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Accelerated storage conditions effect on ginger- and turmeric-enriched soybean oils with comparing a synthetic antioxidant BHT

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Abstract

Commercial and freeze-dried powders of ginger and turmeric rhizomes were incorporated in the soybean oil at the concentration of 10% (w/w) to develop a food seasoning containing natural antioxidants to improve lipid stability. The phenolic composition, antioxidant activity, and oxidative stability of ginger- and turmeric-enriched soybean oils were evaluated during storage at 62 °C for 28 days. The phenolic characterization was performed by detecting total polyphenols through Folin-Ciocalteu assay and HPLC analyzing 6-gingerol and curcumin, respectively. The antioxidant activity was spectrophotometrically measured through 2,2-di(4-tertoctylphenyl)-1-picrylhydrazyl (DPPH) radical scavenging capacity and ferric ion reducing antioxidant power (FRAP) assays. The peroxide value (PV) and induction period (IP) have been determined through spectrophotometric and Rancimat methods thus monitoring the primary and secondary phases of lipid oxidation, respectively. The addition of freeze-dried powders derived especially from turmeric rhizome contributed to enhanced antioxidant activity and oxidative stability of soybean oil under accelerated storage conditions thanks to its enrichment in bioactive compounds highly resistant to thermal degradation. Hence, ginger and turmeric powders can be valorized as functional ingredients to be incorporated in vegetable oils for preventing their lipid structure against to oxidation, and simultaneously providing health benefits to consumers.

Keywords: Oil stability; Rancimat; Natural antioxidants; 6-Gingerol; Curcumin.

1. Introduction

Soybean oil, which is widely used in the formulation and manufacture of foods, has a high content of polyunsaturated fatty acids susceptible to the oxidation reactions contributing to its reduced oxidative stability during storage and heat treatments such as cooking and frying (Banerjee et al., 2015; Yang et al., 2016; Freitas, Cattelan, Rodrigues, Luzia, & Jorge, 2017; Tinello et al., 2018). In fact, the lipid oxidation is one of the most critical factors affecting not only the shelf-life but also the quality attributes of oil as a consequence of the formation of volatile and non-volatile decomposition products (Choe & Min, 2007).

The addition of antioxidants can effectively counteract the lipid oxidation by giving their hydrogen to free radicals formed during initial stages of autoxidation or by stalling the propagation phase (Laguerre, Lecomte, & Villeneuve, 2007). However, the food application of synthetic antioxidants has been regulated in most countries to ensure safety and avoid any hazardous effects on human health (Carocho, Morales, & Ferreira, 2018).

Currently, the research is moving towards replacing synthetic additives such as BHA (butylated hydroxyanisole) and BHT (butylated hydroxytoluene) with natural substances that have more antioxidant activity and thermal stability in different edible oils and meet the increased attention of consumers to health (Taghvaei & Jafari, 2015). Agro-food products, by-products, and wastes contain several bioactive compounds (Tinello & Lante, 2018) that can be used for developing functional products (Tinello, Mihaylova, & Lante, 2018). In this regard, soybean oil has been previously enriched with plant extracts derived from olive leaf (Taghvaei et al., 2014), aromatic plants (Saoudi et al., 2016), rosemary (Yang et al., 2016), grape seed (Freitas et al., 2017), coffee husk (Ribeiro & Jorge, 2017),

peanut skin (Franco et al., 2018), and goji berry (Pedro et al., 2018) to improve oxidative stability.

The Zingiberaceae family includes ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*) rhizomes, which are mainly used as spices and are widely recognized for their intake of phenolic antioxidants (Chen et al., 2008). Ginger rhizome is rich in gingerols and shogaols belonging to the class of hydroxycinnamic or phenylpropanoic acids consisting of a phenolic ring bound to a chain of three carbon atoms (Hu et al., 2011). These phenolic compounds contributed to the antioxidant, anti-inflammatory, anticancer, antidiabetic, and anti-obesity effects of ginger (Shukla & Singh, 2007). Turmeric rhizome mainly contains curcuminoids consisting of a diarylphotanoic structure bound to two phenolic rings, also called aryls, by a chain of seven carbon atoms (Osorio-Tobón et al., 2016). Curcumin is the major yellow curcuminoid, which brings several health benefits to humans thanks to its antioxidant potential (Rauf, Imran, Orhan, & Bawazeer, 2018).

Several studies have demonstrated the strong antioxidant properties of ginger and turmeric rhizomes and peels (Singh et al., 2010; Pawar, Pai, Nimbalkar, & Dixit, 2011; Li, Hong, Han, Wang, & Xia, 2016; Tinello & Lante, 2019), but none has added them to soybean oil for investigating their effects on its lipid stability. Hence, in the present study soybean oil has been added with different ginger and turmeric powders at the concentration of 10% (w/w), which is generally used to prepare a homemade aromatic oil for human consumption, with the aim of valorizing a food seasoning rich in natural antioxidants to prevent lipid oxidation during thermal storage.

2. Materials and methods

2.1 Materials and chemicals

Soybean oil, fresh rhizomes, as well as commercial spices of ginger and turmeric, were purchased by a local supplier. All of the reagents and HPLC standards were purchased from Sigma-Aldrich (St. Louis, MO, USA).

2.2 Preparation of ginger- and turmeric-enriched soybean oils

The fresh rhizomes were manually peeled, cut into small pieces, freeze-dried at -40 °C, and grounded in a water-cooled laboratory miller (IKA Werke M20, Germany) to particles sizes of 1 mm. The dry matter, which was measured after drying samples in a stove at 103 °C for 24h (AOAC, 2000a), was 90.8% and 96.3% for commercial and freeze-dried powders of ginger while it was 90.0% and 91.2% for commercial and freeze-dried powders of turmeric, respectively. The ginger- and turmeric-enriched soybean oils have been prepared by following the traditional procedure of a homemade aromatic oil. In details, the ginger and turmeric powders were dissolved in soybean oil at 10% (w/w) concentration. The soybean oils containing ginger and turmeric powders were then subjected to the mixing of 10 minutes through an ULTRA-TURRAX® disperser tool, which corresponded to a maceration of 1 week as observed in a preliminary study. After centrifuging for 10 minutes at 5,000 rpm and 4 °C, the oily supernatant was recovered. The soybean oils with commercial and freeze-dried powders of ginger (GC and GR, respectively) and turmeric (TC and TR, respectively) were placed in amber bottles, flushed with nitrogen, and stored at -18 °C until analysis.

2.3 Schaal oven test

Schaal oven test, which is aimed at evaluating the accelerated storage conditions effect on the oxidative stability of oils, has been performed as described by Yang et al. (2016) on soybean oils without any addition (C), with ginger (GC and GR,) and turmeric (TC and TR)

powders, and with butylated hydroxyl toluene (BHT) as a synthetic antioxidant at the 0.02% (w/w) concentration corresponding to the maximum level set by Codex Alimentarius (2019). In detail, the oil samples were accurately weighed (40 g ± 0.01 g) into amber bottles without headspace and stored in an oven at a constant temperature of 62 ± 1 °C for 28 days. Every 7 days the samples were taken and subjected to the following analysis.

2.4 Determination of the oxidative stability of soybean oil samples

The oxidative stability was evaluated by peroxide value (PV) and Rancimat test for monitoring the primary and secondary phases of lipid oxidation, respectively.

2.4.1 PV

The PV was determined using AOAC (2000b) method. The oil sample (0.5 g) was dissolved in 25 mL mixture of acetic acid-chloroform (3:2 v/v) and then 0.5 mL saturated KI solution was added. The reaction solution was shaken and kept at room temperature under dark condition for 5 min. After adding 75 mL distilled water and 1mL starch indicator, the reaction solution was titrated with 0.01 N until reaching the endpoint of colorless. The PV was calculated as follows:

PV (meq O/kg oil) = (V x N x 1000)/m

where V is the volume of sodium thiosulfate added to the oil sample (mL); N is the normality of sodium thiosulfate; m is the mass of oil sample (g).

2.4.2 Rancimat test

The Rancimat test was performed in a fixed amount of oil sample (3 g) using a Rancimat apparatus (Metrohm, model 743, Herisau, Switzerland) and measuring over time the water conductivity at 110 °C temperature and 20 L h^{-1} air flow (Tinello et al., 2017). The oxidative stability was expressed as the induction period (IP) corresponding to the time (h)

126 at the intersection point between the horizontal (conductivity, μS min^{-1}) and vertical (time,
127 h) tangents of the fitted exponential oxidation curves. At this break point, the water
128 conductivity increased over time because of the production of lipid oxidation-related
129 compounds.

130 *2.5 Analysis on the phenolic extracts of soybean oil samples*

131 *2.5.1 Phenolic extraction*

132 Before detecting the antioxidant activity and the contents of bioactive compounds, the
133 phenolic extraction has been performed by following the slightly modified procedure of
134 Capannesi, Palchetti, Mascini, & Parenti (2000). An amount equal to 5 g of oil sample was
135 extracted three times with 5 mL mixture of MeOH and 10% v/v Tween 80 (80:20 v/v) by
136 using an orbital shaker for 5 min. After centrifuging for 20 minutes at 5,000 rpm and 10 °C,
137 all of the supernatants were collected and stored under refrigerated and dark conditions
138 until use. The phenolic extracts of soybean oil samples were subjected to the following
139 analysis.

140 *2.5.2 Determination of antioxidant activity*

141 The antioxidant activity was spectrophotometrically detected through 2,2-di(4-
142 tertoctylphenyl)-1-picrylhydrazyl (DPPH) radical scavenging capacity and ferric ion
143 reducing antioxidant power (FRAP) assays according to Tinello & Lante (2019). The
144 antioxidant activity was expressed as Trolox equivalents per gram of oil (mg TE/g).

145 *2.5.3 Measurement of the total phenolic content*

146 The total phenolic content was detected through the Folin-Ciocalteu colorimetric method
147 according to Tinello & Lante (2019). The total phenolic content was expressed as gallic
148 acid equivalents per gram of oil (mg GAE/g).

149 *2.5.4 HPLC analysis of 6-gingerol and curcumin*

150 The 6-gingerol and curcumin contents were determined in the phenolic extracts of
151 respectively ginger- and turmeric-enriched soybean oils by HPLC using a Thermo Finnigan
152 SpectraSystem UV6000LP HPLC system (Thermo Finnigan, San Jose, CA, USA) with
153 diode-array detection and a Supelcosil LC-18 column (Sigma-Aldrich). Before their
154 injection into the column, samples were filtered through 0.22 μm Millipore cellulose
155 acetate filters (Merck Millipore, Billerica, MA, USA). Regarding 6-gingerol, the HPLC
156 operating parameters were according to the slightly modified method of Hu et al. (2011):
157 mobile phase consisting of distilled water (solvent A) and acetonitrile (solvent B) at
158 different gradient elution (0–8 min, 50% B; 8–17 min, 50–55% B; 17–32 min, 55–100% B;
159 32–38 min, 100% B; 38–40 min, 100–45% B; 40–50 min, 45% B; 50–60 min, 45–50% B);
160 0.2 mL/min flow rate; 10 μL injection volume; 30 °C column temperature; 60 min
161 chromatographic run time. Regarding curcumin, the HPLC operating parameters were
162 according to the slightly modified method of Osorio-Tobón et al. (2016): mobile phase
163 consisting of acetonitrile/0.1% v/v acetic acid (solvent A) and distilled water/0.1% acetic
164 acid (solvent B) at different gradient elution (0–6 min, 45–35% B; 6–21 min, 35–10% B;
165 21–27 min, 10% B; 27–30 min, 10–25% B; 30–39 min, 25% B; 39–51 min, 25–45% B;
166 51–70 min, 45% B); 1.2 mL/min flow rate; 10 μL injection volume; 55 °C column
167 temperature; 70 min chromatographic run time. The 6-gingerol and curcumin contents were
168 expressed as milligrams per gram of oil (mg/g).

169 *2.6 Statistical analysis*

170 All of the data obtained from three replicates were analyzed by one-way analysis of
171 variance (ANOVA), after verifying the normal distribution and homogeneity of variance,

using the PROC GLM of SAS® 9.3 software package. Differences among means with $P \leq 0.05$ were accepted as representing statistically significant differences according to the Bonferroni test.

3. Results and discussion

3.1 Phenolic characterization

The phenolic content of soybean oil, which was zero as confirmed also by Lee, Lee, & Choe (2007), increased after adding ginger and turmeric powders. The concentration of total polyphenols detected by Folin-Ciocalteu assay statistically differed ($P \leq 0.05$) among soybean oil samples at each thermal storage day depending on the powder type and following this order: TR > GR > TC > GC (Fig. 1). At day 0, their corresponding amounts (4,133, 1,398, 1,272, and 1,211 mg GAE/kg oil, respectively) were higher than those found by Saoudi et al. (2016) in soybean oils macerated in the darkness for 7 days with 6% (w/w) dried leaves of thyme and rosemary (926 and 37 mg GAE/kg oil, respectively) and subjected to a similar phenolic extraction. A lower total phenolic content was also achieved by Yang et al. (2016) in soybean oil stirred for 10 min at room temperature with 4% (w/w) commercial rosemary extract containing 70% (w/v) carnosic acid (approximately 400 mg/kg oil). After 28 days of storage at 62 °C, the total phenolic content of TR (3,947 mg GAE/kg oil) was 3 times higher than that of GR (1,297 mg GAE/kg oil) and 4 times higher than that of TC (1,102 mg GAE/kg oil) and GC (1,002 mg GAE/kg oil). Generally, phenolic antioxidants undergo degradation during high-temperature storage of oils and fats thus forming several oxidation products (Shahidi & Ambigaipalan, 2015). However, they have more thermal stability than synthetic additives in edible oils during heat processing (Taghvaei & Jafari, 2015). In fact, Fig. 1 showed that the phenolic reduction was very slow

195 with increasing storage days and was approximately 3 times lower in soybean oils
196 containing freeze-dried rhizomes (GR = - 7% and TR = - 4%) compared with those
197 containing commercial powders (GC = - 17% and TC = - 13%).
198 The phenolic antioxidants containing in ginger and turmeric such as respectively 6-gingerol
199 and curcumin are hydrophobic compounds highly soluble in oil (Eshghi et al., 2014;
200 Banerjee et al., 2015; Zou et al., 2015; Xu et al., 2016; Si, Chen, Zhang, Chen, & Chung,
201 2018). Comparing 6-gingerol and curcumin contents of oil samples at day 0 (GC = 361
202 mg/kg oil, GR = 763 mg/kg oil, TC = 1669 mg/kg oil, and TR = 5694 mg/kg oil; Fig. 2)
203 with those of the corresponding powders analyzed in our previous study (Tinello & Lante,
204 2019), their oil solubility for ginger and turmeric commercial powders (60% and 65%,
205 respectively) was lower than that for freeze-dried ones (100% and 90%, respectively). In
206 this regard, several studies confirmed that the bioaccessibility and bioavailability of
207 phytonutrients were affected by the food matrix, processing, and preservation techniques
208 (Ribas-Agustí, Martín-Belloso, Soliva-Fortuny, & Elez-Martínez 2018; Thakur et al.,
209 2020). Moreover, the 6-ginger and curcumin contents of soybean oils added with
210 respectively ginger (Fig. 2A) and turmeric (Fig. 2B) powders were almost unchanged
211 during thermal storage. Only a slight decrease in curcumin content up to 4% was observed
212 in TC oil (Fig. 2B).
213 *3.2 Evaluation of antioxidant activity*
214 The antioxidant of soybean oil, which was zero as confirmed by DPPH and FRAP data,
215 increased after adding ginger and turmeric powders. The DPPH (Fig. 3A) and FRAP (Fig.
216 3B) assays gave essentially the same antioxidant curves and results by using different
217 oxidants that captured an electron from the antioxidant causing specific color and

absorbance changes (Huang et al. 2005). The averaged values of Trolox equivalents corresponding to the percentage of the DPPH remaining and the Fe(III) ion reducing capability significantly differed ($P \leq 0.05$) among soybean oils at each thermal storage day depending on powder type as follows: TR > GR > TC > GC (Fig. 3A and Fig. 3B, respectively). At 0 day, the DPPH and FRAP values of TR (2,847 and 4,008 mg TE/kg oil) were 2 times higher than that of GR (1,505 and 1,984 mg TE/kg oil), 4 times higher than that of GC (846 and 1,124 mg TE/kg oil), and 9 times higher than that of TC (384 and 582 mg TE/kg oil). After 28 days of storage at 62 °C, the DPPH and FRAP values of TR (2,024 and 2,960 mg TE/kg oil) were 2 times higher than that of GR (990 and 1,390 mg TE/kg oil), 4 times higher than that of GC (540 and 760 mg TE/kg oil), and 9 times higher than that of TC (220 and 370 mg TE/kg oil). The antioxidant activity of all ginger- and turmeric-enriched soybean oils decreased over storage time as confirmed by DPPH and FRAP assays (Fig. 3A and Fig. 3B, respectively). However, the antioxidant reduction after 28 storage days was lower in soybean oils containing freeze-dried rhizomes (DPPH: GR = - 34% and TR = - 29%; FRAP: GR = - 30% and TR = - 26%) compared with commercial powders (DPPH: GC = - 36% and TC = - 43%; FRAP: GC = - 32% and TC = - 36%). This could be related to the highest yields of total polyphenols (Fig. 1) as well as curcumin (Fig. 2A) and 6-gingerol (Fig. 2B) in soybean oils enriched with freeze-dried rhizomes. In fact, the correlation between the antioxidant activity and the phenolic composition of agro-food products and wastes has been widely demonstrated (Tinello et al., 2018; Tinello & Lante, 2019). Several authors confirmed also the strong antioxidant properties of 6-gingerol (Pawar et al., 2011; Gan et al., 2016; Li et al., 2016) and curcumin (Ak & Gulcin, 2008).

3.3 Evaluation of oxidative stability

241 Hydroperoxides are the primary products of lipid oxidation without undesirable flavor,
242 whereas their decomposed products are mostly responsible for rancid off-flavor (Choe &
243 Min, 2007). The peroxide value (PV) and induction period (IP) have been selected as
244 reference oxidative parameters for respectively the primary and secondary phases of lipid
245 oxidation with the aim of evaluating the oxidative stability of soybean oil samples
246 with/without antioxidants during storage at 62 °C for 28 days. The increasing trend in PV
247 of soybean oil samples was slow at the first 14 days while a sharp increment was observed
248 until the end of thermal storage (Fig. 4A). The PV increasing trend was previously
249 observed in soybean oil samples heated at 55 °C for 20 days (Taghvaei et al., 2014), 60 °C
250 for 20 days (Ribeiro & Jorge, 2017), 62 °C for 24 days (Yang et al., 2016), 180 °C for 20 h
251 (Freitas et., 2017), and 180–190 °C for 24 h (Banerjee, Ghosh, & Ghosh, 2015). The PV
252 significantly differed ($P \leq 0.05$) among soybean oils at each storage day. After 21 storage
253 days at 62 °C, the PV of oil samples with turmeric powders (TC = 42.6 meq O_2/kg oil and
254 TR = 36.1 meq O_2/kg oil) was lower than that of control oil (C= 46.4 meq O_2/kg oil) and oil
255 samples with synthetic antioxidant (BHT = 36.2 meq O_2/kg oil) and ginger powders (GC =
256 61.0 meq O_2/kg oil oil and GR = 52.7 meq O_2/kg oil). The PV of ginger- and turmeric-
257 enriched soybean oils was lower than that of soybean oil added with 200 mg/kg of coffee
258 husk extract (74.1 meq O_2/kg oil) and a mixture of 100 mg/kg of coffee husk extract and
259 100 mg/kg of BHA and (87.5 meq O_2/kg oil) but higher than that of soybean containing a
260 mixture of 100 mg/kg of coffee husk extract and 100 mg/kg of TBHQ (3.51 meq O_2/kg oil)
261 after 20 heating days at 60 °C (Ribeiro & Jorge, 2017). Their PV data was approximately 2
262 times lower than that of soybean oil containing 1,000 mg/kg of peanut skin extracts (92.4
263 meq O_2/kg oil) after 16 storage days at 60 °C (Franco et al., 2018). Moreover, the PV

264 inhibition of TR and BHT (22% compared to C sample) was greater than that found by
265 Taghvaei et al. (2014) in soybean oils added with protein hydrolysates isolate from Crucian
266 carp (*Carassius carassius*) fish (2.5, 14.2 and 17.6% for 200, 500 and 1,000 mg/kg oil,
267 respectively) and from cow's intestine (5.9 and 13.6% for 200 and 500 mg/kg oil,
268 respectively) after 20 days storage at 55 °C. After 28 storage days at 62 °C, the C sample
269 achieved the highest PV of 70.9 meq O_2/kg oil, which was similar to that found by
270 Taghvaei et al. (2014) after 20 days of storage in an oven at 55 °C with forced air
271 circulation. Instead, the PV results of TR (61.3 meq O_2/kg) and BHT (57.1 meq O_2/kg oil)
272 samples were significantly lower than those of TC, GC, and GR samples (71.7, 95.0, and
273 90.4 meq O_2/kg, respectively). The IP increment of TR (+ 76%) and BHT (+ 80%) samples
274 after 28 storage days was lower than that of C oil (+ 85%) and other enriched soybean oils
275 (+ 90%). Moreover, TR, as well as BHT, had the highest PV inhibition rate (19% and 14%
276 compared to C sample, respectively). In this regard, Banerjee et al. (2015) showed that the
277 marination of potato chips with turmeric powder before frying was useful to lower PV of
278 soybean oil at 180–190 °C for 24 h (8 h daily for 3 consecutive days).
279 Contrariwise, the IP value detected by the Rancimat test in soybean oil samples linearly
280 decreased with increasing storage days at 62 °C (Fig. 4B). This IP decreasing trend was
281 previously found in soybean oil samples heated at 60 °C for 20 days (Ribeiro & Jorge,
282 2017) and 180 °C for 24 h (Saoudi et al., 2016). The IP value significantly differed ($P \leq$
283 0.05) among soybean oils at each storage day depending on the sample type. At 0 day, the
284 IP value of soybean oil containing freeze-dried powders (TR = 10.7 h and GR = 9.1 h) was
285 higher than that of control oil (C = 5.8 h) and oil samples with synthetic antioxidant (BHT
286 = 6.1 h) and commercial spice (TC = 6.7 h and GC = 6.9 h). The IP values of TR and GR

287 samples were higher than those showed by Freitas et al. (2017) in soybean oils containing
288 100 mg/kg of grape seed extract (7.5 h) and 50 mg/kg of both BHT and extract (7.2 h).
289 Moreover, their IP values were much lower than those of soybean oils added to coffe husk
290 extract alone and with BHA (approximately 6 hours) but similar when compared to that of
291 soybean oil containing a mixture of coffe husk extract and TBHQ (approximately 10 hours)
292 (Ribeiro & Jorge, 2017). The IP increments after adding antioxidants to soybean oil were as
293 follows: TR (+ 4.9 h) > GR (+ 3.3 h) > GC (+ 1.1 h) > TC (+ 0.9 h) > BHT (+ 0.3 h). The
294 IP increments of TR and GR samples were much greater than those observed by Taghvaei
295 et al. (2014) in soybean oils containing 1,000 mg/kg protein hydrolysates isolate from
296 cow's intestine or 1,823 mg/kg olive leaf extract encapsulated by arabic gum (+ 2.2 h and +
297 0.4 h, respectively). Moreover, they were greater than that found by Yang et al. (2016) in
298 soybean oil added with 400 mg/kg of rosemary extract (+ 3.4 h) and by Freitas et al. (2017)
299 in soybean oil containing grape seed extract alone and with BHT (+ 0.7 h and + 0.4 h,
300 respectively). After 28 storage days, TR sample had an IP value (5.5 h) approximately 2
301 times higher than that of control oil (C = 3.5 h) and soybean oils with synthetic antioxidant
302 (BHT = 3.9 h), commercial spices (TC = 3.2 h and GC = 2.5 h), and ginger freeze-dried
303 powder (GR = 3.0 h). The IP reduction of TR (- 49%) after 28 storage days was lower than
304 that of soybean oils with turmeric commercial spice (TC = - 52%) and ginger powders (GC
305 = - 64% and GR = - 67%). Moreover, its IP reduction was lower than that achieved in
306 soybean added to coffee husk extract alone and with BHA (approximately - 70%) after 20
307 storage days at 60 °C (Ribeiro & Jorge, 2017). Hence, TR achieved the best PV and IP
308 results because its enrichment with turmeric freeze-dried powder was effective in

significantly decreasing lipid oxidation and enhancing stability during thermal storage (Fig. 4).

Several authors associated the oxidative stability of plant extracts-enriched soybean oils with their phenolic composition and antioxidant activity (Taghvaei et al., 2014; Saoudi et al., 2016; Yang et al., 2016; Franco et al., 2018; Pedro et al., 2018). Thus, the best oxidative stability of TR sample could be due not only to its higher phenolic yields (Fig. 1) and antioxidant performance in DPPH and FRAP assays (Fig. 3A and Fig. 3B, respectively) but also to the stability of curcumin during storage under accelerated oxidation conditions (Fig. 2B). In this regard, the thermal resistance of curcuminoids has been demonstrated by Prathapan, Lukhman, Arumughan, Sundaresan, & Raghu (2009) evaluating the effect of heat treatment at different temperatures (60–100 °C) for di□erent durations (10–60 min) in fresh turmeric rhizome. Park et al. (2019), studying the effects of extraction temperature (60–90 °C) and time (15–180 min) on curcuminoids of aqueous turmeric extracts, showed that the contents of curcumin, demethoxycurcumin, and bisdemethoxycurcumin increased until achieving the maximum extraction at 90 °C for 60 min but decreased under prolonged heating. Nevertheless, Eshghi et al. (2014) confirmed that turmeric-derived curcumin was significantly effective in decreasing the oxidation rate of soybean oil at 55 °C based on peroxide, acid, and iodine values.

4. Conclusions

The oxidative stability of soybean oil under accelerated storage conditions was significantly improved after adding freeze-dried powders derived especially from turmeric rhizome. The greatest antioxidant properties of GR and TR oils have been attributed to their strong enrichment in phenolic antioxidants such as respectively 6-gingerol and curcumin, which

showed high solubility in oil and resistance to thermal degradation. Hence, the freeze-dried powders of ginger and turmeric rhizomes can be proposed not only as eco-friendly alternatives to synthetic additives for preventing the lipid oxidation in oil- and fat-containing products but also as functional food ingredients.

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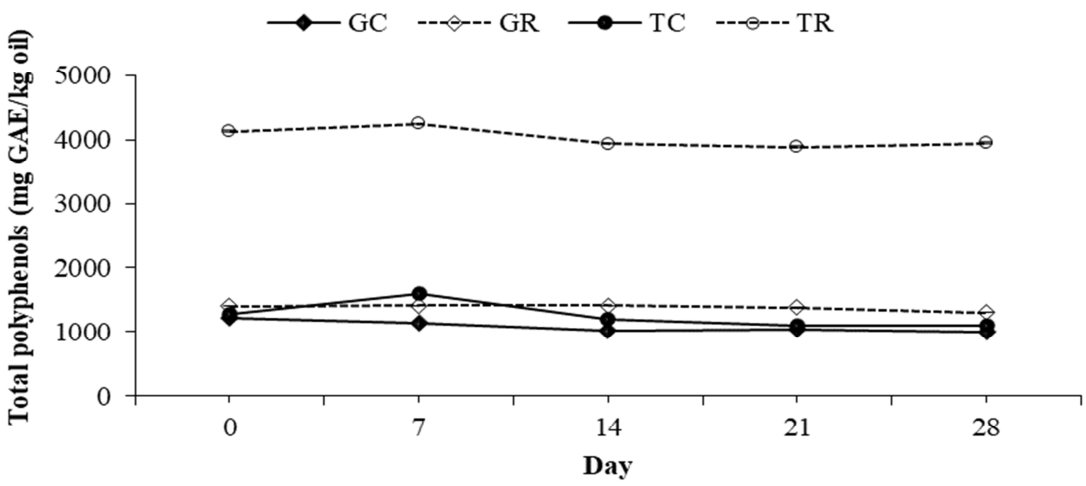
466 83.

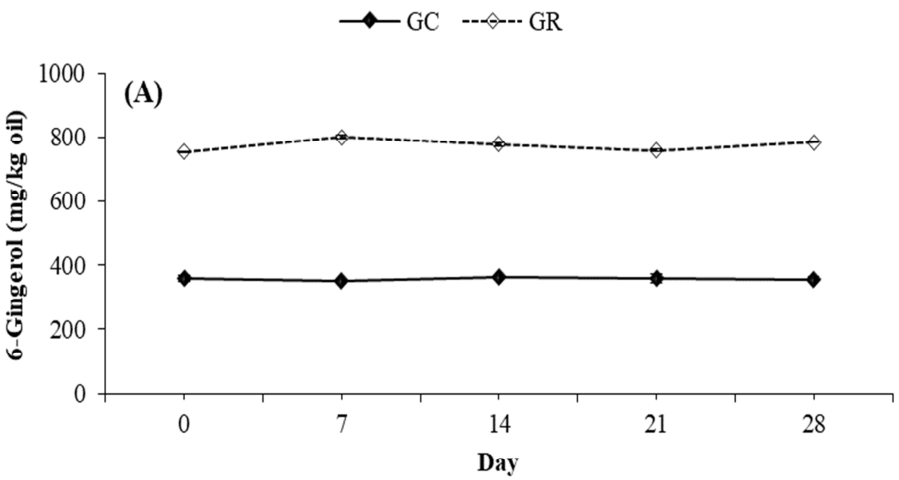
Fig. 1. The total phenolic content of soybean oil samples enriched with ginger commercial powder (GC), ginger freeze-dried rhizome powder (GR), turmeric commercial powder (TC), and turmeric freeze-dried rhizome powder (TR) during 28 days storage at 62 °C.

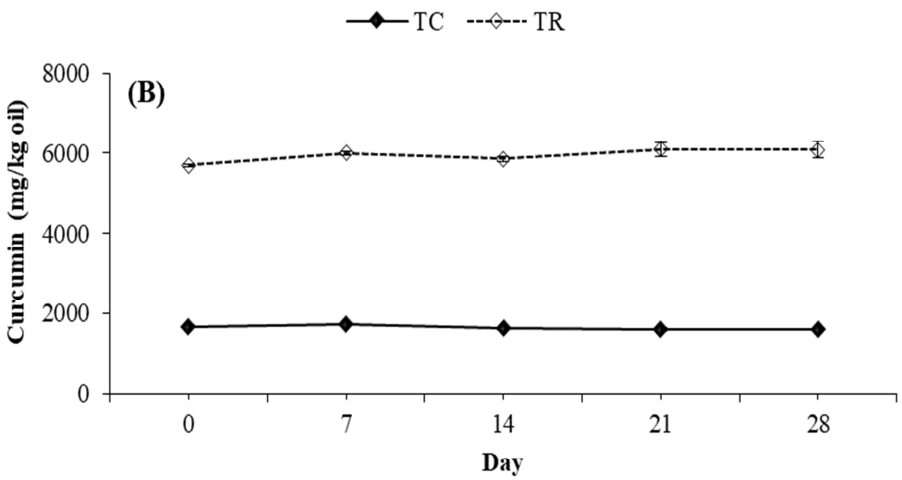
Fig. 2. The 6-gingerol (A) and curcumin (B) contents of soybean oil samples enriched with respectively ginger commercial powder (GC), ginger freeze-dried rhizome powder (GR), turmeric commercial powder (TC), and turmeric freeze-dried rhizome powder (TR) during 28 days storage at 62 °C.

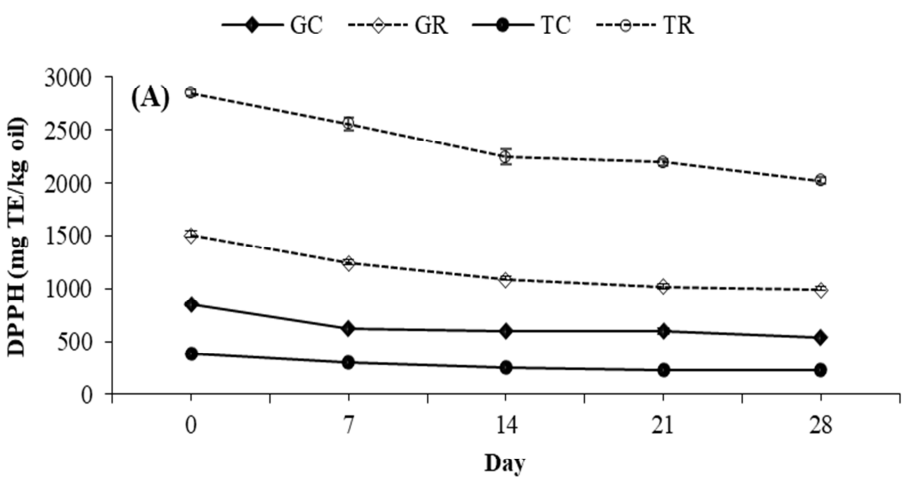
Fig. 3. The antioxidant activity performed by DPPH (A) and FRAP (B) assays in soybean oil samples containing ginger commercial powder (GC), ginger freeze-dried rhizome powder (GR), turmeric commercial powder (TC), and turmeric freeze-dried rhizome powder (TR) during 28 days storage at 62 °C.

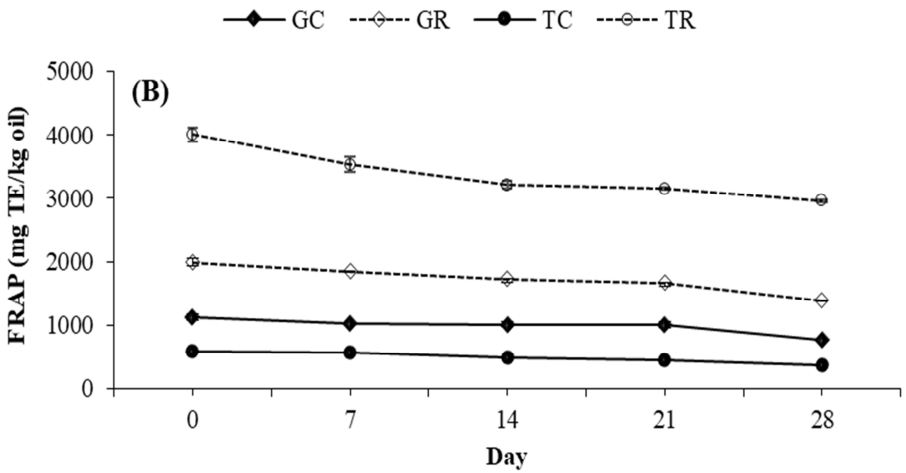
Fig. 4. The PV (A) and IP (B) values of soybean oil samples without any additives (C) and with 0.02% w/w butylated hydroxyl toluene (BHT), ginger commercial powder (GC), ginger freeze-dried rhizome powder (GR), turmeric commercial powder (TC), and turmeric freeze-dried rhizome powder (TR) during 28 days storage at 62 °C.

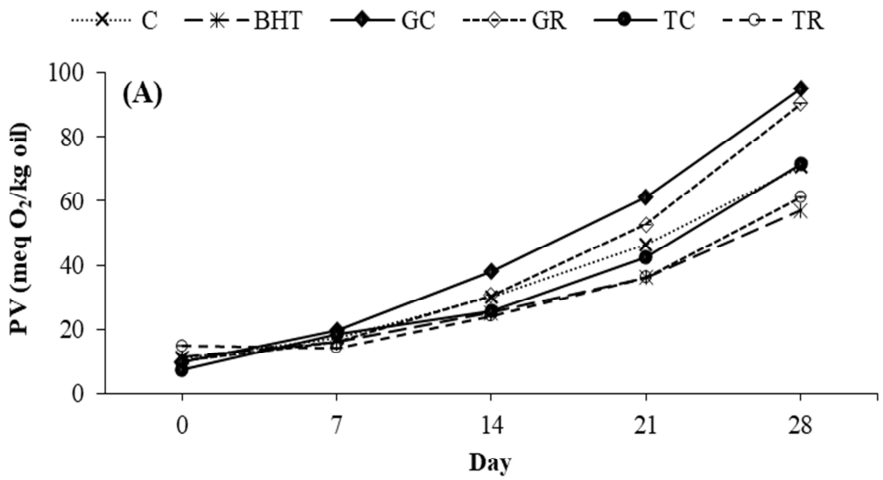


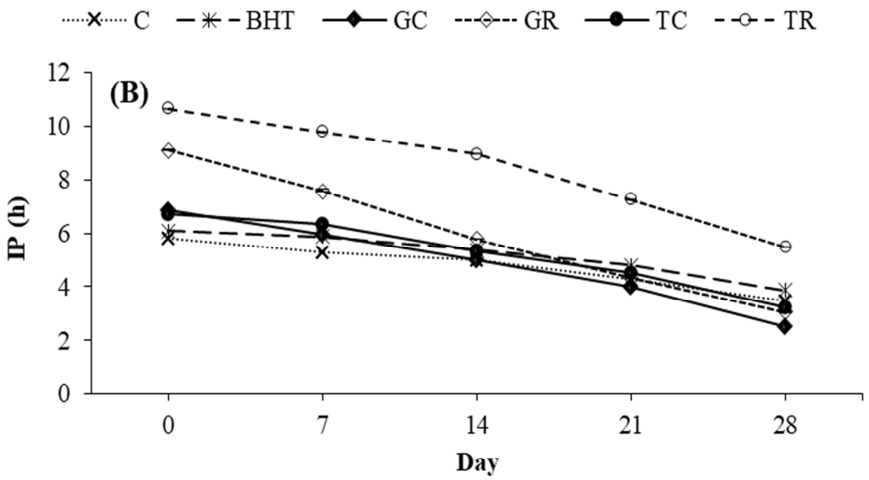

GC
GR
(A)
6-Gingerol (mg/kg oil)
1000
800
600
400
200
0
0
7
14
21
28
Day


TC
TR
(B)
Curcumin (mg/kg oil)
8000
6000
4000
2000
0
0
7
14
21
28
Day


GC
GR
TC
TR
(A)
DPPH (mg TE/kg oil)
3000
2500
2000
1500
1000
500
0
0
7
14
21
28
Day


GC
GR
TC
TR
(B)
FRAP (mg TE/kg oil)
5000
4000
3000
2000
1000
0
0
7
14
21
28
Day





- The oxidative stability of soybean oil was improved after adding antioxidants.
- GR and TR oils showed the best antioxidant properties during thermal storage.
- 6-gingerol and curcumin were found as heat-resistant phenolic compounds.
- Ginger and tumeric freeze-dried powders can replace synthetic antioxidants in oils.

DIPARTIMENTO DI AGRONOMIA ANIMALI ALIMENTI RISORSE NATURALI E AMBIENTE
DAFNAE
DEPARTMENT OF AGRONOMY, FOOD, NATURAL RESOURCES, ANIMALS AND ENVIRONMENT

UNIVERSITÀ DEGLI STUDI DI PADOVA

Legnaro, 28 th February 2020

Dear Editor

We are submitting our manuscript entitled “Evaluation of the phenolic composition, antioxidant activity and oxidative stability in ginger- and turmeric-enriched soybean oils under accelerated storage conditions” by Federica Tinello and Anna Lante, for consideration by your referees.

THE AUTHORS DECLARE NO CONFLICT OF INTEREST, FINANCIAL OR OTHERWISE.

We hope that you will consider the paper of interest for the Journal *LWT*.

We look forward to hear from you.

Sincerely yours,

Anna Lante (on behalf of my co-author)

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