01^{a}	79.2 ± 0.1^{h}	1.4565 ± 0.0000^{a}	0.83 ± 0.01^{a}	204 ± 0.0^{a}
Additivated with 0.05% ascorbyl palmitate	Unheated	1.76 ± 0.01^{j}	0.85 ± 0.01^{k}	84.5 ± 0.1^{a}	1.4586 ± 0.0000^{a}	0.21 ± 0.01^{h}	195 ± 0.0^{g}
	90°C	2.21 ± 0.02^{i}	0.99 ± 0.01^{j}	83.8 ± 0.7^{ab}	1.4585 ± 0.0000^{a}	0.29 ± 0.01^{g}	196 ± 0.0^{f}
	120°C	4.36 ± 0.03^{g}	1.86 ± 0.01^{h}	83.5 ± 0.1^{bc}	1.4583 ± 0.0000^{a}	0.37 ± 0.01^{ef}	197 ± 0.0^{e}
	150°C	6.13 ± 0.03^{e}	3.43 ± 0.01^{f}	82.6 ± 0.1^{cd}	1.4579 ± 0.0001^{a}	0.58 ± 0.01^{d}	199 ± 0.0^{d}
	180°C	7.23 ± 0.01^{c}	4.92 ± 0.01^{d}	81.4 ± 0.1^{ef}	1.4576 ± 0.0001^{a}	0.66 ± 0.02^{c}	200 ± 0.0^{c}
	210°C	8.46 ± 0.01^{a}	6.10 ± 0.02^{b}	80.7 ± 0.1^{fg}	1.4571 ± 0.0000^{a}	0.76 ± 0.01^{b}	202 ± 0.0^{b}

a) PV, peroxide value; TBARS, thiobarbituric acid reactive substances; IV, iodine value; RIV, refractive index value; AV, acid value; SV, saponification value.
b) Values are expressed as mean ± standard deviation of three replicates for each parameter.
c) Different letters in the same column indicate statistically significant differences at $p < 0.05$ (Tukey's test).

with temperature due to an increased rate of initiation reactions.

Several authors have reported an increase in PV of fats and oils during heating or frying [22 - 24]. The effect of temperature on the antioxidant activity of α- and δ-tocopherol in pork lard using the Oxipres apparatus was also studied [25]. The research showed that the activity of α-tocopherol was constant in the temperature range from 80 to 110°C and decreased with increasing temperature. Elhamirad and Zamanipoor [26] evaluated the temperature-dependent antioxidant activity of α-tocopherol, gallic acid, caffeic acid, and polyphenolic compounds during thermal oxidation of sheep tallow olein in a Rancimat. At 120°C, gallic and caffeic acids were more effective than the polyphenolic compounds, but at 180°C, quercetin was the most effective, catechin was comparable to gallic acid and more effective than caffeic acid. At all temperatures, the polyphenolic compounds were more effective than α-tocopherol. Song *et al.* [27] have studied the thermal oxidation of tallow and analysed the peroxide value, *p*-anisidine value (*p*-AV), acid value, and the volatile compounds produced in different oxidation conditions. The researchers reported that beef flavour precursors, such as hexanal, 1-octen-3-ol, (E,E)-2,4-decadienal and (E,E)-2,4-heptadienal, reached a maximum value when heated at 140°C for 2 h, whereas at the same temperature PV and *p*-AV were at high levels, and AV was relatively low.

TBARS is a measure of the number of secondary oxidation products (aldehydes, ketones, or other matrix compounds) present in the fat sample. As peroxide value, thiobarbituric acid reactive substances values increased significantly ($p < 0.001$) with heating temperature in all fats but were reduced by the addition of ascorbyl palmitate in the proportion of 0.05%.

Thiobarbituric acid reactive substances test increased from 1.14 to 8.54 mg MDA/kg in non-additivated chicken fat and to 7.65 mg MDA/kg in additivated chicken fat subjected to heating at varying temperatures; from 0.82 to 7.28 mg MDA/kg in non-additivated turkey fat and to 6.10 mg MDA/kg in additivated turkey fat subjected to heating. Thiobarbituric acid reactive substances test exceeded the limit (8 mg MDA/kg fat) in non-additivated chicken fat subjected to heating at 210°C. TBARS was significantly ($p < 0.001$) influenced by the type of fat, additivation, and heating temperature. Regardless of the heating temperature, the highest TBARS level was found in non-additivated fat. Strong positive correlations between PV and TBARS were found in chicken ($r = 0.94$; $p < 0.001$) and turkey fat ($r = 0.92$; $p < 0.001$).

The ability of some phenolic compounds to inhibit butter oxidation was evaluated by Soulti and Roussis [28]. The researchers monitored the thiobarbituric acid reactive substances and peroxide values during heating of butter at 50°C and at 110°C. They found that gallic acid, caffeic acid, and catechin, each at 80 mg/L, inhibited butter oxidation at 50°C to a degree equal to that of butylated hydroxyanisole at 200 mg/L, and gallic acid was more effective than butylated hydroxyanisole in inhibiting butter oxidation at 110°C. According to the study by Wanakamol and Poonlarp [29] the frying temperature, frying time, and frying cycles negatively affected the quality of vacuum fried pineapple chips as measured by thiobarbituric acid test, peroxide value, moisture content, and colour.

Refractive index value and iodine value are measures of the degree of unsaturation of fatty acids. Chicken fat presented a higher value of refractive index compared to turkey fat and the values decreased with the increase in heating temperature. Refractive index value was significantly influenced by the type of fat and heating temperature ($p < 0.001$ and $p < 0.05$, respectively) but not by the addition of ascorbyl palmitate. In chicken fat were found the highest levels of RIV and IV followed by the turkey fat. Regardless of the type of fat, the lowest level of RIV was found under heating at 210°C. Positive correlations between RIV and IV were found in chicken ($r = 0.83$; $p < 0.01$) and turkey fat ($r = 0.81$; $p < 0.01$).

Iodine index values decreased significantly ($p < 0.001$) with heating temperature for all types of fats. Iodine index values decreased from 85.4 to 78.2 g I_2/100 g in non-additivated chicken fat and to 79.3 g I_2/100 g in additivated chicken fat subjected to heating at varying temperatures; from 84.7 to 79.2 g I_2/100 g in non-additivated turkey fat and to 80.7 g I_2/100 g in additivated turkey fat subjected to heating. IV was significantly ($p < 0.001$) influenced by the type of fat, additivation, and heating temperatures. The decrease of RIV and IV levels indicates a reduction of the unsaturation degree of fatty acids. Strong negative correlations between IV and TBARS were found in chicken ($r = -0.99$; $p < 0.001$) and turkey fat ($r = -0.98$; $p < 0.001$). In the study by Farhooshi and Moosavi [30], ethanolic extract of citrus peel was added to palm olein at 0.2% concentration and used to fry fish crackers at 180°C for 5 h per day for 4 consecutive days. Analyses of iodine value, peroxide value, totox value, and viscosity indicated strong antioxidant and antipolymerisation effects of the citrus peel extract.

Free acidity represents an analytical parameter which is used to evaluate the hydrolysis extension in fats during the thermal process. An increase in this parameter indicates a higher presence of free fatty acids in the animal fat, a direct consequence of hydrolysis, and it is an important indicator of fat chemical deterioration. Turkey fat presented a lower content of free fatty acids compared to chicken fat. The AV of the different fats increased in parallel with the heating intensity and the rate of increase tended to slow down at the highest temperatures. Chicken fat and additivated chicken fat

Table IV - Changes in fatty acid content (g/100 g fat) of alimentary poultry fats subjected to heating at 210°C

Fatty acids	Chicken fat			Turkey fat		
	Non-additivated (control)	Non-additivated fat subjected to heating at 210°C	Ascorbyl palmitate additivated fat subjected to heating at 210°C	Non-additivated (control)	Non-additivated fat subjected to heating at 210°C	Ascorbyl palmitate additivated fat subjected to heating at 210°C
Myristic (14:0)	$0.32^{a} \pm 0.10$	$0.55^{b} \pm 0.05$	$0.37^{a} \pm 0.05$	$0.54^{a} \pm 0.04$	$0.71^{ab} \pm 0.06$	$0.88^{b} \pm 0.09$
Pentadecanoic (C15:0)	$0.54^{a} \pm 0.14$	$0.69^{ab} \pm 0.07$	$0.59^{a} \pm 0.04$	$0.66^{a} \pm 0.06$	$0.85^{b} \pm 0.01$	$0.89^{b} \pm 0.02$
Palmitic (C16:0)	$0.64^{a} \pm 0.12$	$0.73^{a} \pm 0.12$	$0.61^{a} \pm 0.12$	$1.19^{a} \pm 0.10$	$1.16^{a} \pm 0.08$	$1.28^{a} \pm 0.13$
Palmitoleic (C16:1)	$1.83^{a} \pm 0.03$	$1.43^{b} \pm 0.02$	$1.60^{b} \pm 0.07$	$1.79^{a} \pm 0.13$	$1.86^{a} \pm 0.13$	$1.85^{a} \pm 0.11$
Hexadecadienoic (C16:2)	$0.76^{a} \pm 0.08$	$0.60^{a} \pm 0.09$	$0.62^{a} \pm 0.06$	$0.79^{a} \pm 0.05$	$0.46^{b} \pm 0.11$	$0.35^{b} \pm 0.04$
Hexadecatrienoic (C16:3)	$0.54^{a} \pm 0.04$	$0.31^{b} \pm 0.10$	$0.49^{a} \pm 0.08$	$0.57^{a} \pm 0.02$	$0.32^{ab} \pm 0.12$	$0.22^{b} \pm 0.09$
Hexadecatetranoic (C16:4)	$0.57^{a} \pm 0.11$	$0.36^{ab} \pm 0.15$	$0.56^{a} \pm 0.13$	$0.18^{a} \pm 0.06$	$0.16^{a} \pm 0.01$	$0.15^{a} \pm 0.01$
Heptadecanoic (C17:0)	$0.52^{a} \pm 0.05$	$0.65^{ab} \pm 0.06$	$0.58^{a} \pm 0.09$	$0.88^{a} \pm 0.03$	$1.01^{ab} \pm 0.05$	$1.13^{b} \pm 0.05$
Stearic (C18:0)	$0.34^{a} \pm 0.09$	$0.33^{a} \pm 0.08$	$0.31^{a} \pm 0.11$	$0.94^{a} \pm 0.09$	$1.08^{a} \pm 0.02$	$1.08^{a} \pm 0.15$
Oleic (C18:1)	$1.48^{a} \pm 0.13$	$1.21^{ab} \pm 0.03$	$1.44^{a} \pm 0.05$	$2.26^{a} \pm 0.14$	$1.89^{ab} \pm 0.09$	$2.18^{a} \pm 0.13$
Linoleic (C18:2)	$0.64^{a} \pm 0.04$	$0.44^{b} \pm 0.08$	$0.49^{b} \pm 0.08$	$0.43^{a} \pm 0.11$	$0.32^{ab} \pm 0.07$	$0.38^{a} \pm 0.10$
Linolenic (C18:3)	$0.55^{a} \pm 0.06$	$0.43^{b} \pm 0.01$	$0.45^{ab} \pm 0.01$	$0.28^{a} \pm 0.12$	$0.17^{ab} \pm 0.03$	$0.25^{a} \pm 0.11$
Stearidonic acid (C18:4)	$0.79^{a} \pm 0.15$	$0.55^{b} \pm 0.04$	$0.82^{a} \pm 0.13$	$0.09^{a} \pm 0.05$	$0.06^{a} \pm 0.06$	$0.08^{a} \pm 0.07$
Total FA	$9.58^{a} \pm 0.95$	$8.29^{b} \pm 0.90$	$8.41^{b} \pm 1.03$	$10.58^{a} \pm 0.88$	$10.07^{b} \pm 0.67$	$10.75^{a} \pm 1.09$
Total SFA	$2.33^{a} \pm 0.32$	$2.57^{ab} \pm 0.32$	$2.38^{a} \pm 0.40$	$4.20^{a} \pm 0.32$	$4.98^{ab} \pm 0.06$	$4.93^{ab} \pm 0.44$
Total MUFA	$2.37^{a} \pm 0.16$	$3.08^{c} \pm 0.05$	$2.63^{b} \pm 0.12$	$4.07^{a} \pm 0.27$	$3.65^{b} \pm 0.22$	$4.03^{a} \pm 0.23$
Total PUFA	$3.88^{a} \pm 0.48$	$2.64^{c} \pm 0.47$	$3.40^{b} \pm 0.50$	$2.31^{a} \pm 0.30$	$1.44^{c} \pm 0.40$	$1.79^{b} \pm 0.42$

[a] FA, fatty acids; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.
[b] Values are expressed as mean ± standard deviation of three replicates for each parameter.
[c] For each type of animal fat, different letters in the same row indicate statistically significant differences at $p < 0.05$ (Tukey's test).

had higher AVs compared to turkey fats for all heating temperatures. AV was significantly (p <0.001) influenced by the type of fat, additivation, and heating temperature. Regardless of the heating temperature, the highest AV level was found in non-additivated fat. Regardless of the type of fat, the highest level of AV was found under heating at 210°C. Acid value increased from 0.24 to 0.92 g oleic acid/100 g in non-additivated chicken fat and to 0.83 g oleic acid/100 g in additivated chicken fat subjected to heating at varying temperatures; from 0.22 to 0.81 g oleic acid/100 g in non-additivated turkey fat and to 0.76 g oleic acid/100 g in additivated turkey fat subjected to heating. Strong positive correlations between AV and PV were found in chicken (r = 0.97; p <0.001) and turkey fat (r = 0.95; p <0.001).

Szabó *et al.* [21] also reported an increase in the acid value of Mangalica pig and goose fat subjected to heating at seven temperatures (140, 150, 160, 165, 170, 175 and 180°C). Gertz *et al.* [20] studied thermooxidative structural changes of fats and oils at ambient temperatures, under accelerated conditions using 110°C and under frying temperature of 170°C and showed that Rancimat test at 110°C had a strong negative correlation with the iodine value and a weak correlation between acid value and anisidine value was recorded. The effect of the rosemary extract and 2,6-di-*t*-butyl-*p*-hydroxytoluene (BHT) on the quality of fried Escolar fish fillets was studied by Sarabi *et al.* [31]. The research showed that rosemary extract retarded oxidative changes to a better extent than BHT.

Saponification value indicates the average molecular weight of lipids. Oxidative rancidity causes the formation of aldehydes and ketones via fatty acids oxidation and thus an increase in SV. Strong positive correlations between SV and AV were found in chicken (r = 0.93; p <0.001), and turkey fat (r = 0.96; p <0.001). Saponification value was significantly (p <0.001) influenced by all treatments. SV increased significantly with heating temperature in chicken and turkey fat (p <0.001, respectively p <0.01). Patel *et al.* [32] reported a significant improvement in the stability of clarified butterfat fortified with 0.5% commercial steam distilled coriander extract and oleoresin in a model frying of wet cotton balls at 180°C. The steam distilled extract exhibited better performance than the oleoresin based on the determination of conjugated dienes, thiobarbituric acid value, peroxide value, saponification value, and the Rancimat at 120°C of the fried oils. Réblová *et al.* [33] studied the prooxidant capacity of rapeseed, sunflower, soybean, and olive oil before and after heating at a temperature of 180°C for 2, 4, and 6 hours. The researchers determined that prooxidant capacity of the heated oils ranged from 58 mg to 360 mg α-tocopherol/kg, it did not correlate with the content of polymerised triacylglycerols and was generally higher than the residual content of α-tocopherol.

Fatty acid content in chicken and turkey fat, before and after subjected to heating at 210°C are shown in Table IV. Between fatty acids, oleic (C16:1), palmitoleic (C18:1), and palmitic (C16:0) are the most abundant in turkey fat; palmitoleic (C18:1) and oleic (C16:1) in chicken fat. In turkey fat, saturated fatty acids (SFA) predominate, but in chicken fat monounsaturated fatty acids (MUFA). Conversely, the highest level of polyunsaturated fatty acids (PUFA) was noticed in chicken fat, followed by the turkey fat.

The high-temperature heating treatment led to an increase in total SFAs from 2.33 (g/100 g fat) in control to 2.57 in non-additivated chicken fat subjected to heating at 210°C, and from 4.20 in control to 4.98 in non-additivated turkey fat subjected to heating at 210°C. The total PUFAs decreased from 3.88 in control to 2.64 in non-additivated chicken fat subjected to heating at 210°C, and from 2.31 in control to 1.44 in non-additivated turkey fat subjected to heating at 210°C. The heating of fats at 210°C did not significantly change the composition of palmitic and stearic acids, while a significant increase in the composition of myristic and heptadecanoic acids was determined. The heat treatment of fats induces modifications of unsaturated fatty acids, these may undergo isomerization from cis to the trans form. Such formation of trans fatty acids has been observed during thermal treatment of chicken fat [34].

Considering that the highest levels of RIV and IV were found in chicken fat, its poor stability compared to turkey fat can be thus explained.

Total MUFAs was significantly affected by heating temperature both in chicken and turkey fat (to a greater extent in non-additivated fat). Taking into account that in chicken fat was found the highest level of PV, the decrease of total MUFA may be due to the oxidation of monounsaturated fatty acids.

Palmitoleic acid (C18:1) significantly decreased in chicken fat subjected to heating at 210°C (with 0.42 units) and 0.05% additivated fat subjected to heating at 210°C (with 0.23 units).

Linolenic acid (C18:3), which is a polyunsaturated fatty acid, also decreased significantly in chicken fat subjected to heating at 210°C (with 0.19 units) and additivated fat subjected to heating at 210°C (with 0.11 units).

Heating temperature showed to be most correlated with MUFA for chicken (r = 0.91), followed by the turkey fat (r = 0.84). The fatty acid profile of the heated fats changed as a result of cyclization, polymerization and hydrolytic, oxidative and other chemical reactions promoted by heat treatment [35].

Ascorbyl palmitate was an effective antioxidant and provided good protection against oxidation of poultry fats; it can be used to monitor the oxidation of fats and to predict their shelf life stability.

4. CONCLUSIONS

Lipid oxidation in alimentary poultry fats varied with the heating temperature, type of fat and antioxidant addition. Peroxide value and thiobarbituric acid reactive substances values increased significantly with heating temperature in all fats but were reduced by the addition of ascorbyl palmitate in the proportion of 0.05%. The results showed that turkey fat was more stable to heating, producing smaller amounts of peroxides. Peroxide value, thiobarbituric acid reactive substances, acid value, and saponification value were significantly (p <0.001) influenced by the type of fat, additivation, and heating temperature.

Total MUFAs was significantly affected by heating temperature both in chicken and turkey fat (to a greater extent in non-additivated fat). Statistical analysis of the data revealed that the development of rancidity in poultry fats subjected to heating at varying temperatures was significantly (p <0.01) reduced by the addition of ascorbyl palmitate in concentration of 0.05%.

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