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ORIGINAL PAPER

EFFECT OF METAL IONS FROM *GINKGO BILOBA* EXTRACTS ON THE OXIDATIVE STABILITY OF RAPESEED OIL AND ITS TRIACYLGLYCEROLS*

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Abstract

Total antixodative effect is difficult to predict because the total antiradical capacity depends not only on properties of individual compounds, but also on their mutual interactions. The study examined the effect of the addition of *Ginkgo biloba* antioxidants to refined rapeseed oil on the stabilization of the oil and its triacylglycerols, measured by an Oxidograph accelerated oxidative stability test and the Rancimat test. The mineral composition of oil was also determined. The tested samples were observed to respond differently in terms of the induction period, which was the longest periods for ethanolic extracts, and the shortest for aqueoeus ones. The highest values of the protective factor were observed in the samples with added ethanolic extract of green leaves, while the lowest ones were noted in all aqueous extracts. In all the tested samples, values of the protection factor increased along with the growing extract concentration in a sample. Among the tested additives, butylated hydroxytoluene added to a sample of oil resulted in the longest induction period. Among the analysed microelements, iron was the prevalent one, with its concentration being significantly higher in water extracts. The least abundant was selenium. The antioxidative capacity of *Ginkgo biloba* extract resulted from the presence of transitional metals and polyphenols, as the presence of zinc, copper and iron affects the bioavailability of flavonoids. Negative relationships were noted between microelements in the extracts and its oxidative stability, which indicated the oxidative activity of the former. *G. biloba* extracts may be a new source of stabilising additives for high-fat foods. However, further

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reasearch I needed to confirm this assumption, particularly because food is a complex matrix, in which ingredients might interact with one another, causing higher or lower antioxidative capacity.

Keywords: *Ginkgo biloba*, minerals, lipid, oil, antioxidants, triacylglycerol.

INTRODUCTION

Ginkgo biloba originates from China, where it has long been used as an ingredient in tradtional Chinese medicine. Currently, it is cultivated in various parts of the world due to the high demand for its extract, which is used as a dietary supplement. In France and Germany, *G. biloba* extracts are available as medicine for people suffering from cerebral ischemia, intermittent claudication and stupor (Lee, Birks 2018). Standard *G. biloba* extracts significantly limit behavioural and psycological symptoms of dementia (Savaskan et al. 2018). Although *Ginkgo biolba* is usually recommended for treatment of neurodegenerative diseases, recent papers have shown its beneficial action against tittinus, cardiovascular diseases and dyslipidemia (Mahmoudian-Sani et al. 2017, Tian et al. 2017, Fan et al. 2018). Moreover, *G. biloba* extracts can be used as an ergogenic agent. The properties of *G. biloba* result from its high polyphenols content. Standard extracts of this plant may contain over 60 bioactive compounds, including quercetin and kaempferol, which directly scavenge free radicals and indirectly reduce free radical fromation by inducing the activity of P450 cytochrom (Sadowska-Krępa et al. 2017). Studies show that antioxidative capacity of flavonoids is not limited solely to free radicals, but is also connected with chaletion of metal ions. Metal ion chelation plays a key role in preventing the generation of reactive oxygen species (Farooqui, Farooqui 2018). Bioacumulation of metals, especially iron, copper, lead and mercury, leads to oxidative stress and cellular disorders, finally causing organs damage. Oxidative stress, induced by the presence of metals, disrupts the functioning of cell memebranes, as well as inducing H_2O_2 synthesis, lipid peroxidation and protein oxidation (Singh et al. 2019).

Raw materials

The material for the research consisted of leaves of *G. biloba* cv. Hipokrates collected at a Poznań University of Life Sciences plantation (Baranowo, Poland 52°44′E 16°78′N). Leaves were collected in August (green leaves) and October (yellow leaves), dried at 50°C, and then ground in a Grindomix GM 200 from Retsch (Haan, Germany) for 15 s at a speed of 500 rpm at 21°C. The 0.8 - 0.09 mm fraction was subjected to further analyses.

The basic chemical composition of the raw material was assayed according to the methods by Gramza-Michałowska et al. (2016). Green dried leaves (A) contained: dry mass 87.92 ± 0.42%, ash 12.19 ± 0.36%, fats 4.34 ± 0.09%,

proteins 8.1 ± 0.08% and yellow dried leaves (B): dried mass 91.16 ± 0.01%, ash 12.99 ± 0.02%, fats 5.50 ± 0.10%, proteins 2.4 ± 0.04%. All assays were performed in triplicate.

Dried and ground leaves were extracted with water (W), acetone-water solution (A) (3:2 v v^{-1}) and (96%) ethanol (E) (Sigma-Aldrich, Germany) at a ratio of 2 g dried leaves per 100 ml of the extractant. Single extraction was carried out at a set time and temperature, and next the extract was centrifuged for 5 min at 4500 rpm. For futher studies, clarified supernatant was collected and either evaporated or freeze-dried, and finally stored until analysis in the presence of nitrogen in dark containers at 4 ± 1°C.

Extraction parameters (time and temperature) were selected based on the references and own preliminary studies.

Rapeseed oil and triacylglycerols

In an Oxidograph test, rapeseed oil and triacylglycerol fractions were separated with the help of activated carbon and aluminium oxide.

Native antioxidants from rapeseed oil were separated according to a modified method propsed by Shin et al. (2019) before an Oxidograph test. Oil was dissolved in hexane (1:3 v v^{-1}) and eluted through a preparatory column filled with activated carbon, Al_2O_3 activated at 300°C and anhydrous sodium sulfate (Bilska et al. 2019). The column and receiving flask were wrapped in aluminum foil to protect against daylight. Next, hexan was evaporated in a vacuum evaporator (RVO 200A, Ignos, the Czech) at a temp. of 40°C. After this stage, triacylglycerols (TAG) were stored in modified atmosphere (nitrogen).

Fatty acid composition was analysed according to Bilska et al. (2019); the composition (%) of rafinated rapeseed oil was as follows: oleic acid (18:1) 60.69 ± 0.51, linoic acid (18:2) 19.32 ± 0.39, linoleic acid (18:3) 11.51 ± 0.07, palimitic acid (16:0) 4.45 ± 0.02, stearic acid (18:0) 1.70 ± 0.03, erucic acid (22:1) 1.20 ± 0.14, arachidic acid (20:0) 0.58 ± 0.02, behenic acid (22:0) 0.33 ± 0.01 and oleopalmitic acid (16:1) 0.22 ± 0.01.

Oxidograph test

An oxidograph appartus (Mikrolab, Denmark) was used to measure the amount of oxygen absorbed by 5 g oil or triacylglycerols incubated in 110°C. Oxidation o fats resulted in a pressure drop in the reaction flask, which was registered by the detectors as a fucntion of the induction time. An instant curve deviation was considered to indicate fat oxidation. Anti-radical efficiency of the tested extracts was given analogically as in the Rancimat test, in W_0 protection factor units.

Mineral composition

The content of Fe, Zn, Cu, Cr and Mg was determined on an absorbtion atomic spectroscometer AAS-3 (Zeiss), according to XIE et al. (2008). Extract samples were mineralised in quartz pots in a muffle furnace at a temp. of 500°C. The resulting white ash was dissolved in warm 1N HNO_3. The solution thus obtained was filtered, transfered quantitavely to 50 ml volummetric flasks, and replenished with nitrogenous acid. The results were given in mg or μg g^{-1} of dry matter in the extract. The selenium content (Se) was determined using an AA Varian Spectra 200 Plus flame absorbation atomic spectrometer. The results were given in μg 100 g^{-1} of dry matter in the extract.

The analytical methods were validated by perfoming analysis of certified reference material INCT-TL-1 Tea Leaves. The determined content of minerals tested in the study was between 95.2 to 98.6% of the certified content.

Statistical analysis

Statistical analysis was performed using Statistica™ PL 13.0 (StatSoft, Poland) software. Basic descriptive statistics were calculated for individual parameters. Mean values of each variable were compared with the help of variance analysis for a set of various number of observations, and significant differences were assessed with the Tukey's and Spjtvoll's (the Tukey's test for variables with various number of repetitions) tests.

In order to determine the strengh of relationships between the variables, the Pearson's linear correlation factor was calculated. Significance of the correlation factor was validated with *t*-Student test at a relevance level α=0.05.

RESULTS

Our analyses of the content of the metals content demonstrated considerable deviations between the extracts in the amounts of both macro- and micronutrients (Table 1). Iron, with its content ranging from 11.00 μg g^{-1} DM in AE sample to 95.86 μg g^{-1} DM in AW, dominated among the analysed microelements. Selenium was found to be the least abundant. However, its content was higher in ethanolic extracts (1.01 μg 100 g^{-1} DM in BE and 0.74 μg 100 g^{-1} DM in AE) than in aqueous ones (0.59 μg 100 g^{-1} DM in AW and 0.96 μg 100 g^{-1} DM in BW). Acetone-water extracts had the least selenium. Statistical analyses showed that the applied extractant significantly affected the total amount of extracted microelements (p<0.05). The total extracted microelements in aqueous extracts of green leaves made up 200.37 μg g^{-1} DM, which was 2.7-fold higher than in the aceton-water extract and 5.4-fold higher than in the ethanolic extract. The aqueous extract of yel-

Table 1

Content of selected microelements in *G. biloba* extracts

Extract	Fe (μg g^{-1} DM)	Zn (μg g^{-1} DM)	Cu (μg g^{-1} DM)	Cr (μg g^{-1} DM)	Se (μg 100 g^{-1} DM)	Mg (mg g^{-1} DM)
AW	$95.86^{e} \pm 0.33$	$39.28^{f} \pm 0.66$	$49.94^{e} \pm 0$	$15.28^{f} \pm 0$	$0.59^{b} \pm 0.03$	$13.97^{c} \pm 0.06$
AA	$35.76^{c} \pm 0.02$	$22.76^{e} \pm 0.05$	$5.62^{b} \pm 0$	$9.20^{e} \pm 0$	$0.49^{a} \pm 0.02$	$6.45^{b} \pm 0.33$
AE	$11.00^{a} \pm 0.18$	$8.98^{a} \pm 0.93$	$13.00^{c} \pm 0$	$3.99^{c} \pm 0$	$0.74^{d} \pm 0.04$	$0.18^{a} \pm 0.02$
BW	$69.66^{d} \pm 0.41$	$18.77^{d} \pm 0.65$	$17.90^{d} \pm 0$	$5.30^{d} \pm 0$	$0.96^{e} \pm 0.05$	$16.15^{d} \pm 0.18$
BA	$29.39^{b} \pm 0$	$15.75^{c} \pm 0$	$6.87^{b} \pm 0$	$3.18^{b} \pm 0$	$0.62^{c} \pm 0.03$	$7.79^{b} \pm 0.41$
BE	$62.06^{d} \pm 0$	$12.05^{b} \pm 0$	$0.30^{a} \pm 0$	$2.06^{a} \pm 0$	$1.01^{f} \pm 0.05$	$0.34^{a} \pm 0$

Mean values marked with lower-case letters in the same column indicate significant differences at $p \leq 0.05$. AW – water extract of green dried leaves, AA – acetone-water extract of green dried leaves, AE – ethanol extract of green dried leaves, BW – water extract of yellow dried leaves, BA – acetone-water extract of yellow dried leaves, BE – ethanol extract of yellow dried leaves.

low leaves contained twofold more micronutrients than BA (55.20 μg g^{-1} DM), and 1.5-fold higher than BE (76.47 μg g^{-1} DM).

The content of magnesium in the tested *G. biloba* extracts differed significantly depending on the applied extractant, while the ripeness stage of leaves hada weaker influence on this parameter. The highest magnesium content was observed in the BW extract (36.16 mg g^{-1} DM), while the lowest one was determined in AE (0.12 mg g^{-1} DM).

Aqueous extracts of green and yellow leaves had the highest concentration of elements able to catalyse the ROS generation process *in vivo*, i.e. iron and copper. Also, they were the richest in magnesium. On the other hand, AW was the richest in zinc, an element which may act as an antioxidative agent. Ethanolic extracts were observed to contain little amounts of magnesium but the highest content of selenium and zinc. A similarly high zinc content was determined in acetone-water extracts. Yellow leaves were richer in selenium than green ones.

Antixodative properties of *G. biloba* extracts were detremined in a lipid medium in an Oxidograph test. The induction period and protection factor values are presented in Table 2.

The results confirmed antioxidative properties of *Ginkgo biloba* extracts. The longest induction times of rapeseed oil were determined in samples of ethanolic extracts, and the shortest ones were identified for aqueous extracts. The highest protection factors were measured for the oil samples with added AE at concentrations 200 ppm (1.61) and 500 ppm (1.67). The least efficient was the addition of AW and BW, where W_0 ranged between 1.12 - 1.28. In all the tested samples, the protection factor declined along with an increase in the concentration of an extract. However, among the tested additives, butylated hydroxytoluene (BHT) resulted in the longest induction period for enriched samples (9.35), 90% longer than the control.

Table 2

Effect of the addition of *G. biloba* extract on rapeseed oil stability

Extract	Induction period (h)		Protection factor	
	200 (mg kg^{-1})	500 (mg kg^{-1})	200 (mg kg^{-1})	500 (mg kg$^{-1)}$
AW	$5.57^{b} \pm 0.10$	$6.53^{a} \pm 0.30$	$1.09^{a} \pm 0.02$	$1.28^{a} \pm 0.06$
AA	$5.82^{c} \pm 1.33$	$8.30^{cd} \pm 1.18$	$1.14^{b} \pm 0.27$	$1.63^{cd} \pm 0.24$
AE	$8.23^{f} \pm 0.12$	$8.50^{d} \pm 0.36$	$1.61^{e} \pm 0.02$	$1.67^{d} \pm 0.07$
BW	$6.08^{d} \pm 0.33$	$6.48^{a} \pm 0.16$	$1.19^{c} \pm 0.07$	$1.27^{a} \pm 0.03$
BA	$5.80^{c} \pm 0.51$	$7.97^{b} \pm 0.13$	$1.14^{b} \pm 0.10$	$1.56^{b} \pm 0.03$
BE	$7.57^{e} \pm 0.12$	$8.20^{c} \pm 1.51$	$1.48^{d} \pm 0.02$	$1.61^{c} \pm 0.30$
BHT	$9.35^{g} \pm 0.53$	na	$1.83^{f} \pm 0.11$	na
Control	$5.10^{a} \pm 0.61$			

Mean values marked with lower-case letters in the same column indicate significant differences at $p \leq 0.05$, na – not analysed

Antioxidants were also added to triacylglycerols isolated from rapeseed oil. In oil purified off its native antioxidants, the highest protection value was observed in samples with the addition of acetone-water extracts at concentrations of 200 and 500 mg kg^{-1} (AA – 1.72 and 2.27; and BA - 1.68 and 1.99, respectively), while the lowest ones were determined for aqueous extracts. An increase from 200 to 500 mg kg^{-1} affected the predicted growth of the induction period in each sample.

Statistical analysis was performed to relate antioxidative properties of the *G. biloba* extracts in rapeseed oil systems with selected extract ingredients (Table 3).

It was noted that the antioxidative activity of the tested extracts was negatively correlated with the content of iron, copper, zinc and also magnesium. Moreover, a strong negative correlation was found between the chromium content and results of the Oxidograph test for pure triacylglycerols (Table 4).

The opposite location of protection factors as well as induction factors in order to Cr, Zn, Mg, Cu and Fe show that the correlations describing them are negative. The grouping of plots describing samples of ethanolic and acetone-water extracts suggest that differences in amounts of the analysed compounds in extracts depend on these extractants (Figure 1.)

DISCUSSION

The content of iron and copper is essential to fat stability, since these microelements may catalyse oxidation processes. Their availability induces the generation of a hydroxyl radical, the most harmful reactive oxygen species. On

Table 3

Effect of addition of extracta of *G. biloba* leaves on the stability of triacylglycerides in rapeseed oil

Extract	Induction period (h)		Protection factor	
	200 (mg kg^{-1})	500 (mg kg^{-1})	200 (mg kg^{-1})	500 (mg kg^{-1})
AW	$4.47^{a} \pm 0.41$	$5.02^{a} \pm 0.10$	$0.96^{a} \pm 0.09$	$1.08^{a} \pm 0.02$
AA	$7.95^{d} \pm 1.07$	$10.52^{e} \pm 0.71$	$1.72^{d} \pm 0.23$	$2.27^{e} \pm 0.15$
AE	$5.95^{c} \pm 0.18$	$6.17^{b} \pm 0.08$	$1.29^{c} \pm 0.04$	$1.33^{b} \pm 0.02$
BW	$4.87^{b} \pm 0.08$	$5.07^{a} \pm 0.10$	$1.05^{b} \pm 0.02$	$1.09^{a} \pm 0.02$
BA	$7.77^{d} \pm 1.50$	$9.23^{d} \pm 0.88$	$1.68^{d} \pm 0.32$	$1.99^{d} \pm 0.19$
BE	$5.83^{c} \pm 0.43$	$8.10^{c} \pm 0.93$	$1.26^{c} \pm 0.09$	$1.75^{c} \pm 0.20$
BHT	$11.13^{e} \pm 1.36$	na	$2.40^{e} \pm 0.29$	na
Control	$4.63^{b} \pm 0.53$			

Mean values marked with lower-case letters in the same column indicate significant differences at $p \leq 0.05$, na – not analysed.

Table 4

Correlations between the content of elements in *G. biloba* extracts and their activity (protection factor) in rapeseed oil and triacylglicerols matrix

Matrix	Fe	Zn	Cu	Cr	Se	Mg
Oil	-0.85	-0.66	-0.70	-	-	-0.73
TAG	-0.60	-0.71	-0.84	-0.52	-	-0.83

TAG – triacylglycerols. Correlation coefficient values are significant at the relevance level α=0.05.

the other hand, zinc acts as an antioxidant, a fact observed in numerous studies Jarosz et al. (2017), Narasimhaiah et al. (2018). Similar antioxidative properties are demonstrated by selenium, which in this study was determined to appear at small amounts. Many authors have indicated that chromium may accelerate fat oxidation by catalysing the decomposition of lipid peroxides into free radicals (Iztleuov et al. 2017). However, our experiment on *G. biloba* leaves suggests that chromium ions improved the capacity of *G. biloba* extracts owing to their chelation by molecules of flavonoids (Bajpai et al. 2017). Moreover, some complexes of iron with flavonoids may inhibit the Fenton-type reaction, which is a major source of hydroxyl radicals and which is catalysed by ferrous and cupric cations. Quercetin, which is a genoprotective agent, may also act as a protective agent in an even of an iron overdose. It was observed that the quercetin-copper complex might be intercalated into the DNA (Babenkova et al. 2018, Xiao et al. 2018). Moreover, research showed that as the molar ratio between the metal and quercetin DPPH increases, so does the quenching capacity. However, a decrease in the antiradical capacity was noted when the metal content was significantly higher (Jomova et al. 2017, Trifunschi, Munteanu 2018).

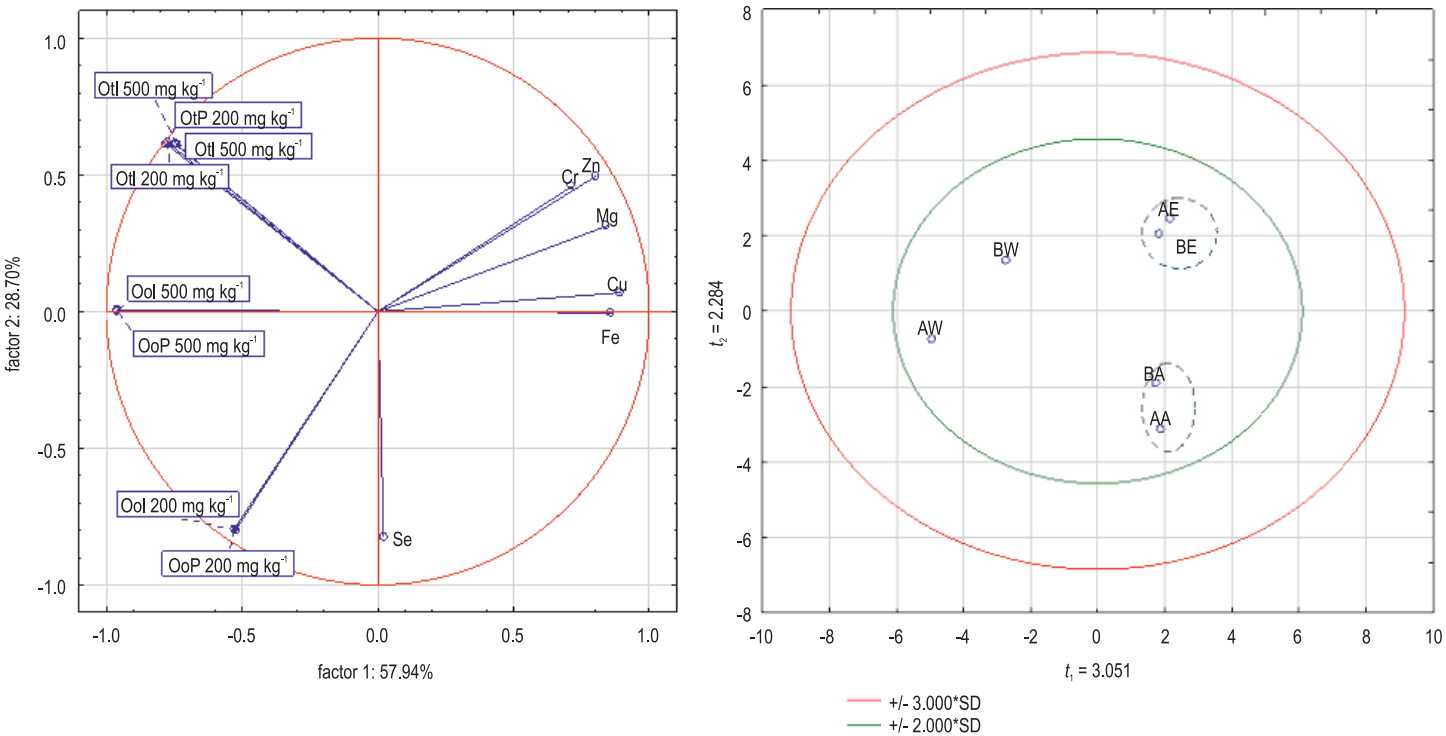

Fig. 1. Principal component analysis (PCA) of induction period, protection factor and minerals in *Ginkgo biloba* extracts: OoI – induction period for rapeseed oil, OoP – protection factor for rapeseed oil, OtI – induction period for TAG, OtP – protection factor for TAG

Lysiuk et al. (2018) underlined that the content of macro- and microelements in plant tissues depends on growing conditions and plant varieties. Differences in the content of elements are also an individual feature. Significant differences were observed in the content of macro- and microelements in *G. biloba* leaves, which depended on the tree gender. Leaves of female trees contained more microelements such as Zn (2.1-fold higher), Fe (1.2-fold higher) than male ones, but leaves from male trees were richer in calcium and magnesium. The cited authors also tested the effect of an applied extractant, water and ethanol (80%), on the extraction level of selected elements. Same as in our study, the extractant applied significantly affected the content of analysed elements (Nowak et al. 2017, Lysiuk et al. 2018).

Synergistic interactions between antioxidants contained in rapeseed oil and antioxidants from the added extract affected the final value of the protection factor. The content of tocopherols in rapeseed oil ranges between 140-340 100 μg g^{-1}, depending on the degree of physicochemical treatment (Wu et al. 2019). Moreover, when tocopherols appear at lower concentrations, tocotrienols occur as well, and these have slightly higher antioxidative activity than tocopherols (Fairus et al. 2019). Oil also contains synergents of tocopherols, i.e. phospholipids, and other protective compounds, such as carotenoids and steroids including squalene (Agregán et al. 2017).

The available references indicate that the protection factor for rapeseed oil with the adition of 0.2% *G. biloba* extract reached the value of 1.06. Higher concentrations of the extract, namley 0.5%, 0.7% and 1%, resulted in the following W_0 values, such as 1.08 or 1.11 (Nowak et al. 2017). The results achieved in our experiment was higher than reported by these researchers.

The presence of zinc, copper and iron affects bioavailability of flavonoids from *G. biloba* (Lee et al. 2019). In another study, chlorophyll was found to have acted as an antioxidant when in dark, but it accelerated fat oxidation in daylight (Sarijeva et al. 2007).

The activity of plant extracts results from the presence of minerals, solely, but it also depends on the content of polyphenols. Therefore, antioxidative capacity is higher in emulsions than in oils, because both mineral salts and polyphenols in emulsions are absorbed at interphases. Brovarets and Hovorun (2019) noted high bioactivity of flavonoids and zinc, which for example affects the activity of quercetins. Flavonoids of *Isatis tinctoria* differed significantly in their activity because of their different hydrophilicity and various extractants applied (Wakeel et al. 2019). Other authors have indicated that hydrophilic properties of metal-chelating flavonoids affected their properties in oil and in emulsions (Yi et al. 2017, El-Guendouz et al. 2019). Flavonoids and mineral salts prevented oxidation reactions only in emulsions, in which their occurred at the interphase. The literature provides evidence that compounds with a higher number of hydroxyl groups are more active in water-oil conditions than in pure oil (Santos-Sánchez et al.

2019). In specific conditions, polyphenols might cause a pro-oxidative effect. The outcome depends not only on the concentration of an antioxidant, but also on a solvent, pH, presence of oxygen and light, or on high temperature (Eghbaliferiz, Iranshahi 2016, D'Angelo et al. 2017). Such findings might explain the oxidative effect of the AW extract on TAG.

Because the addition of *G. biloba* extracts significantly lengthened induction periods, especially in the case of acetone-water extracts and ethanolic extract of green leaves, such extracts may be considered as potential antioxidative additives to fats and high-fat foods.

CONCLUSIONS

Ginkgo biloba extracts produced varied effects on the duration of the induction period of rapeseed oil and its triacylglycerols, measured by the Rancimat and Oxidograph tests. Green leaf extracts had a higher protection factor than extracts of yellow leaves. The longest induction periods were demonstrated for ethanolic extracts, while the shortest ones were noted for aqueous ones. Negative correlation was noticed between microelements in extracts and oxidative stability, which indicates oxidative activity of the extracts. *G. biloba* extracts may be a new source of stabilising additives for high-fat foods. However, further reasearch is needed, as food is a complex matrix, in which ingredients might interact, resulting in higher or lower antioxidative capacity.

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