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Effect of Smoking-method on Biochemical and Microbiological Quality of Nile Tilapia (*Oreochromis niloticus*)

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ABSTRACT

Changes in biochemical and microbiological quality of Nile tilapia during two smoking process were investigated. Total fatty acid and amino acid contents in Nile tilapia were 4.24 and 17.36 g/100 g fresh sample, respectively, The major fatty acids present were linoleic acid (C18:2n-6). The difference in the proximate composition between smoked and fresh samples was significant ($p<0.05$). After industrial smoking and traditional smoking treatments, the total lipids' peroxide value and thiobarbituric acid reactive substances increased significantly ($p<0.05$) to reach 2.61 and 3.44 meq active O_2 kg^{-1} oil and 0.76 and 1.29 mg MA kg^{-1} oil, respectively. Fatty acid profile of non-polar lipid remains unchanged during industrial and traditional smoking process. However, polyunsaturated fatty acids (% of total fatty acids) of polar lipid decreased significantly ($p<0.05$) during both smoking processes. Smoking conditions had a significant effect on the microbiological quality. Therefore, mesophiles and total coliforms increased within smoking treatment with higher counts in the traditional smoking process.

Key words: Nile tilapia, smoking, biochemical composition, quality changes

INTRODUCTION

In Tunisia, Nile tilapia was introduced in 1999 in order to take advantage of the enormous geothermal water resources in the south of the country, which had hither being under used for aquaculture purposes. This species is usually sold as a raw product and it is characterized by its sources of nutrients such as proteins and lipids, but also by its high humidity content which can be the most important cause of their deterioration, especially in such hot countries. Major negative quality changes that occur during processing, distribution and final preparation of lipid-rich food may be attributable to oxidation effects (Chaijan *et al.*, 2006) which can adversely affect nutritional quality, wholesomeness, safety, colour, flavour and texture.

The application of hot smoking to Nile tilapia, in order to extend its shelf life is a process of interest. Smoke curing is a traditional fish preservation method of considerable economic importance worldwide. The smoke is produced by the process of incomplete combustion of wood in order to impart a characteristic flavour and colour to the fish. In addition, smoking increases the shelf life of fish as a result of the combined effects of dehydration, antimicrobial and antioxidant activity of several of the smoke constituents mainly: formaldehyde, carboxylic acids, phenols (Horner, 1997; Doe, 1998; Leroi *et al*., 2000; Rorvik, 2000).

Despite the numerous cited studies on aquaculture of the Nile tilapia, no detailed on lipid oxidation and biochemical analysis of these fish are available during the smoking process. The objective of the present study was to evaluate the nutritional value of the Nile tilapia (*Oreochromis niloticus*) and the changes in lipid quality during traditional and industrial smoking process.

MATERIALS AND METHODS

Samples collection and preparation: The Nile tilapia (*Oreochromis niloticus*) was collected from the dam of El Hma (36°35'32" N, 10°18'15"E) in September 2010. The average weight and length of sampled fish were 198.12 g and 18.05 cm, respectively. The samples were kept in ice and transported to the laboratory where they were rapidly weighted, measured headed and filleted. The flesh has been cut away from the bone by cutting lengthwise along one side of the fish parallel to the backbone. In preparation for filleting, any scales on the fish should be removed.

The fillets were separated into three lots: (1) The first one was used for raw material (stored at -40°C until analysis), (2) The second was traditionally smoked and (3) The third was smoked using a Räucher F V2A. -Heizung industrial smoking chamber with an external smoke generator.

The traditional method of smoking was conducted in designed smoking kilns following pattern of old smoking chambers with internal smoke generator and furnace. Total time of drying and smoking process in the traditional chamber was 3 h and 45 min (Ciecierska and Obiedziski, 2007). After that time, smoked products were steamed until the temperature of 68-72°C was reached. Subsequently, they were chilled to a temperature below 10°C.

The industrial method of smoking was conducted in the following order: a light drying period (150 min, 50-60°C), a hot smoking period (30 min, 65-70°C) and cooking period until the temperature of 68-72°C in centre was reached. Finally, fish were cooled by using cold air to temperature below 10°C. The oak wood was used for both smoking process (Cardinal *et al*., 2001). The dried fillets of fish obtained were put in polyethylene bags, vacuum-packed and stored at -40°C until analysis. Frozen period was no longer than 28 days (Kumolu-Johnson *et al*., 2010).

Biochemical analysis:

- **Moisture:** Moisture of the fish samples was determined according to the AOAC (1990) method by drying in an oven at 105°C. Results were expressed as percentage of wet weight (n = 6)
- **Ash content:** Ash content was determined by burning sample for 12 h in a furnace at 525°C according to the AOAC (1990) method. Results were expressed as percentage of wet weight (n = 6)
- **Total protein content:** Total protein content in samples was determined using Kjeldahl method (AOAC, 1990). Results were expressed as percentage of wet weight (n = 3)

- **Lipid:** Lipid was extracted by the Bligh and Dyer method (Bligh and Dyer, 1959). The obtained oil was solubilized in chloroform with BHT (50 ppm) and stored at -20°C (n = 6 for each sample). Non polar and polar lipids were obtained by separating in a solid phase silica column (Isolute SPE column, UK) with the recovered elution of 60 mL hexane-diethyl ether (1:2) and 20 mL methanol, respectively
- **Fatty acids methyl esters (FAMEs):** Fatty acids methyl esters (FAMEs) were obtained by the method described by Metcalfe *et al.* (1966). The resulting methyl esters were analysed (n = 4) using an Agilent Gaz chromatograph system 6890N equipped with a Flame Ionization Detector (FID), a splitless injector and a polar INNOWAX fused silica capillary column (30 m* 0.25 mm i.d. *0.25 μm film thickness). The temperature of the injector and the detector were 250 and 275°C, respectively. Helium was used as a carrier gas with a flow rate of 1.5 mL min^{-1}. Peaks were identified by comparison of their retention times with PUFA 3 FAMEs standards (SUPELCO). Fatty acid composition of Polar lipids and Non polar lipids were expressed as percentage of total fatty acids (n = 4). The values were expressed in g/100 g of edible flesh using conversion factors indicated by Weihrauch *et al.* (1977)
- **Total amino acid (AA):** Total amino acid (AA) composition was determined using an Agilent chromatograph L1100 (high performance liquid chromatography HPLC) equipped with a quaternary pump, a 20 μL injection valve and a diode array and fluorescence detectors. Mobile phase A was composed of 10% of acetonitrile/methanol/water (45:45:10; v/v/v) and the mobile phase B was composed of 90% of sodium phosphate buffer Na_2HPO_4 (pH 6.5). The flow rate was constant at 1 mL min^{-1} and the column temperature was set at 25°C. The fluorescence excitation and emission wavelengths were 340 nm of λ_{ex} and 450 nm of λ_{em}, respectively. Samples were hydrolysed in 6 M HCl in evacuated sealed tubes at 110°C for 24 h. After derivatization by O-phthalaldehyde, amino acids were identified by comparison of their retention times with those of standards (Sigma) and quantified with the software EZChrom Elite™ CDS Chromatography, using Sigma amino acids as external standard. The results were expressed as g of amino acid per 100 g flesh
- **The peroxide value (PV):** The peroxide value (PV) was determined according to the ferric thiocyanate method with slight modification (Chapman and Mackay, 1949). The results were expressed in terms of meq. of oxygen per kg of oil (n = 3)
- **Thiobarbituric acid reactive substances (TBARS):** Thiobarbituric Acid Reactive Substances (TBARS) were determined according to the AOCS (1998) method. This procedure allows the direct determination of TBARS in oils and fats without preliminary isolation of secondary oxidation products. The results were expressed as mg malonaldehyde/kg of oil (n = 3)
- **Free fatty acids:** Free fatty acids were determined according to the method described by Bernardez *et al.* (2005). Quantification was based on a calibration curve using oleic acid as standards (n = 3)

Microbiological analyses: Microbiological counts were made on fresh samples and after smoking. Mesophile counts were determined using Plate Count Agar (Biokar Diagnostics, Beauvais, France), after incubation for 48 h at 30°C. For the numeration of total coliforms, appropriate dilutions were poured plated with melted Violet Red Bile Agar (Difco, Detroit, MI), plates were incubated at 30°C for 24 h. The count of *Pseudomonas* (NF V04-504, 1998) was made using Cetrimide agar (Fluka Biochemika, Steinheim, Switzerland).

Statistical analysis: Statistical analysis was performed using SPSS software, version 10.0.5. The comparison of different biochemical parameters was realized using Duncan's test (95% confidence interval) with one-way ANOVA.

RESULTS AND DISCUSSION

Proximate composition: The lipid and protein contents found in fresh fillets of Tilapia were 4.24 and 17.36 g/100 g, respectively (Table 1). Generally, lipid content varies within species (1.46-5.77 g/100 g) and is affected by the catching season (1.20-18.4 g/100 g) (Bandarra *et al.,* 1997; Osman *et al.,* 2001). Ash content in the fresh fillets was 1.28 g/100 g, such levels were higher than those found in other species (Ben-Gigirey *et al.,* 1999; Mazorra-Manzano *et al.,* 2000).

Significant differences ($p<0.05$) were found in the moisture, protein and ash contents among fresh Tilapia, traditional and industrial smoked Tilapia. Moisture content in the final traditional and industrial smoked products (25.45 and 22.99%, respectively) lessens approximately three times compared to the initial product (77.12%). This is due to a loss in moisture during hot smoking. Moisture content in industrial smoked fillets of Tilapia was significantly ($p<0.05$) lower than traditional smoked fillets.

The percentage crude protein and fat contents in smoked fillets of Tilapia were significantly ($p<0.05$) higher than fresh samples values for both treatments (industrial and traditional smoking process). This could be explained by the decrease in water activity due to the high temperature especially in the case of industrial smoking process. For this, the highest value of crude protein (59.04±6.67%) and fat content (21.98±4.51%) were recorded in industrial smoked fish. Similar results for chemical composition of smoked fish have been reported in previous studies (Goulas and Kontominas, 2005; Bilgin *et al.,* 2008).

Total fatty acid and amino acid analyses: Fatty acid composition of Tilapia's fillets during traditional and industrial smoking process is shown in Table 2. In fresh fillets, Saturated Fatty Acids (SFA) (2.97 g/100 g edible Tilapia) constitute the majority of the fatty acids pool, followed by monounsaturated (MUFA) (1.89 g/100 g edible Tilapia) and PUFA (1.27 g/100 g edible Tilapia). n-3 and n-6 PUFA levels were 0.44 and 0.74 g/100 g edible Tilapia respectively, in which, C22:6n-3 and C18:2n-6 were the prominent PUFA. Many studies have clearly shown the importance of omega 3 and 6 fatty acids for human health and nutrition (Connor, 2000; Sidhu, 2003). Significant differences ($p<0.05$) were found in fatty acid content during and between the two smoking process. Therefore, all fatty acid groups increased within drying treatment with higher levels in the industrial smoking process. All treatments led to significant increases in a-linolenic acid (18:3n-3), eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (C22:6n-3).

Table 3 shows the amino acid content of Tilapia's fresh and smoked fillets. In fillets, glutamic acid (1.73 g/100 g) had the highest concentration. Isoleucine and valine constituted the highest

Table 1: Composition of Nile tilapia (*Oreochromis niloticus*) during traditional and industrial smoking process

Composition (%)	FT	TST	IST	AV
Moisture	77.12±0.2^{a}	25.45±0.57^{b}	22.99±0.48^{c}	***
Protein	17.36±1.13^{a}	54.77±5.08^{b}	59.04±6.67^{c}	***
Lipids	4.24±0.32^{a}	17.24±3.86^{b}	21.98±4.51^{b}	***
Ash	1.28±0.08^{a}	5.71±0.29^{b}	6.13±0.21^{c}	***

Means with the same letter within rows are not significantly different ($p<0.05$), AV: Analysis of variance, ***Significance at 0.001, FT: Fresh tilapia, TST: Traditional Smoked Tilapia, IST: Industrial Smoked Tilapia

Table 2: Fatty acid profile of total Nile tilapia (*Oreochromis niloticus*) lipids

Fatty acid (g/100 g)	FT	TST	IST	AV
C14:0	0.37±0.01^{a}	0.99±0.01^{b}	1.01±0.02^{b}	***
C16:0	1.95±0.07^{a}	6.15±0.06^{b}	6.41±0.07^{c}	***
C18:0	0.54±0.01^{a}	1.16±0.02^{b}	1.31±0.02^{b}	***
Others SFA	0.08	0.19	0.22	
Total SFA	2.97±0.08^{a}	8.49±0.06^{b}	8.95±0.07^{c}	***
C16:1n-7	0.64±0.01^{a}	1.79±0.01^{b}	2.12±0.02^{c}	***
C18:1n-9	0.86±0.02^{a}	2.21±0.02^{b}	2.47±0.02^{c}	***
C18:1n-7	0.16±0.01^{a}	0.48±0.01^{b}	0.51±0.01^{b}	**
Others MUFA	0.04	0.07	0.12	
Total MUFA	1.70±0.05^{a}	4.55±0.08^{b}	5.22±0.07^{c}	***
C18:2n-6	0.56±0.02^{a}	1.39±0.01^{b}	1.48±0.01^{b}	**
C20:4n-6	0.18±0.01^{a}	0.63±0.01^{b}	0.70±0.01^{b}	**
C20:5n-3	0.13±0.01^{a}	0.32±0.01^{b}	0.42±0.03^{b}	**
C22:5n-3	0.03±0.01^{a}	0.09±0.00^{b}	0.11±0.01^{b}	**
C22:6n-3	0.28±0.02^{a}	0.54±0.02^{b}	0.78±0.02^{c}	***
Others PUFA	0.11	0.27	0.32	
Total PUFA	1.29±0.13^{a}	3.24±0.12^{b}	3.81±0.16^{c}	***

Means with the same letter within rows are not significantly different ($p<0.05$), AV: Analysis of Variance, **Significance at 0.01, ***Significance at 0.001, FT: Fresh Tilapia, TST: Traditional Smoked Tilapia, IST: Industrial Smoked Tilapia, Others SFA: C15:0. C17:0, Others MUFA: C20:1n-9, Others PUFA: C16:2n-4. C16:3n-4. C18:3n-3. C20:2n-9. C20:3n-6. C20:4n-3

Table 3: Amino acid profile of fresh Nile tilapia (*Oreochromis niloticus*)

Amino acid (g/100 g)	FT	TST	IST	AV
Aspartic acid	0.721±0.05^{a}	2.31±0.11^{b}	2.51±0.13^{b}	***
Glutamic acid	1.73±0.08^{a}	4.26±0.15^{b}	4.42±0.14^{b}	***
Serine	0.27±0.03^{a}	1.18±0.08^{b}	1.25±0.14^{b}	***
Glutamine+Histidine	0.34±0.01^{a}	0.80±0.06^{b}	0.93±0.07^{b}	***
Alanine+Arginine	1.64±0.09^{a}	4.62±0.11^{b}	4.82±0.13^{b}	***
Glycine	1.19±0.11^{a}	3.41±0.11^{b}	3.53±0.13^{b}	***
Threonine	0.80±0.06^{a}	2.02±0.09^{b}	2.07±0.06^{b}	***
Valine	0.76±0.08^{a}	2.42±0.13^{b}	2.48±0.09^{b}	***
Methionine	0.03±0.00^{a}	0.20±0.02^{b}	0.17±0.02^{b}	***
Lysine	0.31±0.03^{a}	0.89±0.06^{b}	0.96±0.07^{b}	***
Tyrosine	0.42±0.06^{a}	1.52±0.09^{b}	1.48±0.08^{b}	***
Tryptophan	0.19±0.06^{a}	0.62±0.05^{b}	0.53±0.04^{b}	***
Phenylalanine	0.29±0.03^{a}	1.12±0.07^{b}	0.99±0.06^{b}	***
Leucine	0.40±0.04^{a}	1.23±0.08^{b}	1.33±0.11^{b}	***
Isoleucine	0.92±0.08^{a}	2.39±0.14^{b}	2.46±0.13^{b}	***
Tryptophan	nd	nd	nd	

Means with the same letter within rows are not significantly different ($p<0.05$), AV: Analysis of Variance, ***Significance at 0.001, FT: Fresh Tilapia, TST: Traditional Smoked Tilapia, IST: Industrial Smoked Tilapia, nd: Not determined because they were destroyed during acidic protein hydrolysis

essential amino acid concentration with levels of 0.92 and 0.76 g/100 g flesh, respectively. Amino acid content increased within smoking treatment to reach in traditional and industrial smoked fillets 28.99 and 29.93 g/100 g flesh, respectively. Tilapia's smoked fillets results were compared with amino acids in eggs and showed that smoked fillets were very rich in amino acids.

Table 4: PV, TBARS and FFA during traditional and industrial smoking process of Nile tilapia (*Oreochromis niloticus*)

	FT	TST	IST	AV
PV (meq active O_2/kg oil)	0.72±0.05[a]	3.44±0.13[b]	2.61±0.13[c]	***
TBARS (mg MA/kg oil)	0.47±0.05[a]	1.29±0.09[b]	0.76±0.08[c]	***
FFA (g/100 g oil)	1.23±0.16[a]	4.27±0.12[b]	2.25±0.18[c]	***

PV: Peroxide Value, TBARS: Thiobarbituric Acid Reactive Substances, FFA: Free Fatty Acids, MA: Malonaldehyde, Means (n = 3) with the same letter within rows are not significantly different ($p<0.05$), AV: Analysis of Variance, ***Significance at 0.001, FT: Fresh Tilapia, TST: Traditional Smoked Tilapia, IST: Industrial Smoked Tilapia

Lipid degradation: Changes in peroxide value, Thiobarbituric acid reactive substances and free fatty acids of fillets of Tilapia during traditional and industrial smoking process are shown in Table 4. Such levels were lower that found in other species like black-skipjack (*Euthynnus lineatus*), sardine (*Sardinella gibbosa*) and mackerel (*Trachurus novaezelandiae*) (Ryder *et al.*, 1984; Mazorra-Manzano *et al.*, 2000; Chaijan *et al.*, 2006).

Results showed that smoking process had a significant effect ($p<0.05$) on the formation of primary oxidation products in the fillets, with higher PV levels obtained in traditional smoked Tilapia. The increase in PV levels is probably due to the temperature of smoking and the high content of unsaturated fatty acids. According to Conne (1995), the acceptability limit for PV of fish oil is 20 meq O_2/kg oil. In this study, all examined fillets oil samples didn't reach this limit after smoking process. Moreover, lipid hydroperoxides are readily decomposed into a wide range of carbonyl compounds, aldehydes, ketones and other compounds that contribute to off flavour of foods as well as colour and texture deterioration (Frankel, 1991; Kolakowska, 2002). Therefore, the accumulation of secondary oxidation products was measured by determining the thiobarbituric acid reactive substances. The initial value of TBARS was 0.47 mg MA/kg oil, suggesting that lipid oxidation didn't occur during post-mortem handling to some extent. From this result, TBARS slightly increased within smoking treatment more in traditional than in an industrial one (1.29 and 0.76 mg MA/kg oil, respectively). Such results were in agreement with Goulas and Kontominas (2005), who reported that the initial TBA value of chub mackerel (*Scomber japonicus*) was 0.23 mg MDA/kg. This value increased to 0.54 and 0.47 mg MDA/kg after the smoking process. The increase in TBA value during the smoking procedure may be attributed to the partial dehydration of fish and to the increased oxidation of unsaturated fatty acids as a result of smoking at relatively high temperatures (up to 70°C). Our results are in agreement with results reported by Goktepe and Moody (1998) who observed a two fold increase in TBA value of raw catfish after smoking (smoke temperature up to 82°C).

In addition to oxidative changes in lipid, free fatty acids were measured to determine the degree of lipolysis in smoked fillets of Tilapia. Hydrolysis of glycerol-fatty acid esters is one of the important changes that occur in fish muscle lipids during post-mortem with the release of free fatty acids. Generally, the formation of FFA in fish oil during storage is related to some factors such as the initial lipid content, the lipolytic activity and temperature. The percentage of FFA in fresh Tilapia lipids was 1.23%. FFA increased significantly ($p<0.05$) within smoking treatment to reach in traditional and industrial smoked fillets of Tilapia 4.27 and 2.25%, respectively. Such increase suggested that Tilapia oil hydrolysis caused by lipases or phospholipases occur especially in traditional smoking process. Azad Shah *et al.* (2009) found that free fatty acid contents increased from 4.55-5.12% within 4 days of drying and then gradually increased up to 10 days of drying (6.86%).

Fatty acid composition: Fatty acids compositions of non polar and polar lipids of Tilapia during different smoking process are presented in Table 5 and 6, respectively.

Table 5: Fatty acids composition of non polar lipids during traditional and industrial smoking process of Nile tilapia (*Oreochromis niloticus*).

	Non polar lipids			
Fatty acid (%)	FT	TST	IST	AV
C14:0	2.98±0.21^{a}	3.06±0.17^{a}	3.18±0.29^{a}	ns
C16:0	29.51±1.04^{a}	30.25±0.94^{a}	31.54±0.74^{a}	ns
C18:0	4.24±0.17^{a}	5.63±0.23^{b}	5.72±0.19^{a}	**
Others SFA	1.63	1.69	1.48	
Total SFA	38.36±0.34^{a}	40.63±0.32^{b}	41.92±0.61^{a}	*
C16:1n-7	10.99±0.32^{a}	10.78±0.19^{a}	10.87±0.32^{a}	ns
C18:1n-9	11.56±0.34^{a}	11.11±0.28^{a}	11.74±0.48^{a}	ns
C18:1n-7	0.83±0.15^{a}	0.92±0.11^{a}	0.94±0.13^{a}	ns
Others MUFA	0.11	0.34	1.07	
Total MUFA	23.49±0.27^{a}	23.15±0.19^{a}	24.62±0.29^{a}	ns
C18:2n-6	10.69±0.32^{a}	10.72±0.31^{a}	10.55±0.32^{a}	ns
C20:4n-6	4.36±0.11^{a}	4.11±0.05^{a}	4.28±0.09^{a}	ns
C20:5n-3	2.73±0.13^{a}	3.21±0.08^{b}	2.67±0.11^{a}	**
C22:5n-3	1.15±0.08^{a}	0.89±0.04^{b}	1.17±0.16^{a}	*
C22:6n-3	5.73±0.17^{a}	5.08±0.13^{b}	5.68±0.21^{a}	*
Others PUFA	2.13	1.91	2.1	
Total PUFA	26.79±0.21^{a}	25.92±0.17^{b}	26.45±0.24^{a}	*

Means (n = 4) with the same letter within rows are not significantly different ($p<0.05$), AV: Analysis of Variance, *Significance at 0.05, **Significance at 0.01, ns: Not significant, FT: Fresh tilapia, TST: Traditional smoked tilapia, IST: Industrial smoked tilapia, Others SFA: C15:0. C17:0, Others MUFA: C20:1n-9, Others PUFA: C16:2n-4, C16:3n-4. C18:3n-3, C20:2n-9. C20:3n-6. C20:4n-3

Table 6: Fatty acids composition of polar lipids during traditional and industrial smoking process Nile tilapia (*Oreochromis niloticus*)

	Polar Lipids			
Fatty acid (%)	FT	TST	IST	AV
C14:0	3.04±0.11^{a}	3.28±0.08^{b}	3.22±0.13^{a}	*
C16:0	35.16±1.36^{a}	37.02±1.18^{a}	35.50±1.21^{a}	ns
C18:0	7.05±0.12^{a}	8.00±0.27^{b}	7.23±0.25^{a}	*
SFA	45.25±0.27^{a}	48.30±0.36^{b}	45.95±0.37^{a}	**
C16:1n-7	5.45±0.26^{a}	5.92±0.31^{a}	5.64±0.38^{a}	ns
C18:1n-9	14.38±0.56^{a}	15.73±1.02^{a}	14.49±0.21^{a}	ns
C18:1n-7	2.30±0.21^{a}	2.93±0.21^{b}	2.78±0.08^{b}	*
Others MUFA	0.38	0.37	0.42	
Total MUFA	22.51±0.36^{a}	24.95±0.45^{b}	23.33±0.24^{c}	***
C18:2n-6	7.72±0.08^{a}	7.67±0.07^{b}	7.66±0.09^{a}	*
C20:4n-6	3.19±0.09^{a}	2.39±0.11^{b}	2.94±0.13^{a}	**
C20:5n-3	3.70±0.26^{a}	2.94±0.21^{b}	3.13±0.23^{ab}	*
C22:5n-3	0.97±0.12^{a}	0.66±0.06^{b}	0.88±0.07^{a}	**
C22:6n-3	5.00±0.29^{a}	5.88±0.16^{b}	6.11±0.28^{c}	***
Others PUFA	4.02	4.15	4.07	
Total PUFA	24.6±0.24^{a}	23.69±0.11^{b}	24.79±0.21^{c}	***

Means (n = 4) with the same letter within rows are not significantly different ($p<0.05$), AV: Analysis of Variance, *Significance at 0.05, **Significance at 0.01, ns: Not significant, FT: Fresh tilapia, TST: Traditional smoked tilapia, IST: Industrial smoked tilapia Others MUFA: C20:1n-9, Others PUFA: C16:2n-4. C16:3n-4. C18:3n-3. C20:2n-9. C20:3n-6. C20:4n-3

Saturated Fatty Acids (SFA) constituted the majority of the fatty acids pool, followed by Polyunsaturated Fatty Acids (PUFA) and Monounsaturated Fatty Acids (MUFA). Within these groups, the major fatty acids were palmitic acid (C16:0), oleic acid (C18:1n-9) and linoleic acid (C18:2n-6). The high-level of C18:1 and C16:0 was in accordance with findings reported by other authors (Passi *et al.,* 2002; Osman *et al.,* 2001), who pointed out that the main saturated and monounsaturated fatty acids detected in marine lipids usually contained 16 and 18 carbon atoms, respectively. Saturated, monounsaturated and polyunsaturated fatty acids percentages remain constant during industrial smoking process. However, saturated and polyunsaturated fatty acids show a significant ($p<0.05$) change throughout traditional smoking process. The marked decrease in PUFA may indicate the oxidation of these unsaturated fatty acids during processing. Such findings are in accordance with PV and TBARS analysis which reported high levels in traditional than industrial smoking process.

Polar lipid shows the same profile of non polar lipid with a dominance of saturated ones. The total amount PUFA was ranged between 18.34 and 22.97%. Within this group, the major fatty acid was docosahexaenoic acid C22:6n-3. According to Duncan's test, PUFA decreased significantly ($p<0.05$) during both smoking process to reach 18.34 and 20.79% in traditional and industrial smoked samples. Such decreases are in agreement with that found in herring filets during the drying process (Azad Shah *et al.*, 2009). Due to their high degree of unsaturation, DHA decreased with 26.5% in traditional smoking process. It is well known that PUFA are especially sensitive to oxidation and degradation phenomena both by enzymatic and chemical oxidation, which produces a great variety of volatile compounds (Coutron-Gambotti and Gandemer, 1999; Kolakowska, 2002). Oxidative degradation of phospholipids might be one of the reasons for the development of the characteristic taste and flavour of fillets of Tilapia during smoking process. Triqui and Reineccius (1995) reported that lipid oxidation (mainly of n-3 PUFAs) is likely to be responsible for flavour development in anchovy during ripening. They also stated that increases in the concentration of volatile compounds are generally associated with the development of typical flavour.

Microbiological quality: The initial loads of mesophiles and total coliforms in the fresh fillets were 5.11 and 4.71 $\log_{10}$ CFU g^{-1}, respectively (Table 7). *Pseudomonas* bacteria haven't been observed in the initial load. Significant differences ($p<0.05$) were found in microbial counts during and between the two smoking process. Therefore, mesophiles and total coliforms increased within smoking treatment with higher levels in the traditional smoking process. Such results were in agreement with Mahmoud *et al.* (2006) which reported that total microbial counts in smoked carp fillet reached 9.5 $\log_{10}$ CFU g^{-1} after drying treatment. Smoking conditions had a significant effect on the microbiological quality of the final dried product. In the traditional smoking process, the temperature and relative humidity are variable. Inversely, these conditions are more stable for

Table 7: Microbial counts of during traditional and industrial smoking process Nile tilapia (*Oreochromis niloticus*)

Bacteria $\log_{10}$ (CFU g^{-1})	FT	TST	IST
Total mesophiles	5.11	7.32	6.47
Total coliforms	4.71	6.48	4.43
Pseudomonas	-	1.63	-

FT: Fresh tilapia, TST: Traditional smoked tilapia, IST: Industrial smoked tilapia

industrial smoking treatment. The smoking of fish is a process whose objective is the preservation of product thanks to the combined effect of dehydration, antioxidant and antimicrobial properties of several smoke constituents mainly phenolic compounds (Serot *et al*., 2008; Koral *et al*., 2009).

CONCLUSION

The results of the present study showed that both traditional and industrial smoking process have a significant effect on lipid and microbiological quality. It was found that PV, TBARS and FFA levels increased significantly during the smoking period with high levels in the traditional smoking process. Such finding indicates partial degradation of lipid especially in polar fraction. Other experimental smoking tests should be created to minimize such oxidation and hydrolysis which may be responsible for off-flavours and off-odours in the final smoked product. Further sensory analysis must be undertaken to determine and to compare the sensory profile of each product.

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