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STABILITY OF PALM OLEIN WITH OR WITHOUT ANTIOXIDANTS DURING INDUSTRIAL CONTINUOUS DEEP-FAT FRYING OF WHEAT SNACKS

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ABSTRACT

The stability of palm olein (POo) was evaluated during deep-fat frying of wheat pellet snacks in an industrial continuous frying system. Refined, bleached and deodourised POo free of antioxidants was employed, or with the addition of natural antioxidant (1000 ppm rosemary extract, RE) or with synthetic antioxidant (200 ppm tertbutylhydroquinone, TBHQ) at a rate of 975 kg hr^{-1}. For comparison, frying with POo without antioxidants was carried out at a rate of 1800 kg hr^{-1}. Several chemical indices in POo were evaluated. Also, sensory evaluation during storage of the final fried products was conducted. Addition of antioxidants did not have an effect on the free fatty acids during continuous frying (p>0.05). POo without antioxidants or added with RE had higher total polar compounds and p*-anisidine values in comparison with POo with TBHQ. Measured indices were under recommended limits established by regulations, especially frying at 1800 kg hr^{-1}, due to the rapid oil turnover in the continuous system. In the sensory evaluation during accelerated shelf-life test, no differences were found between snacks at different production rates and with or without addition of antioxidants (p>0.05). The POo showed high stability for continuous industrial frying of wheat snacks, producing foods with long shelf-life.*

Keywords: industrial continuous frying, oil stability, palm olein, wheat snacks.

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INTRODUCTION

Deep-fat frying is one of the most popular processes in snack preparation. It is a complex process comprising simultaneous heat and mass transfer, where several chemical reactions and textural changes take place. The high heat and mass transfer rates during frying are the principal reason for the development of the most important physical properties, such as density, porosity and volume, as well as sensory attributes of snacks, such as crunchy texture, desired colour, and characteristic flavour (Pedreschi, 2012). During frying, pieces of snack come into contact with hot oil, resulting in water loss and an increase of fat content in the product. The quality of the frying oil becomes an important factor to consider in the process, as it is absorbed by the food. During frying, oils are degraded by thermal oxidation to form volatile and non-volatile off-products, which can also affect the quality of the

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snacks (Pambou-Tobi *et al*., 2010). Many factors like the type of food, moisture content, type of oil used, and/or the frying conditions affect oil degradation (Choe and Min, 2007).

The frying process may be carried out by continuous or discontinuous way (by batches). The industrial market for the preparation of extruded snacks, chips, pre-fried breaded meat products, and fried potatoes uses continuous frying, while the institutional market (fast-food outlets, restaurants, and bakeries) uses discontinuous frying (Ferreira *et al*., 2014). Batch frying is not common at industrial scale, being more expensive than continuous frying (Bou *et al*., 2012). There are diverse indices to analyse the quality of the oils for frying operations. Percentage of free fatty acids as an indicator of hydrolytic rancidity, and peroxide value as an indicator of primary oxidative rancidity are commonly employed (Faridah *et al.,* 2015). Also, total polar compounds (TPC), *p*-anisidine value (AV), and oxidative stability index (OSI) are used as degradation indicators in the industry (Enríquez-Fernández *et al*., 2012).

The quality of fried products is not only determined by the frying conditions, but also by the type of oil and food used in the process. The nature of the fried food influences the oil quality, especially when trace metal, emulsifiers, or other fats/oils from the food migrate to the frying oil (Flores-Álvarez *et al*., 2012). In terms of oil stability, deterioration depends on the degree of saturation of the fatty acid composition of the oil. Saturated oils are more resistant to degradation, but there are concerns about health consequences. At industrial frying scale, palm olein (POo) which is produced from palm oil by fractionation, is widely popular. POo contains a higher amount of unsaturated and a lower amount of saturated fatty acids than palm oil (Idris *et al.,* 2008; Enríquez-Fernández *et al*., 2011). Palm oil contains endogenous tocopherols and tocotrienols, sources of natural antioxidants, these compounds are present in palm oil and POo in relatively high levels when compared with other vegetable oils.

Despite the stability of POo, the presence of unsaturated fatty acids has led to the addition of antioxidants. The most widely used synthetic antioxidants in foods are butyl-hydroxytoluene (BHT), butyl-hydroxyanisol (BHA), and tert-butyl-hydroquinone (TBHQ) (Politeo *et al.,* 2007). Nevertheless, safety and toxicity issues have been associated with the use of synthetic antioxidants (Sharif *et al.,* 2009). Therefore, the addition of natural antioxidants is a promissory way to delay the oxidation of the oil and to avoid nutritional concerns. Different natural extracts and compounds have been evaluated as antioxidants during operations of repeated deep-fat frying such as phenolic compounds from fruits, vegetables, nuts, seeds, leaves, roots, barks, as well as tocopherols, tocotrienols, essential oils and extracts from herbs (Idris *et al*., 2008; Cardoso-Ugarte *et al.,* 2013). In order to delay the onset of off-odours as a result of oxidation, one of the most widely used synthetic an antioxidants in foods is the TBHQ, nevertheless rosemary extract (RE) has been reported as an antioxidant during batch deep-frying of potato chips in POo (Che Man and Tan, 1999). Reported compounds in RE that prevent oxidation include carnosol, rosmarinic acid, carnosic acid, caffeic acid, rosmanol, and rosmadial (Lalas and Dourtglou, 2003), which may act synergistically with other minor substances such as flavonoids, providing thermal stability and enhancing antioxidant activity.

Wheat pellet snacks are typically small, have large expansion, a porous structure and a crispy texture. Pellets, with approximately 20%-30% moisture content (w.b.) are subjected to a drying process under mild temperature conditions to obtain a semi-processed product of 11%-12% moisture equally distributed throughout the pellet´s volume (Nems *et al.,* 2015). To obtain ready-to-eat products, a thermal process such as frying is necessary. During the process, the pellet expands, increases in volume 3-8 times, and a typical porous, light structure and crispy texture are obtained (Lusas and Rooney, 2001). Few information is available about oxidation in a continuous frying system of wheat pellets. Thus, the objective of this study were to evaluate the stability of POo during the deep-fat frying of wheat pellet snacks in an industrial continuous frying system, with or without antioxidants and to evaluate the sensory attributes during accelerated storage of the fried pellets.

MATERIALS AND METHODS

Raw Materials

Materials were kindly provided by the Mexican Snack Company Fritos-Totis (Fritos Totis S.A. de C.V., Tizayuca, Hidalgo, Mexico). The three frying media were refined, bleached and deodourised POo: 1) POo without antioxidants (NA), 2) POo with 1000 ppm of natural antioxidant RE, and 3) POo with 200 ppm of synthetic TBHQ. RE contained approximately 5% of phenolic diterpenes (carnosic acid and carnosol) and maltodextrin as a carrier. The dry-pellets had ring form with 1 cm diameter, and moisture content of 10% (w.b).

Frying Process

The industrial deep-fat frying process was carried out in the Fritos-Totis Company facilities, using an industrial continuous fryer (model Popper, Heat and Control, Jalisco, Mexico) equipped with an immersion conveyor. For each experiment, before starting the frying process, the fryer was filled with 350 litres of fresh POo, and the operation temperature and pellet inlet rate were adjusted to fry at 180°C for 30 s (adjusting the internal conveyor speed). The process was operated continuously with constant inlet of wheat pellets in order to obtain 975 or 1800 kg final fried product hr^{-1}. The fryer automatically maintains the POo level by the constant addition of fresh POo.

A sample of 500 ml of POo was taken from the top of the fryer every 20 min until 1000 litres of POo were consumed. The POo samples were cooled at room temperature and then kept in dark flasks at -20°C until analyses.

Oxidation Analyses

The following analyses were performed in triplicate to evaluate the POo stability. The free fatty acids (FFA) content was determined by titration with 0.1 N NaOH according to the official method 940.28 (AOAC, 2000). The TPC were determined using the Testo instrument (Testo 270, Lenzkirch, Germany). The instrument was immersed in 50 ml of POo at 180°C, giving the TPC percentage calculated from the dielectric constant of the sample (Cardoso-Ugarte *et al.,* 2013). The OSI was determined using a Metrohm Rancimat model 679 (Herisau, Switerland), based on the measurement of time before the oil oxidation, also known as induction period (Farhoosh, 2007). The test was done with 2.5 g of POo at 120°C at an airflow rate of 9 litres hr^{-1}. The *p*-AV was determined following the official method Cd 18-90 (AOCS, 1992).

Sensory Evaluation

Fried snacks were packed in polypropylene bags (30 μm thick), sealed, and stored at 40°C and 10% relative humidity (RH) conditions in a controlled chamber for accelerated tests. Rancid flavour and odour in the fried snacks were periodically evaluated (0, 8, 13, 23, 38, 45 and 55 days after production) using a four-point scale (1 = no rancidity, 2 = slight rancidity, 3 = evident rancidity, 4 = extreme rancidity). Tests were performed by 20 semi-trained judges, employees of Fritos-Totis Company. On every evaluation day, three coded samples were randomly presented to the judges and water and green apple slices (as a palate cleanser) were provided to them between samples.

Statistical Analysis

Results of POo oxidation analyses were examined by analysis of variance (ANOVA) using general linear models analysing the effects of the addition or no addition of antioxidants, and using the frying time as a co-variable. Comparisons were carried out using the Tukey test with a confidence level of 95%. Sensory data were statistically analysed using ANOVA and Tukey´s pairwise comparison test when differences were found. The significance level was established at $p<0.05$. The software Minitab 17 (Minitab Inc., State College, Pa., USA) was used to perform the statistical analysis.

RESULTS AND DISCUSSION

The FFA values in POo with or without antioxidants are presented in *Table 1*. The initial percentages of FFA in POo were low (0.04%-0.06%) and slightly increased as the continuous frying process progressed. Frying at 1800 kg hr^{-1} with POo without antioxidant maintained lower FFA due to the higher work capacity and a lower turnover time, this means a faster fresh oil addition to the system. The FFA values at 975 kg hr^{-1} capacity reached a stable value around 0.07%, without effect of addition of antioxidants ($p>0.05$). FFA value is an indicator of hydrolytic rancidity. When food is fried, moisture from the food forms steam generating bubbles that gradually decrease as the frying process continues. The combination of steam, oxygen and water begins a series of chemical reactions in the frying oil and food. The water reacts with the triglycerides ester bond producing di- and mono-glycerides, glycerol and FFA. FFA has been used and reported in several publications as an indicator of oil hydrolysis (Tarmizi *et al*., 2016). The high oil turnover value of the continuous frying system and the low moisture content of the wheat pellets contributed to the low FFA values found (lower than 0.08% for all the cases). Similar to the findings reported in this work, Ismail (2005) reported that in continuous frying, the oil inside the fryer has lower FFA due to the oil's turnover. The FFA did not exceed the allowed limit for this index, established in most countries as 2.5% (Bou *et al*., 2012). In the continuous frying process, the change in FFA in the frying oils used presents no clear tendency, being attributed to the high turnover rate of POo.

The percentages of TPC in the POo during the continuous frying are presented in *Table 2*. TPC determination provides an indicator of the quality of used frying oils, giving a measure of the extent of deterioration and provides information of the total amount of formed compounds having higher polarity than triacylglycerol, which is related to by-products from fatty acids oxidation (Abdulkarim *et al.,* 2007; Cardoso-Ugarte *et al.,* 2013). A relatively faster increase in TPC values can be observed for 975 kg hr^{-1} capacity (with or without antioxidant) during the first 40 min until it stabilised around 9%-11%. POo with TBHQ had lower TPC than POo without antioxidants or POo with RE ($p<0.05$). However, lower degradation, in terms of TPC, was observed

TABLE 1. FREE FATTY ACIDS CONTENT (% palmitic acid) OF PALM OLEIN WITH TERTBUTYLHYDROQUINONE (TBHQ), ROSEMARY EXTRACT (RE), OR WITHOUT ANTIOXIDANT (NA), AT DIFFERENT RATES (975 and 1800 kg hr^{-1}) DURING CONTINUOUS FRYING OF WHEAT PELLET SNACKS

Time (min)	TBHQ (975 kg hr^{-1})			RE (975 kg hr^{-1})			NA (1800 kg hr^{-1})			NA (975 kg hr^{-1})		
0	0.06±0.006	A	a,b	0.06±0.003	A	a	0.04±0.003	A,B	b	0.06±0.002	D	a,b
20	0.06±0.001	A	a	0.06±0.001	A	a	0.05±0.004	A	b	0.06±0.002	D	a,b
40	0.06±0.013	A	a	0.07±0.019	A	a	0.05±0.001	A,B	a	0.07±0.004	A,B,C,D	a
60	0.07±0.001	A	a	0.07±0.013	A	a	0.04±0.001	B	b	0.06±0.003	C,D	a,b
80	0.08±0.006	A	a	0.08±0.006	A	a	0.05±0.003	A,B	b	0.07±0.003	B,C,D	a,b
100	0.07±0.006	A	a	0.08±0.009	A	a	0.04±0.001	B	b	0.08±0.003	A	a
120	0.06±0.001	A	a	0.06±0.001	A	a	0.05±0.003	A,B	b	0.07±0.003	A,B,C	a
140	0.07±0.006	A	a	0.08±0.012	A	a	-	-		0.08±0.001	A	a
160	0.07±0.006	A	a	0.08±0.006	A	a	-	-		0.07±0.004	A,B	a
180	0.07±0.006	A	a	0.07±0.005	A	a	-	-		0.07±0.002	A,B,C	a
200	0.07±0.006	A	a	0.07±0.001	A	a	-	-		0.07±0.003	A,B,C	a
220	0.07±0.006	A	a	0.07±0.006	A	a	-	-		0.07±0.003	A,B,C,D	a

Note: Means within each column with different lowercase letters are significantly ($p<0.05$) different. Means within each row with different capital letters are significantly different ($p<0.05$).

TABLE 2. TOTAL POLAR COMPOUNDS (%) OF PALM OLEIN WITH TERTBUTYLHYDROQUINONE (TBHQ), OR ROSEMARY EXTRACT (RE), OR WITHOUT ANTIOXIDANT (NA), AT DIFFERENT RATES (975 and 1800 kg hr^{-1}) DURING CONTINUOUS FRYING OF WHEAT PELLET SNACKS

Time (min)	TBHQ (975 kg hr^{-1})			RE (975 kg hr^{-1})			NA (1800 kg hr^{-1})			NA (975 kg hr^{-1})		
0	7.67±0.29	D	a	7.50±0.05	G	a	7.25±0.25	B	a	7.50±0.50	C	a
20	8.00±0.50	D	b	9.67±0.29	E,F	a	8.00±0.05	A	b	9.00±0.86	B,C	a,b
40	9.50±0.10	B,C	b	10.33±0.19	B,C,D,E	a	8.00±0.07	A	c	9.67±0.28	A,B	b
60	9.50±0.15	B,C	b	10.67±0.20	A,B,C	a	8.33±0.29	A	c	10.17±0.76	A,B	a,b
80	9.67±0.29	A,B,C	b	10.50±0.05	A,B,C,D	a,b	8.00±0.07	A	c	10.67±0.57	A,B	a
100	9.10±0.42	C	b,c	10.67±0.29	A,B,C	a	8.00±0.09	A	c	10.00±0.86	A,B	a,b
120	9.83±0.29	A,B,C	a	9.83±0.20	D,E,F	a	8.25±0.25	A	b	9.50±0.50	A,B	a
140	9.17±0.30	C	b	11.17±0.23	A	a	-	-	-	9.83±0.57	A,B	b
160	10.50±0.10	A	a	11.00±0.07	A,B	a	-	-	-	10.83±0.76	A	a
180	9.17±0.19	C	a	9.50±0.08	F	a	-	-	-	10.33±0.28	A,B	a
200	10.50±0.09	A,B	a	10.17±0.58	C,D,E,F	a	-	-	-	10.33±0.57	A,B	a
220	9.17±0.08	A,B,C	b	10.17±0.29	C,D,E,F	a	-	-	-	10.17±0.28	A,B	a,b

Note: Means within each column with different lowercase letters are significantly ($p<0.05$) different. Means within each row with different capital letters are significantly different ($p<0.05$).

when frying at 1800 kg hr^{-1} with POo free of added antioxidants. In all the evaluated cases, TPC values were under the established limits, being 25% (Bou *et al.*, 2012). It has been reported that the evolution of TPC under continuous frying processes is less pronounced than in intermittent frying operations (Tarmizi *et al*., 2016) that is consistent with the values found in the present work. In a similar manner to that observed for FFA, the change in the TPC values in the POos used for frying does not present a clear trend, attributed to the high turnover rate.

The *p*-AV values for POos are shown in *Table 3*. The *p*-AV indicates the amount of aldehyde compounds formed as a consequence of secondary oxidative rancidity. After an initial increase, the equilibrium was reached after the first 20-40 min, then the obtained values were relatively stable. The lowest degradation values were obtained when frying at 1800 kg hr^{-1} condition, with a maximum value of 8.1 after 80 min of continuous frying. For 975 kg hr^{-1} condition, the presence of TBHQ in POo promoted significantly lower *p*-AV values than RE and NA ($p<0.05$). RE contains carnosol and carnosic acid as their primary phenolic antioxidants, which could react with lipid or hydroxyl radicals and convert them into stable products (Che Man and Tan, 1999). However, it seems to have a slight effect in the case of continuous frying. In general, after an initial increase in TPC in the POo used for continuous frying of wheat snacks, the obtained values were similar and, as in the other evaluated oxidation indexes, this was due to the high turnover of the frying oil.

The results from the analysis of induction time are presented in the *Table 4*, after an initial decrease ($p<0.05$) in most of the cases, the obtained values

TABLE 3. *p*-ANISIDINE VALUE OF PALM OLEIN WITH TERTBUTYLHYDROQUINONE (TBHQ), OR ROSEMARY EXTRACT (RE), OR WITHOUT ANTIOXIDANT (NA), AT DIFFERENT RATES (975 and 1800 kg hr^{-1}) DURING CONTINUOUS FRYING OF WHEAT PELLET SNACKS

Time (min)	TBHQ (975 kg hr^{-1})			RE (975 kg hr^{-1})			NA (1800 kg hr^{-1})			NA (975 kg hr^{-1})		
0	2.6±0.1	H	b	10.3±0.1	J	a	3.2±0.1	D	b	10.5±0.4	F	a
20	4.3±0.1	G	d	13.1±0.1	H,I	b	6.9±0.1	B,C	c	13.6±0.2	E	a
40	11.3±0.1	F	c	13.3±0.1	H	b	6.5±0.2	C	d	14.5±0.2	D,E	a
60	11.9±0.1	E	c	14.6±0.1	F	b	7.2±0.2	B	d	15.3±0.1	C,D	a
80	11.6±0.1	F	c	13.9±0.1	G	b	8.1±0.3	A	d	16.3±0.3	A,B	a
100	13.6±0.1	A,B	c	16.0±0.1	D	a	7.2±0.2	B	d	15.6±0.1	B,C	b
120	12.6±0.1	D	c	16.6±0.1	C	a	7.2±0.2	B	d	16.1±0.2	A,B,C	b
140	12.6±0.1	D	c	18.1±0.2	A	a	-	-	-	16.5±0.1	A,B	b
160	13.0±0.1	C	b	17.2±0.1	B	a	-	-	-	16.5±0.3	A	a
180	13.3±0.1	B	b	12.8±0.1	I	b	-	-	-	16.3±0.5	A,B	a
200	14.0±0.1	A	b	12.9±0.1	I	c	-	-	-	16.1±0.3	A,B,C	a
220	13.5±0.1	A	b	15.4±0.3	E	a	-	-	-	15.8±0.1	A,B,C	a

Note: Means within each column with different lowercase letters are significantly ($p<0.05$) different. Means within each row with different capital letters are significantly different ($p<0.05$).

TABLE 4. INDUCTION PERIODS (hr) OF PALM OLEIN WITH TERTBUTYLHYDROQUINONE (TBHQ), OR ROSEMARY EXTRACT (RE), OR WITHOUT ANTIOXIDANT (NA), AT DIFFERENT RATES (975 and 1800 kg hr^{-1}) DURING CONTINUOUS FRYING OF WHEAT PELLET SNACKS

Time (min)	TBHQ (975 kg hr^{-1})			RE (975 kg hr^{-1})			NA (1800 kg hr^{-1})			NA (975 kg hr^{-1})		
0	6.22±0.05	A	a	4.49±0.04	B	b	4.19±0.05	A	c	4.09±0.05	A	c
20	4.11±0.05	C	a	3.89±0.05	D,E	b	4.24±0.04	A	a	3.79±0.04	B	b
40	4.54±0.07	B,C	a	4.00±0.05	C,D	a	3.74±0.06	B,C	a	3.54±0.03	C,D	a
60	4.83±0.05	B,C	a	3.49±0.05	F,G	b	3.81±0.07	B	b	3.21±0.04	F	b
80	4.67±0.04	B,C	a	4.07±0.06	D	b	3.61±0.05	C	c	3.41±0.05	D,E	d
100	4.74±0.06	B	a	3.61±0.07	E,F	b,c	3.70±0.10	B,C	b	3.50±0.07	C,D	c
120	4.73±0.05	B,C	a	3.21±0.04	G	c	3.87±0.08	B	b	3.39±0.06	E,F	b,c
140	4.44±0.04	B,C	a	3.54±0.05	F,G	b	-	-	-	3.21±0.07	F	b
160	4.32±0.03	B,C	c	3.47±0.07	E,F	b	-	-	-	3.51±0.05	D,E	b
180	4.75±0.08	B	a	4.01±0.10	D	b	-	-	-	3.47±0.04	C,D	c
200	4.43±0.10	B,C	b	4.95±0.05	A	a	-	-	-	3.57±0.05	B,C	c
220	4.73±0.08	B	a	4.41±0.05	B,C	b	-	-	-	3.67±0.06	B,C	c

Note: Means within each column with different lowercase letters are significantly ($p<0.05$) different. Means within each row with different capital letters are significantly different ($p<0.05$).

varied slightly during the continuous frying of wheat pellets. Comparing 975 and 1800 kg hr^{-1} conditions, lower degradation was observed at 1800 kg hr^{-1}. At 975 kg hr^{-1}, TBHQ samples had the highest induction time values, remained stable around 4.5 hr ($p<0.05$) during the 200 min of continuous frying. POo without antioxidant (NA) showed decreasing values after 60 min of frying, and then stabilised between 3.2 and 3.7 hr of induction time. POo with RE showed the lowest induction time (3.2 hr).

The obtained indices for POo employed for continuous frying of wheat pellets were lower than those reported in the work of others. Most of the published work have been done in batch deep-fat frying. The oil typically remains in the fryer for days at high temperature cycles in the presence of environmental oxygen and water from food, which promotes alteration of the properties of the oil like hydrolysis, isomerisation, polymerisation and oxidation reactions, which are the main reasons for the gradual degradation of the oil. Flores-Álvarez *et al*. (2012) reported for batch-fried French fries, 0.8% to 1.4% in FFA and 29.2% TPC. Cardoso-Ugarte *et al*. (2013) reported 0.1%-0.6 % for FFA, 15.26% for TPC, a maximum *p*-AV of 82.5, and values of 1 hr induction time for POo without antioxidant, and 2 hr induction time for POo with basil essential oil (BEO) as antioxidant. Fernandez-Cedi *et al.* (2012) reported *p*-AV of 46.5 for French fries batch-fried in POo with 200 ppm of TBHQ. In the frying of potato chips, Che Man and Jaswir (2000) reported 0.05%-0.42% of FFA and *p*-AV of 50.2 using POo with RE in a batch fryer. Du Pleiss and Meredith (1999) found a maximum FFA value of 0.041% and 13.2% TPC in industrial frying using POo. In other products, Lee *et al.* (2002) reported *p*-AV ranging between 80 and 120 when different concentrations of spinach powder were tested, as a natural antioxidant in soyabean oil. The lower values obtained during the frying of wheat pellet in the industrial continuous system are related to the food type (very low moisture content), short frying time (30 s) and continuous frying.

The continuous frying system consists of a heating system and a conveyor immersed in a hot oil container, wherein the conveyor feeds the system with wheat pellets flowing through the fryer in the same direction as the oil. Due to the fast oil absorption by the wheat pellets during the frying process (30%), the oil losses need to be compensated by introducing a make-up stream of fresh oil, which is adjusted by an automatic control system. Additionally, a temperature controller regulates the heating system in order to reject the effect of external variations (*i.e.* the fed velocity of the wheat pellets, as well as in the flow rate, and temperature of the fresh oil) on the temperature of the frying oil, similar to that described in Wu *et al.* (2010).

Table 5 shows the oil consumption and turnover value for the two different working rates in the industrial continuous frying. The turnover values were low due to the pellet absorbing around 30% of oil, and this absorption occurred in a short frying period of time (30 s) compared to other processes, such as 4 min of frying time for potato chips, or 4 hr of turnover established for frying of breaded chicken (Ferreira, 2014). Therefore, when the speed of fresh oil addition increases as a result of an increase in the food frying capacity, the system results in a lower turnover value (Hosseini *et al*., 2016).

As the flow rate of the make-up stream is proportional to the oil absorption velocity, the whole oil contained within the frying container was replaced in 1.5 hr (turnover time) when the system worked at 975 kg hr^{-1} and 0.8 hr at 1800 kg hr^{-1}. Analyses were recorded during 200 min and 120 min, respectively; which guarantees the process oil has been totally replaced by 2.5 times. As shown in *Tables 1* to *4*, larger variations in the evaluated properties were observed at the beginning of the process, that matched with the higher deviations in temperature and oil level (since the fryer was initially fed, causing the temperature and oil level to drop suddenly). However, after approximately 20 min all the variations became minimal, which suggested that the process had reached steady state. This stable operation, plus the calculated turnover times and rates, allow the good performance of the POo.

Sensory Analysis

Table 6 presents the obtained results from the sensory analysis of the wheat snacks after continuous frying and different periods of storage at accelerated conditions. A slightly rancid flavour (mean scores higher than 2.0) was detected after 23 days of storage of those wheat snacks fried at 975 kg hr^{-1} in POo with or without antioxidants. The rancid flavour sensory scores, as expected, increased during the storage. After 45 days at 40°C, the rancid flavour was evident (mean scores near to 3.0) and a slight rancid odour was detected. The addition of antioxidants in the frying POo did not affect the sensory response in the snacks ($p>0.05$). For POo without antioxidants, there was neither a difference in rancidity flavour or odour of the stored wheat snack associated to the capacity (975 or 1800 kg hr^{-1}) in the continuous fryer ($p>0.05$). The quality of the POo used during continuous frying could affect the stability in terms of rancid sensory (flavour and / or odour) perception (Bou *et al*., 2012), but the relatively high oil turnover used in this work had a positive influence in the frying POo and thus in the snack stability.

CONCLUSION

The use of RE as antioxidant in POo for frying of wheat pellet snacks in an industrial continuous fryer showed slightly higher oxidative degradation, and similar hydrolytic degradation than TBHQ. But, the use of either antioxidant did not result in an increase of the shelf-life of the fried product. Rather than the added antioxidant, the oil turnover had a stronger influence in the stability of POo when used for industrial continuous frying. Lower antioxidant

TABLE 5. OIL TURNOVER AND OIL CONSUMPTION DURING INDUSTRIAL CONTINUOUS FRYING OF WHEAT PELLET SNACKS IN PALM OLEIN (fryer capacity: 350 litres)

Time (min)	975 kg hr^{-1}				1 800 kg hr^{-1}			
	Pellet consumption (kg)	Fried product (kg)	Oil addition (litre)	Turnover (hr)	Pellet consumption (kg)	Fried product (kg)	Oil addition (litre)	Turnover (hr)
0	0	0	0	1.5	0	0	0	0.8
60	743	975	232	-	1 350	1 800	450	-
120	1 486	1 951	465	-	2 700	3 600	900	-
180	2 229	2 926	697	-	-	-	-	-
240	2 972	3 901	929	-	-	-	-	-

TABLE 6. SENSORY SCORES OF RANCIDITY EVALUATION DURING STORAGE OF FRIED WHEAT SNACKS IN PALM OLEIN WITH SELECTED ANTIOXIDANT [tertbutyhydroquinone (TBHQ), rosemary extract (RE), palm olein without antioxidant (NA)] AND TWO DIFFERENT OPERATION RATES (975 and 1800 kg hr^{-1})

	Rancidity flavour#				Rancidity odour#			
Time (day)	975 kg hr^{-1} TBHQ	975 kg hr^{-1} RE	975 kg hr^{-1} NA	1 800 kg hr^{-1} NA	975 kg hr^{-1} TBHQ	975 kg hr^{-1} RE	975 kg hr^{-1} NA	1 800 kg hr^{-1} NA
0	1.00± $^{a\ A}$	1.00± $^{a\ A}$	1.00± $^{a\ A}$	1.00± $^{a\ A}$	1.00± $^{a\ A}$	1.00± $^{a\ A}$	1.00± $^{a\ A}$	1.00± $^{a\ A}$
8	1.30±0.47 $^{a\ A,B}$	1.50±0.51 $^{a\ B}$	1.35±0.49 $^{a\ B}$	1.30±0.39 $^{a\ A,B}$	1.25±0.55 $^{a\ A,B}$	1.50±0.51 $^{a\ B}$	1.20±0.41 $^{a\ A,B}$	1.15±0.40 $^{a\ A,B}$
13	1.45±0.69 $^{a\ B}$	1.60±0.50 $^{a\ B}$	1.45±0.60 $^{a\ B}$	1.45±0.37 $^{a\ B}$	1.45±0.69 $^{a\ B}$	1.60±0.84 $^{a\ B}$	1.25±0.44 ^{B}	1.30±0.33 $^{a\ B}$
23	2.05±0.68 $^{a\ C}$	2.10±0.55 $^{a\ C}$	2.00±0.32 $^{a\ C}$	1.90±0.35 $^{a\ C}$	1.65±0.63 $^{a\ C}$	1.75±0.72 $^{a\ B,C}$	1.50±0.61 $^{a\ C}$	1.55±0.42 $^{a\ B}$
38	2.10±0.72 $^{a\ C}$	2.25±0.79 $^{a\ C}$	2.20±0.70 $^{a\ C}$	2.20±0.51 $^{a\ D}$	1.85±0.55 $^{a\ D}$	1.80±0.41 $^{a\ B,C}$	1.75±0.75 $^{a\ D}$	1.80±0.39 $^{a\ C}$
45	2.70±0.47 $^{a\ D}$	2.80±0.41 $^{a\ D}$	2.90±0.45 $^{a\ D}$	2.85±0.35 $^{a\ D}$	2.15±0.75 $^{a\ E}$	2.05±0.69 $^{a\ C}$	2.10±0.81 $^{a\ E}$	2.00±0.55 $^{a\ C,D}$
55	3.05±0.49 $^{a\ D}$	3.10±0.51 $^{a\ D}$	3.10±0.60 $^{a\ D}$	3.05±0.45 ^{ADE}	2.65±0.39 $^{a\ F}$	2.50±0.31 $^{a\ D}$	2.60±0.31 ^{AF}	2.50±0.27 ^{AE}

Note: Values are means of 20 panellists.
Means within each row with different lowercase letters are significantly ($p<0.05$) different. Means within each column with different capital letters are significantly different ($p<0.05$).
Storage at 40°C and 10% relative humidity conditions in a controller chamber.
1 = no rancidity, 2 = slight rancidity, 3 = evident rancidity, 4 = extreme rancidity.

addition would be recommended in the wheat pellet industrial frying, giving to the consumers a product with fewer additives and cleaner labels. These results are valuable to understand the industrial frying process as it occurs in practical applications.

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