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Influences of hot air drying and microwave drying on nutritional and odorous properties of grass carp (*Ctenopharyngodon idellus*) fillets

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Abstract

Hot air drying and microwave drying were applied to dry fish fillets made of grass carp (*Ctenopharyngodon idellus*), and the correlative influences on nutritional and odorous properties were evaluated by proximate composition, protein solubility, amino acid composition, fatty acid composition, peroxide value, anisidine value, and odour evaluation. Drying resulted in a significant increase of protein but reduced fat content. There was lack of negative influence of the drying process on the amino acid composition of grass carp fillets. Both saturated and monounsaturated fatty acid contents decreased, while polyunsaturated fatty acids increased by an average of 23.8% after drying. Microwave-dried samples showed lower fat loss, higher protein solubility, and lower anisidine values than hot air-dried samples. There was no significant difference in odour quality between hot air-dried and microwave-dried samples. The present study provides a possible application of microwave drying as an efficient drying process for fish fillets.

Keywords: Grass carp; Hot air drying; Microwave drying; Nutrition; Odorous property

1. Introduction

The gross product of low value freshwater fishes, such as grass carp, silver carp and bighead carp, exceeds 60% of the total freshwater fishery yield (Zhang, Zhang, Shan, & Fang, 2007). But the potential of these fishes as a source of low fat, high protein food has not yet been fully utilized, due to the limited storage period and, sometimes, their strong fishy odour. Fresh fish contains up to 80% of water and is highly perishable, with a short storage life (Bala & Mondol, 2001). The appearance of earthy and musty odour or taste in fish may cause a major reduction in the consumption of the products, or make them unsuitable for sale. To improve their preservation quality and acceptance by consumers, more innovative processing techniques need to be applied.

Dried fish fillets are conventional processed products of freshwater fish, because they can be stored for a long time and conveniently used. Hot air drying is the most common drying process, but has significant limitations of uneconomical energy consumption and long processing time. Microwaving changes electricity into high-frequency microwaves that water can absorb, causing water molecular vibration, and results in drying of food (García-Arias, Álvarez-Pontes, García-Linares, García-Fernández, & Sánchez-Muniz, 2003). Microwave drying offers many advantages in processing, including less startup time, faster heating, energy efficiency, space savings, precise process control, selective heating and final products with improved nutritive quality (Sumnu, 2001).

During drying, chemical and physical reactions occur and therefore digestibility is increased, due to protein denaturation, but the content of thermolabile compounds and polyunsaturated fatty acids is often reduced (Finot, 1997). Earthy and musty odour in freshwater fish is often caused by chemical by-products from the growth of blue–green algae, commonly found in lakes and reservoirs (Sung, Li, & Huang, 2005). However, an extensive search of the literature found little information on the nutritional and sensory quality related to drying processes of fish

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fillets. It is therefore interesting to investigate the effects of drying, by different methods, on nutritional quality and sensory properties of grass carp (*Ctenopharyngodon idellus*) fillets.

2. Materials and methods

2.1. Materials and chemicals

Fresh grass carp (*Ctenopharyngodon idellus*) was obtained from a fish market in Hangzhou, China. Fishes were headed, gutted, and skin and bones removed, then cut into pieces with thickness of about 2 cm to get fish fillets. All chemicals used were of analytical grade and supplied by Sigma Co. (St. Louis, USA).

2.2. Drying treatment

Hot air drying of the fillets was performed in a hot air oven (FUMA DGX-9143B-1, China) at 180 °C for 90 min. Microwave drying was performed in a domestic microwave oven (Galanz WP800T, China) at 2450 MHz, 400 W for 8 min. The final moisture content of dried samples was controlled at $20 \pm 2\%$ according to the China aquatic product standard of dried fish fillet (SC/T 3203-2001, 2001). The raw samples were described as RAW; the hot air-dried samples were described as HAD; the microwave dried samples were described as MWD.

2.3. Proximate analysis

Moisture, ash, and crude protein ($N \times 6.25$) were assayed as described by AOAC (2005). Lipid content was determined, as described by Folch, Lee, and Sloane-Stanley (1957).

2.4. Protein solubility in SDS + β-mercaptoethanol

The protein solubility was measured in a solution of sodium dodecylsulphate (SDS) and β-mercaptoethanol (Maruf, Ledward, Nele, & Poulter, 1990). In short, minced fillets (1.5 g) were dispersed in 150 ml of 3 g SDS/100 ml in water containing 1 ml β-mercaptoethanol in 100 ml and magnetically stirred at 20 °C for 30 min. The dispersion was then heated in a boiling water-bath for 30 min, centrifuged at 2500 *g* for 30 min, and filtered. The soluble protein ratio was calculated, comparing the protein contents of the supernatants and that of the grass carp fillets.

2.5. Amino acid composition and amino acid profile

Amino acid content was determined by ion-exchange chromatography in an automatic amino acid analyser (HITACHI L-8800, Japan), as previously described (Castrillón, Alvárez-Pontes, García-Arias, & Navarro, 1996). Prior to hydrolysis, samples were de-fatted with petroleum ether at room temperature. Acid hydrolysis (6 M HCl) was performed at 110 °C for 24 h for all amino acids except sulphur amino acids. Methionine and cysteine were measured after oxidation with performic acid, followed by acid hydrolysis.

The amino acid score was calculated according to the scoring pattern, as suggested by FAO/WHO (1973). The amino acid concentration of the tested protein was compared to the scoring pattern and expressed as grams of amino acid/16 g N in the test protein/g of amino acid/16 g N in the scoring pattern.

Essential amino acid index (EAAI) was calculated according to Oser (1959), using the amino acid composition of whole egg protein published by Hidvegi and Bekes (1984).

2.6. Fat extraction

Fat was extracted from raw and dried fish fillets by the Folch method (Folch et al., 1957). After the addition of a little ethanolic solution of butylated hydroxytoluene (BHT, 1 g/l) to prevent autoxidation, 1 g of sample was homogenized with 20 ml of chloroform–methanol mixture (2:1), the chloroform phase containing fat was evaporated under vacuum in a rotary evaporator. The fat obtained was used to determine peroxide value, anisidine value and fatty acid composition.

2.7. Peroxide value

Fat sample (0.5 g) was mixed with 25 ml of a solution of glacial acetic acid and chloroform (ratio 3:2) in a conical flask, and then 1 ml of saturated potassium iodide was added. The mixture was kept in the dark for about 10 min, and then 30 ml of distilled water and 1 ml of freshly prepared 1% starch were added. After shaking, the samples were titrated with 0.005 M sodium thiosulfate. The peroxide values were expressed as units of mequiv./kg of sample (Egan, Kirk, & Sawyer, 1981).

2.8. Anisidine value

An important indicator of the fat oxidation process is the anisidine value, which defines the secondary oxidation product content. The weighed 0.5 g of fat sample was dissolved in 25 ml of *n*-hexane and left for 30 min; 5 ml of this solution were then transferred to a calibrated test tube. As the blank, 5 ml of *n*-hexane was poured into a second test tube, and subjected to the same process as the test sample. After 1 ml of anisidine reagent was added to each test tube, and rapidly and precisely mixed, tubes were left in the dark for 10 min. The absorbance of the test sample was measured and compared to that of the blank sample at a wavelength of 365 nm. The absorbance of the unreacted solution was also measured against the same blank sample under the same conditions (Regulska-Ilow & Ilow, 2002).

2.9. Fatty acid composition

Fatty acid composition of the fats was determined with gas chromatography (Shimadzu GC-14C, Japan). The GC column used was a 60 m × 0.25 mm, 0.25 μm capillary column (Agilent DB-23, USA). The carrier gas was nitrogen with flow rate of 25 ml/min. The GC oven temperature programme was as follows: the initial temperature was held at 100 °C for 3 min, raised to 190 °C at 20 °C/min, kept 10 min, then raised to 205 °C at 5 °C/min, kept 6 min, then raised to 230 °C at 10 °C/min, and kept 5 min. The identification of the fatty acids was carried out by comparing their retention times with the standards. The amounts of each fatty acid and its isomers present were expressed as percentages of the total fatty acid content.

2.10. Odour evaluation

The raw and the dried fillets were subjected to odour evaluation by a 10-number panel (five females and five males), all of whom were experienced in the odour evaluation of fish foods. Off-odour was assessed and classified on a nine-point scale: 1 (gross taint), 2 (strong taint), 3 (taint), 4 (mild taint), 5 (no taint), 6 (flat aroma), 7 (aroma), 8 (obvious aroma), and 9 (full aroma). The scores from each panellist were averaged for each sample (Robertson, Jauncey, Beveridge, & Lawton, 2005; Zhang et al., 2007).

2.11. Statistical analysis

Amino acid composition and fatty acid composition analysis were replicated three times ($n = 3$), other tests were run in six replicates ($n = 6$). The design was completely randomized. Results were reported as mean values of each determinations ± standard deviation (SD). Analysis of variance was performed by ANOVA procedures (SPSS 12.0 for Windows). Differences among the mean values of the various treatments were determined by the least significant difference (LSD) test, and the significance was defined at $P < 0.05$.

3. Results and discussion

3.1. Proximate composition

The proximate composition of raw and dried grass carp fillets is shown in Table 1. Raw samples presented a low lipid, intermediate protein, and high moisture content, similar to previous reports (Bakir, Melton, & Wilson, 1993). Decrease of the moisture content was the most prominent change in fish fillets after drying. Concomitantly, drying resulted in significant changes of protein and fat composition in fish fillets. Protein, fat and ash contents increased significantly in processed samples on a fresh weight base ($P < 0.05$).

The significant increase in protein levels ($P < 0.05$) in dried fillets, when compared with the raw fillets, suggested that protein nitrogen was not lost during drying. This is in accordance with the findings of other researchers (Gokoglu, Yerlikaya, & Cengiz, 2004; Puwastien et al., 1999). However, there was no significant difference between hot air drying and microwave drying for the protein content.

After drying, there was a significant decrease in fat content that was revealed by the data expressed on a dry matter basis. Microwave-dried fillets retained a higher fat content than hot air-dried samples ($P < 0.05$). This result indicated that the fat loss phenomenon was more intensive in hot air-dried fillets than in microwave-dried samples. Fat may exude with the moisture evaporation and extended heating treatment during hot air drying seems to enhance this phenomenon.

3.2. Protein solubility in SDS + β-mercaptoethanol

Raw samples showed high protein solubility (85.5 ± 1.52%) in SDS + β-mercaptoethanol. After drying, protein solubility in grass carp fillets decreased significantly ($P < 0.05$). Drying showed a significant influence on protein solubility. Hot air-dried fillets displayed a much lower protein solubility (54.4 ± 1.87%) than microwave-dried samples (70.8 ± 1.12%) ($P < 0.05$).

The decreasing of protein solubility in dried samples may be due to heating during the drying process that induces protein denaturation in the fish fillets. The impairment of protein solubility has also been attributed to the formation of stable covalent linkages, although many mechanisms may be involved. The stable covalent linkage formed in the reaction of fish protein with glucose-6-phosphate from muscular glycogen and/or with oxidized lipids could be formed (García-Arias et al., 2003; Jiang, Hwang, & Chen, 1988). Maillard reaction between D-glucose (from glycogen) and muscle proteins might also be considered responsible for the decrease of protein solubility (Castrillón, Navarro, & Alvárez-Pontes, 1997). Therefore, lower

Table 1
Proximate composition of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets

Samples	(g/100 g fresh weight)				(g/100 g dry weight)		
	Moisture	Protein	Fat	Ash	Protein	Fat	Ash
RAW	77.6 ± 1.06a	19.1 ± 0.69b	1.85 ± 0.12c	1.15 ± 0.11b	85.4 ± 1.66b	8.27 ± 0.54a	5.15 ± 0.48a
HAD	20.2 ± 1.06b	69.5 ± 0.68a	5.13 ± 0.11b	4.26 ± 0.14a	87.1 ± 1.03a	6.43 ± 0.14c	5.34 ± 0.23a
MWD	20.4 ± 1.35b	69.2 ± 0.66a	5.56 ± 0.10a	4.28 ± 0.10a	87.0 ± 0.70a	6.99 ± 0.17b	5.38 ± 0.17a

Values in the same column followed by a different letter are significantly different ($P < 0.05$).

protein solubility of hot air-dried fillets than of microwave-dried samples could be explained by more protein denaturation, stable covalent linkage formation, and/or Maillard reaction taking place during hot air drying.

3.3. Composition and quality of amino acids

The composition of the amino acids in grass carp fillets is shown in Table 2, and is similar to other reports (Ismail & Ikram, 2004; Iwasaki & Harada, 1985; Maruf et al., 1990). It was noteworthy that grass carp contained a broad variety of amino acids and their isomers. The main amino acids were found to be aspartic, glutamic, leucine, lysine, and the less abundant ones were cysteine and methionine. Drying caused significant changes in several amino acids. From raw to dried samples significant changes were found for aspartic acid, threonine, glutamic, valine, isoleucine, phenylalanine, lysine and histidine. Aspartic acid, threonine, phenylalanine, lysine and histidine contents were significantly influenced by drying methods ($P < 0.05$).

During drying there was a significant loss of histidine, which confirmed that it is labile to heating (Castrillón et al., 1997). The loss of lysine could be related to the Maillard reaction during the drying process (García-Arias et al., 2003). Cysteine showed negligible changes after drying, indicating its thermostable property (Finot, 1997). Due to the small or little changes undergone in most amino acids, the potential damage of drying should be of very little relevance.

The proportion of essential amino acids (EAA) was about 43.0% in raw fillets, and increased to about 43.4% and 43.8% after hot air drying and microwave drying, respectively (Table 2). The essential amino acid index (EAAI) of raw, HAD and MWD samples were 0.87, 0.88 and 0.89, respectively. There was a slight improvement in EAAI by microwave drying. These results revealed that grass carp is a very good source of amino acids.

The amino acid score evaluates the actual abundance of individual EAA in a food material and relates it to dietary requirements or a reference protein. According to the scoring pattern (FAO/WHO, 1973), the limiting amino acid in raw grass carp fillets was valine. However, drying processes had no particular influence on the amino acid score of fish fillets (Table 3). Protein with a high amino acid score has a high biological value and high net protein utilisation. It was encouraging that drying did not induce much loss of amino acid quality in the fish fillets.

3.4. Fat quality

The qualities of the fats extracted from raw and dried grass carp fillets were determined by peroxide value, reflecting the extent of primary oxidation (Fig. 1) and anisidine value indicating the presence of secondary oxidation (Fig. 2). There was significant difference ($P < 0.05$) in the peroxide values between raw and dried samples, with contents of 7.62, 3.76 and 3.89 mequiv./kg in raw, HAD and MWD samples, respectively (Fig. 1). After drying, peroxide values in fish fillets decreased ($P < 0.05$), but there was no significant difference between hot air drying and microwave drying. Contrary to peroxide values, drying significantly

Table 2
Amino acid composition of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets (g amino acid/100 g protein)

Amino acid	RAW	HAD	MWD
Asp	10.6 ± 0.04a	10.4 ± 0.14b	10.6 ± 0.06a
Thr	4.59 ± 0.02b	4.64 ± 0.01a	4.59 ± 0.02b
Ser	4.22 ± 0.03a	4.27 ± 0.03a	4.18 ± 0.08a
Glu	17.3 ± 0.19a	17.0 ± 0.17ab	16.8 ± 0.32b
Pro	3.60 ± 0.08a	3.64 ± 0.28a	3.49 ± 0.09a
Gly	4.86 ± 0.18a	5.25 ± 0.39a	4.91 ± 0.18a
Ala	5.83 ± 0.09a	5.90 ± 0.11a	5.96 ± 0.04a
Cys	0.52 ± 0.09a	0.60 ± 0.10a	0.59 ± 0.00a
Val	4.56 ± 0.03b	4.72 ± 0.07a	4.77 ± 0.01a
Met	2.96 ± 0.05a	2.97 ± 0.03a	2.93 ± 0.02a
Ile	4.21 ± 0.06b	4.36 ± 0.10a	4.38 ± 0.03a
Leu	8.71 ± 0.05a	8.75 ± 0.12a	8.85 ± 0.08a
Tyr	3.51 ± 0.07a	3.53 ± 0.05a	3.53 ± 0.06a
Phe	4.18 ± 0.07ab	4.11 ± 0.04b	4.27 ± 0.03a
Lys	9.81 ± 0.05ab	9.69 ± 0.13b	9.91 ± 0.05a
His	3.16 ± 0.07a	2.73 ± 0.07c	2.89 ± 0.08b
Arg	6.18 ± 0.02a	6.26 ± 0.10a	6.14 ± 0.04a
Total EAA	43.0 ± 0.21b	43.4 ± 0.56ab	43.8 ± 0.24a
EAAI	0.87	0.88	0.89

Values in the same row followed by a different letter are significantly different ($P < 0.05$).

Table 3
Amino acid score of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets

	RAW	HAD	MWD	Scoring pattern (g/16 g N)
Isoleucine	1.05	1.09	1.10	4.00
Leucine	1.24	1.24	1.26	7.04
Lysine	1.80	1.78	1.82	5.44
Methionine + cysteine	0.99	1.01	1.00	3.52
Phenylalanine + tyrosine	1.26	1.26	1.28	6.08
Threonine	1.15	1.16	1.15	4.00
Valine	0.92	0.95	0.96	4.96

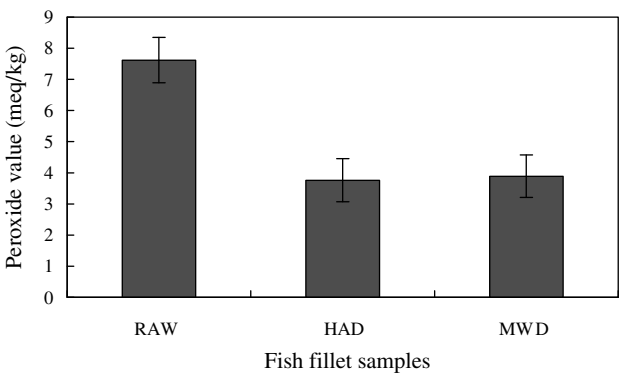

Fig. 1. Peroxide values of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets.

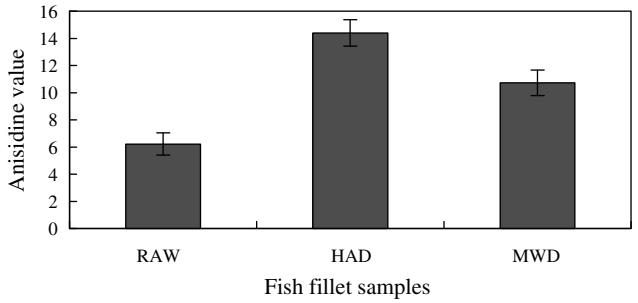

Fig. 2. Anisidine values of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets.

increased anisidine values, the highest being with hot air drying (Fig. 2).

Peroxide value defines the initial stage of the oxidative changes. However, high temperatures accompanying drying processes could speed up the breakdown of peroxides into their carbonyl components, and thus the peroxide value may remain low. On the other hand, anisidine value increased significantly during drying processes. This is a clear indication of the rapid decomposition of hydroperoxides into secondary oxidation products at high temperatures. The data indicate that hydrolytic and oxidative degradations take place during drying. Similar observations were observed by other researchers (Dandjouma, Tchiégang, Kapseu, Fanni, & Parmentier, 2006; Vieira & Regitano-d'Arce, 1999). Because hydroperoxides are unstable and decompose via fission, dehydration and the formation of free radicals, to form a variety of chemical products, such as alcohols, aldehydes, ketones, acids, dimers, trimers, polymers, and cyclic compounds at elevated temperatures (Fristch, 1981; Tan, Che Man, Jinap, & Yusoff, 2002), peroxide value seems to be a poor indicator for heated samples. Alternatively, anisidine value could be reliable and meaningful for evaluating the fat quality of heated samples.

3.5. Fatty acid composition

3.5.1. Saturated fatty acids (SFA)

In grass carp fillets, palmitic acid (C16:0) was the most abundant SFA (Table 4). The relative content of C16:0 was significantly higher in dried fish fillets than in raw ones ($P < 0.05$), with contents of 16.5%, 20.1% and 19.6% in the raw, HAD and MWD samples, respectively. However, the relative content of lauric acid (C12:0) decreased significantly after drying processes ($P < 0.05$). The sum of SFA decreased after drying, ranging from 32.0% in raw fish fillets to 30.6% in hot air-dried fillets and 29.7% in microwave-dried samples ($P < 0.05$).

3.5.2. Monounsaturated fatty acids (MUFA)

Of the fish fillets investigated, the raw samples had the highest proportion of MUFA in their total fatty acids distribution and oleic acid (C18:1) was the predominant fatty acid within this class (Table 4). After drying processes, most of MUFA decreased significantly ($P < 0.05$). Furthermore, erucic acid (C22:1) was undetectable after drying. The total content of MUFA decreased after drying, ranging from 28.0% in raw fish fillets to 21.5% in hot air-dried fillets and 22.6% in microwave-dried samples ($P < 0.05$).

Table 4
Fatty acid composition of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets (g/100 g fatty acids)

Fatty acids	RAW	HAD	MWD
Saturated acids			
C 12:0	9.50 ± 0.10a	3.74 ± 0.14b	3.66 ± 0.16b
C 14:0	0.89 ± 0.03a	0.67 ± 0.01c	0.74 ± 0.02b
C 15:0	0.32 ± 0.01a	0.35 ± 0.03a	0.35 ± 0.02a
C 16:0	16.5 ± 0.06c	20.1 ± 0.10a	19.6 ± 0.20b
C 17:0	0.47 ± 0.09a	0.54 ± 0.03a	0.55 ± 0.01a
C 18:0	4.17 ± 0.28c	5.04 ± 0.07a	4.62 ± 0.05b
C 20:0	0.17 ± 0.04a	0.14 ± 0.01a	0.16 ± 0.01a
Total SFAs	32.0 ± 0.10a	30.6 ± 0.13b	29.7 ± 0.31c
Monounsaturated acids			
C 14:1	0.37 ± 0.01a	0.12 ± 0.01b	0.10 ± 0.00c
C 16:1	3.43 ± 0.30a	2.47 ± 0.02b	2.59 ± 0.06b
C 17:1	0.26 ± 0.02b	0.32 ± 0.01a	0.33 ± 0.00a
C 18:1	22.5 ± 0.04a	17.5 ± 0.20c	18.6 ± 0.10b
C 20:1	0.76 ± 0.03a	0.43 ± 0.03b	0.40 ± 0.01b
C 22:1	0.12 ± 0.01a	0b	0b
C 24:1	0.52 ± 0.01c	0.64 ± 0.03a	0.57 ± 0.01b
Total MUFAs	28.0 ± 0.33a	21.5 ± 0.19c	22.6 ± 0.08b
Polyunsaturated acids			
C 18:2 ω−6	15.0 ± 0.19c	15.6 ± 0.16b	16.8 ± 0.09a
C 18:3 ω−6	0.20 ± 0.03a	0.22 ± 0.01a	0.22 ± 0.02a
C 20:2 ω−6	0.77 ± 0.02b	0.85 ± 0.04a	0.80 ± 0.01b
C 20:3 ω−6	0.78 ± 0.01c	0.94 ± 0.03a	0.86 ± 0.02b
C 22:4 ω−6	0.16 ± 0.03a	0.16 ± 0.02a	0.17 ± 0.01a
Total ω−6 PUFAs	16.9 ± 0.23c	17.8 ± 0.18b	18.8 ± 0.13a
C 18:3 ω−3	8.38 ± 0.07c	10.9 ± 0.16b	12.2 ± 0.12a
C 20:3 ω−3	0.67 ± 0.04b	0.98 ± 0.03a	1.00 ± 0.03a
C 20:4 ω−3	2.50 ± 0.03c	3.31 ± 0.04a	2.71 ± 0.05b
C 20:5 ω−3	0.77 ± 0.03c	2.13 ± 0.05a	1.78 ± 0.04b
C 22:5 ω−3	0.62 ± 0.03c	0.92 ± 0.04a	0.81 ± 0.04b
C 22:6 ω−3	3.50 ± 0.09c	5.12 ± 0.19a	4.10 ± 0.14b
Total ω−3 PUFAs	16.5 ± 0.18c	23.4 ± 0.27a	22.6 ± 0.40b
ω−6/ω−3	1.03 ± 0.01a	0.76 ± 0.01c	0.83 ± 0.01b
Total PUFAs	33.3 ± 0.40b	41.1 ± 0.39a	41.4 ± 0.49a

Values in the same row followed by a different letter are significantly different ($P < 0.05$).

3.5.3. Polyunsaturated fatty acids (PUFA)

The amounts of this fatty acid class varied from about 33% in raw samples to about 41% in dried ones (Table 4). Linoleic acid (C18:2 ω−6) was the most abundant ω−6 PUFA and the concentrations of this fatty acid were 15.0%, 15.6% and 16.8% in the raw, HAD and MWD samples. The content of linoleic acid increased significantly after drying processes ($P < 0.05$). Linolenic acid (C18:3 ω−3) was the most abundant ω−3 PUFA and the content of this fatty acid increased significantly after drying processes ($P < 0.05$); the linolenic acid contents of raw, HAD

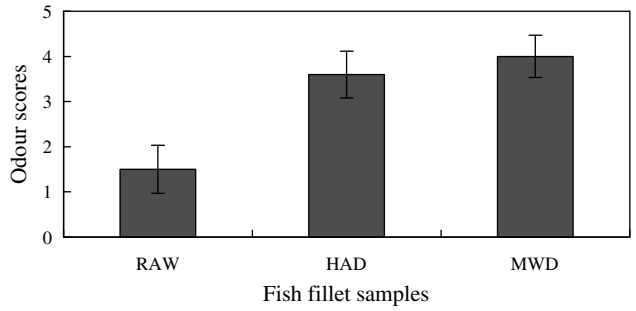

Fig. 3. Odour scores of raw (RAW), hot air-dried (HAD) and microwave-dried (MWD) grass carp fillets.

and MWD samples were 8.38%, 10.9% and 12.2%, respectively. EPA (C20:5) and DHA (C22:6) are typical of fish fatty acids. The HAD samples showed the highest level of EPA (2.13%) and DHA (5.12%); there were significant differences between raw and dried fish fillets ($P < 0.05$). Drying processes significantly increased the relative contents of EPA and DHA in grass carp fillets ($P < 0.05$).

This composition is also evidence that grass carp is a very good source of ω−3 PUFAs that comprised 16.5% of the total fatty acids (Table 4). It is noteworthy that grass carp contains a broad variety of fatty acids and their isomers, and an especially high proportion of PUFAs, a total of ω−3 and ω−6 PUFAs made up around 33.3% of the overall fatty acid content. Most of the PUFAs showed increasing contents after drying process. The relative contents of ω−6 PUFA increased by 0.9% and 1.9% with hot air drying and microwave drying, respectively. However, relative ω−3 PUFA content increased by 6.9% after hot air drying and by 6% after microwave drying.

Fish products represent an important source of ω−3 and ω−6 PUFA that is fundamental for the formation of important structural lipids and elements of cell membranes. In addition, these PUFA are precursors of eicosanoids, which influence inflammation processes and immune reactions (Calder & Grimble, 2002; De Pablo & Àlvarez de Cienfuegos, 2000; Shahidi & Miraliakbari, 2004; Wong, 2005). These two classes of PUFA have opposing physiological functions and their balance is important for normal growth and development. It is recommended that human diet with a ω−6/ω−3 ratio of 1:1 is health-promoting (Dawczynski, Schubert, & Jahreis, 2007; Simopoulos, 2002). This study showed that the ω−6/ω−3 ratio in raw, HAD and MWD samples were 1.03, 0.76 and 0.83, respectively (Table 4). Therefore, the ω−6/ω−3 ratios in grass carp (0.76–1.03) is beneficial for human health.

3.6. Odour evaluation

The odour scores of raw, HAD and MWD samples were 1.5, 3.6 and 4.0, respectively (Fig. 3). As the results show, dried samples received higher odour scores than raw samples. Earthy–musty odour in freshwater-farmed fish represent one of the most significant economic problems encountered in aquaculture. Attempts to mask harvested tainted fish with chemical treatments, various cooking methods and flavourings have achieved limited success (Bett et al., 2000; Mohsin, Bakar, & Selamat, 1999). After drying, the undesirable odorous compounds were partially removed, but mild taint still existed. There was no significant difference in odour quality of grass carp fillets between hot air drying and microwave drying.

4. Conclusions

In general, there were significant influences of drying on nutritional and sensory qualities of grass carp fillets. Lack of negative influence of the drying processes on the amino acid and fatty acid composition of grass carp fillets is of great practical importance, although drying resulted in a significant loss of MUFA content. These results show that different amino acids and fatty acids undergo different changes at elevated temperatures. However, microwave drying could improve the protein quality and prevent lipid oxidation in fish fillets, as compared with the conventional hot air drying. The microwave-dried samples showed lower fat loss, higher protein solubility and lower anisidine values than hot air-dried samples. This research provides basic nutritional information on freshwater grass carp, both raw and dried. The present study also provides a possible application of microwave drying as an efficient drying process for fish fillets.

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