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Production and Characterization of New Hot and Cold Smoked Mussel (*Brachidontes pharaonis*) Meat Products using Sawdust and Liquid Smoke

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ABSTRACT

The main aim of this study was to increase the added value of mussel (*Brachidontes pharaonis*) by producing a new female and male hot and cold smoked meat products using both sawdust and liquid smoke. The results indicated that, new smoked products were rich in protein (19.9 - 45.8 %), ash (13.4 - 17.8 %), considerable level of lipids (12.06 -18.4 %) and carbohydrates (20.4 - 23.8%) on dry weight basis, with 6.73 - 6.25 pH, 3 - 6 % salt content, less than 20 mg/100g TVBN, <3 mg/100g TMA-N, <3 mg MDA/ Kg TBA, 2.95 - 3.95 log CFU/g TVC, 1.34 - 2.15 log CFU /g *S. aureus*, and free from *E. coli* and coliform bacteria. The colour, odour, taste, texture and overall acceptability of these products were very good as described by panelists. Some PAHs of smokes compounds were qualitative detected in some products as estimated by GC-MS method and according to their percentage of the presence probability great acceptance of the samples smoked with sawdust and liquid smoke, with slight differences appearing between them.

INTRODUCTION

Molluscs consider one of an important group of seafood; they live in temperate coastal intertidal ecosystems such as Mediterranean and Red Sea. They are usually found attached to rocks, sea grass and other objects (**Van den Burg *et al*., 2022**). Marine mussels such as *Brachidontes pharaonis* belongs to Mytilidae family, Mytilida Order, within Bivalvia class, Phylum Mollusca (**Vine, 1986; Rusmore-Villaume, 2008**). Through the period from 1995 to 2018, the production of bivalve molluscs around the world was increased from 8.2 to 17.5 million tons due to their yield of an aquaculture (**EUMOFA, 2019; FAO, 2020**). This was attributed to their sensorial properties and lower price comparing with other seafood. Accordingly, attention to diversifying their processing methods and an introducing in different acceptable forms to the consumer are interest to increase from their production. However, smoking is one of the oldest methods of food preservation; it is still widely used in food processing. It is enhanced the flavours and colours in addition to extend the shelf life of smoked products (**Ledesma *et al*., 2017**). This process carried out inside kilns using smoldering wood, shavings and sawdust as a smoke source. The smoke temperature is around 30 ± 5 °C in cold-smoking method and ranged from 30 to 90 °C in hot smoking procedure which includes three stages, drying at 30°C, cooking at 60°C and heavily smoking

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at 90 °C (**Stołyhwo and Sikorski, 2005**). According to **Alomirah *et al*. (2011)** and **Mercogliano *et al*. (2016**), wood smoke has hazardous chemicals such as polycyclic aromatic hydrocarbons (PAHs) therefore in last years, America and Europe using liquid smoke for preparing 70% and 30% of their smoked products, respectively (**Alçiçek and Balaban, 2015; Holley and Patel, 2005**). Liquid smoke is a natural food flavouring additive. It is a safe food ingredient, easier and faster in application, reduces from cost, lowers hazardous chemicals such as PAHs and considers an environmental friendliness (**Martinez *et al*., 2004; Maga, 2009; Alçiçek and Atar, 2010; Alçiçek, 2011; Maga, 2018**).

The current study was planned to increase the added value of mussels (*Brachidontes pharaonis*) by prepare a new male and female hot and cold smoked mussels meat products using each of sawdust smoke and liquid smoke. The different characterization of these products including processing conditions, proximate composition, physicochemical, microbiological, and sensorial qualities, in addition to the qualitative detection and presence of PAHs in smoked female mussels' meat, were detected by GC-MS.

MATERIALS AND METHODS

Materials:

Fresh black bivalve mussels (*Brachidontes pharaonis*) were purchased from the eastern port of Abu Qir, Alexandria, Egypt in October 2022; natural smoke concentrate was obtained from Meat and Fish Technology Research Department, Agriculture Research Center, Giza, Egypt. Analytical grade chemicals and reagents were obtained from EL-Nasr Pharmaceutical Chemical Company, Egypt. Refined common salt, Foam plate and low-density polyethylene bags were purchased from local market at Suez, Egypt.

Methods:

1-Technological Methods: Shucking of black mussels: Fresh black mussels (*Brachidontes pharaonis*) **(Fig. 1)** with 6 - 9 cm an average length, were washed and cleaned from dirt and mud by running tap water, then an edible meat was separated from shells by immersing the mussels in boiling water at 95°C for 2 min., followed by soaking in iced water. The male and female cleaned edible meats **(Fig. 1)** were removed from shells according to their meat color where meats of males have a light cream color while females have an orange color. The edible meat was brined in 10% salt solution for 10 min then rinsed under running water and left to drain for 5 min in plastic strainers

a- Hot and cold smoking by sawdust smoke: As shown in **Fig. 2**, brined edible meats of male and female mussels were hot and cold smoked using sawdust smoke in an electrical smoking kiln. Hot smoking process included three stages, drying at 30 °C for 30 min followed by cooking at 50 °C for 30 min and an intensive smoking at 80 °C for 30 min. Cold smoking process was performed at 30°C for 20 hrs. Thereafter hot and cold smoked male (MHT and MCT, respectively) and female (FHT and FCT, respectively) black mussels were collected separately and cooled to ambient temperature then packed in foam plates inside polyethylene bags and stored at 5 ± 2 °C until analysis.

Fig. 1. The whole black mussel and its edible male and female meats

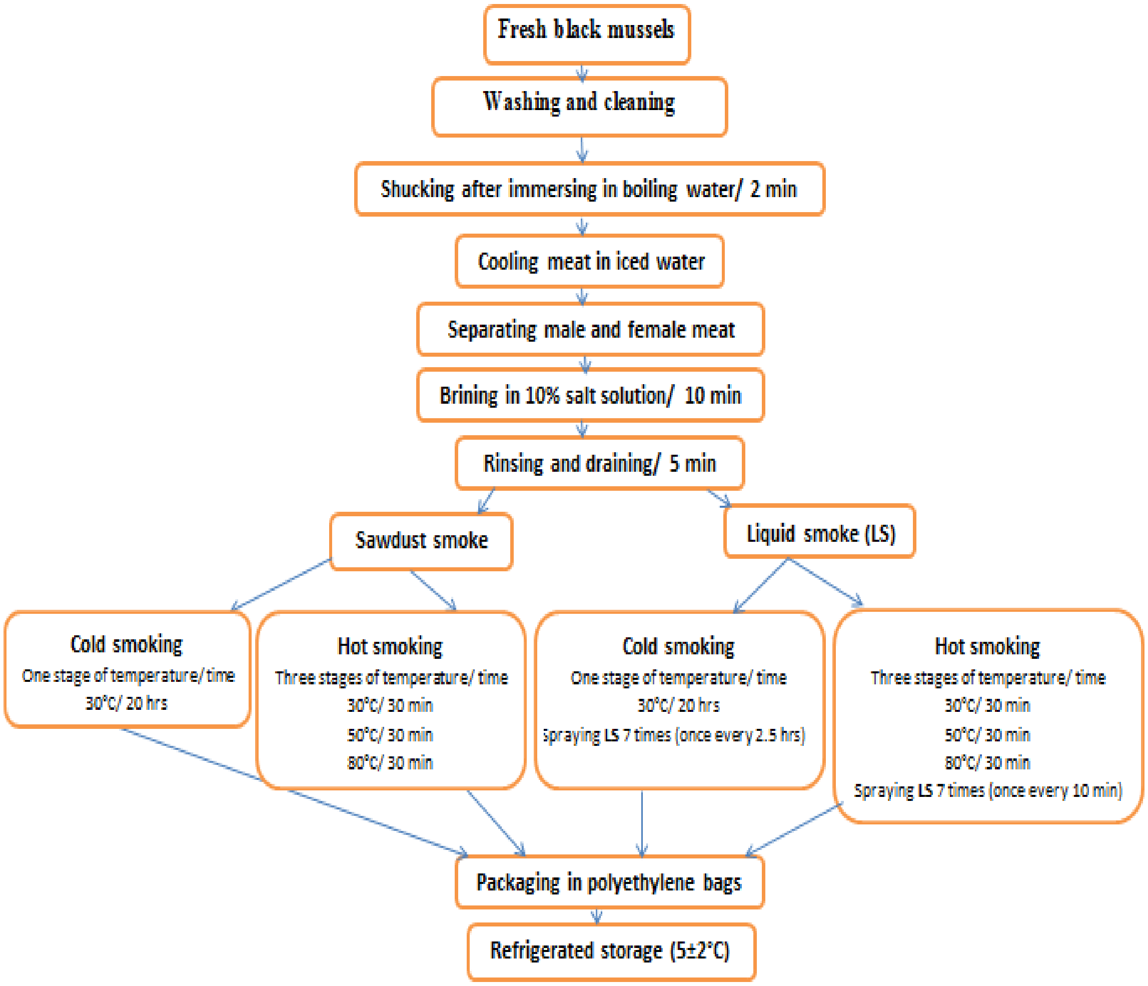

Fig. 2. Flow chart for production of hot and cold smoked black mussels (*Brachidontes pharaonis*) meat

b- Hot and cold smoking by liquid smoke: As mentioned before, both brined edible meats of male and female black mussels were hot and cold smoked inside electrical smoking kiln by spraying diluted liquid smoke solution 2:1 v/v (natural smoke concentrate : water) over the edible meats as the only source of smoke (**Fig. 2**). In hot smoking process, spraying of liquid smoke solution was done every 10 min, seven times starting from the end of drying step at 30 °C for 30 min, and through cooking (50 °C for 30 min) and final at 80 °C for 30 min stage. Cold smoking process was performed by spraying diluted liquid smoke solution seven times (once every 30 min) after 3 hrs from starting drying step to the final stage at 30 °C for 20 hrs. The resulted products of liquid hot and cold smoked male (MHL and MCL, respectively) and female (FHL and FCL, respectively) mussels were separately cooled, packed in polyethylene and stored at 5 ± 2 °C as mentioned before.

2- Chemical methods:

2-1- Proximate composition: The contents of fresh and smoked mussels' meat from moisture, crude protein, crude fat, and ash were determined (**AOAC, 2000**), while carbohydrate was calculated by difference.

2-2- Quality parameters:

2-2-1- Physicochemical: pH was determined using a calibrated pH meter type 2100 Bench pH meter, OHAUS Instruments (USA) at room temperature (23

± 2˚C) (**AOAC, 2000**). Salt content was determined according to **Varlık *et al*. (2007)**, total volatile basic nitrogen (TVB-N) using distillation method of **Antonacopoulos *et al.* (1968)** was followed by this equation **(Antonacopoulos, 1973):**

TVB-N (mg)/ 100 g = (ml 0.1 N HCl × 1.4 × 100) / weight of sample (g)

Trimethylamine (TMA) content was determined using the Conway microdiffusion assay **(Conway and Byrne, 1933)**. Thiobarbituric acid (TBA) was calorimetrically assayed at 537 using T60 UV-Visible Spectrophotometer and expressed as mg malonaldehyde per kilogram sample **(Park *et al*., 2007)**.

2-2-2- Microbiological examination: Ten grams of each smoked mussel meat sample were used to prepare a serial dilution of sterilized peptone water. Total viable count (TVC) was enumerated on plate count agar medium and incubated at 35 °C/ 48 hrs (**Maturin and Peeler, 1995**). ***Staphylococcus aureus*** was counted on Barid Parker agar medium (Difico) after incubation at 35 °C/ 48 hrs according to **ICMSF (1978)**. Coliform was carried out using most probable method (MPN) on lauryl sulphate broth with inverted Durham's tubes at 35 ºC/ 48 hrs. Also, *E. coli* test was performed using MPN on eosin methylene blue plates at 35 ºC/ 24 hrs according to **Chesbrough (2000)**.

2-2-3- Sensorial evaluation: Ten trained panelists from the workers in Fish Processing unit of Fish Processing and Technology Department, Faculty of Fish Resources, Suez University, Egypt evaluated the odour, taste, colour, texture, and overall acceptability of different types of the prepared smoked mussel meat samples, using 9-point hedonic scale ranging from 9, like extreme, to 1, dislike extreme (**Lawless and Heymann, 2010**).

3- Qualitative detection of polycyclic aromatic hydrocarbons (PAHs) residues:

The extraction of these compounds was done as described by **Mittendorf *et al*. (2010),** and estimated using GC-MS type, thermo Scientific with Trace GC Ultra / ISQ Single Quadrupole MS, and TG-5MS fused silica capillary column (30 m, 0.251 mm, 0.1 mm film thickness) according to the procedures of **Mahugija and Njale (2018).** They were identified by their relative retention time and mass spectra.

3- Statistics analysis:

Mean and standard deviation were calculated from triplicate samples. ANOVA one way test analysis through IBM SPSS Statistics version 22 was used to estimate the variation in values.

3. Results and discussion:

3.1. Proximate composition: The results of proximate composition on wet and dry weights of fresh and smoked meats of male and female mussels (*Brachidontes pharaonis*) reported in (**Table 1**). The data in this table showed that no significance differences were noticed in moisture between fresh male and female mussel meats. On dry weight basis, male fresh mussel meats contained higher protein, lower lipids, ash and carbohydrate than female. **Stratev *et al*. (2017)** found that fresh meat of *Mytilus galloprovincialis* had 77.09 – 81.92 % moisture, 13.02 – 17.63 % protein and 1.50 - 1.52 % ash. Both hot and cold smoking process either by sawdust and/or liquid smoke caused a reduction in moisture content of male and female meats (**Table 1**). This reduction was clearer due to cold smoking process, which extended to long period than that hot one. Meanwhile, there is a slight difference in moisture content between male and female mussel smoked meats products due to the use of sawdust or liquid smokes (**Table 1**). Generally, female smoked mussel meat had slight high level of moisture content than male ones. According to **Balachandran and Prabhu (1980)** moisture content of cold smoked mussel meat was less than 10%.

Due to moisture loss during salting step and smoking process, the others compounds, protein, lipid, ash, and carbohydrate of male and female smoked mussel meats were increased (**Table 1**). Such changes were more noticed in cold smoked products than hot ones. The cold smoking process led to an increase in protein, ash, and carbohydrate and lower in lipids of smoked mussel meat than hot one. Slight variations were observed in the values of these components due to the sex of mussel meats. **Şengör *et al*. (2008)** showed that the moisture, protein, lipid, and ash contents of smoked mussel meat ranged from 69.4-72.8 %, 16.5-20.4 %, 3.3-4.9 %, and 2.2-2.4 % respectively. **Turan *et al*. (2008)** found that hot smoked mussel meat had < 65% moisture, 22.2 % protein, 10.04 % lipid, and 6.02 % ash.

Table 1. Proximate composition of hot and cold smoked male and female mussels (Brachidontes pharaonis) meat by sawdust and liquid smoke.

Mussel products		Moisture	Protein	Lipid	Ash	Carbohydrate
Fresh						
Male	ww	73.77±0.92[a]	16.30±0.02[g]	3.33±0.19[e]	1.69±0.20[e]	4.91±0.41[f]
	dw		62.14 ±0.07[a]	12.70±0.72[d,e]	6.44±0.76[d]	18.72± 1.56[d]
Female	ww	74.79±0.51[a]	14.67±0.04[h]	3.87±0.14[d]	1.28±0.09[e]	5.39±0.37[f]
	dw		58.19±0.16[b]	15.35±0.55[b]	5.08±0.36[e]	21.38±1.47[a,b,c]
Hot smoked male by						
Sawdust smoke	ww	49.95±0.62[d]	23.89±0.85[d]	7.82±0.13[c]	7.32±0.35[c]	11.02±0.39[d]
	dw		47.73±1.7[d,e]	15.62±0.25[b]	14.63±0.70[b,c]	22.02± 0.81[a,b,c]
Liquid smoke	ww	50.74±0.40[d]	23.57±0.41[d]	8.03±0.29[c]	6.62±0.44[c,d]	11.04±0.97[d]
	dw		47.85±0.83[d,e]	16.30 0.59[b]	13.44 0.89[c]	22.41 1.97[a,b,c]
Hot smoked female by						
Sawdust smoke	ww	53.75±0.87[c]	21.65±0.25[e]	8.36±0.42[c]	6.88±0.27[c,d]	9.36±0.66[e]
	dw		46.81±0.54[e]	18.08±0.90[a]	14.88±0.58[b]	20.24±1.43[b,c,d]
Liquid smoke	ww	55.88±0.23[b]	19.93±0.32[f]	8.12±0.20[c]	6.01±0.45[d]	10.06±0.39[d,e]
	dw		45.17±0.72[f]	18.40±0.45[a]	13.62±1.02[b,c]	22.80± 0.88[a]
Cold smoked male by						
Sawdust smoke	ww	9.08±0.45[f,g]	43.77±0.22[b]	10.96±0.27[b]	15.69±0.97[a]	20.50±0.55[a,b]
	dw		48.14±0.24[d,e]	12.06 ±0.29[e]	17.26±1.06[a]	22.55± 0.60[a,b]
Liquid smoke	ww	8.98±0.58[h]	45.82±0.71[a]	11.03±0.43[b]	16.00±0.73[a]	18.17±1.68[c]
	dw		50.34±0.78[c]	12.12±0.47[e]	17.58±0.80[a]	19.96± 1.84[c,d]
cold smoked female by						
Sawdust smoke	ww	10.06±0.41[e,f]	43.03±0.15[c]	12.18±0.44[a]	13.32±0.65[b]	21.41±0.77[a]
	dw		47.84±0.16[d,e]	13.54±0.49[c,d]	14.81±0.72[b,c]	23.81± 0.85[a]
Liquid smoke	ww	10.69±0.66[e]	43.42±0.35[b,c]	12.66±0.37[a]	13.41±0.19[b]	19.82±0.76[b]
	dw		48.62±0.39[d]	14.18±0.41[c]	15.02±0.21[b]	22.19± 0.85[a,b,c]

ww, Wet weight; dw, Dry weight. [a–h] Letters denote significant difference in the same column ($P < 0.5$).

3.2. Quality parameters:

3.2.1. Physicochemical:

a) pH: According to the data in **Table 2**, pH of fresh, hot and cold smoked male and female mussel meats was varied from 6.32 to 6.16 this range agree with that mentioned by **Kyriazi-Papadopoulou *et al*. (2003)**, **Turan *et al*. (2008)** and relatively higher than that stated by **Aaraas *et al*. (2004)**, **Erkan (2005**) and **Tosun *et al*. (2018)** (5.6 - 6.3). After smoking process and due to acids in smoke resulting from the thermohydrolysis of wood, the pH was decreased to 5.73 - 6.25 in smoked products especially that prepared by liquid smoke which applied several times during smoking process, **Table 2**. Results of **Turan *et al*. (2008)** indicated that pH of smoked mussel meat was 4.51.

b) The salt content: Due to salting step and moisture loss during smoking, salt content was increased from 0.82 - 0.96 % in fresh mussels' meat to nearly more than 3 % and around 6 % after hot and cold smoking process, respectively. This parameter did not influence by sex and / or the smoke source. **Petridis *et al*. (2013)** found that salt content of mussel (*Mytilus galloprovincialis*) meat was 3.39 % after 5 min salting in a 10% salt solution.

c) The TVB-N and TMA-N: Results in **Table 2** showed that TVB-N and TMA-N of fresh male and female mussel meats were 9.89 and 1.33, 10.99 and 1.51 mg/100g respectively. Such values are within acceptable limits (<20 and <3 mg/100g, respectively) according to **Sikorski *et al*. (1990), Ruiz-Capillas *et al*. (2003), Erkan (2005), Goulas *et al*. *(*2005),** and **Huss (1995). Tosun *et al*. (2018)** found that fresh mussel had 17.52 and 1.65 mg/100 g, respectively as TVB-N and TMA-N. After smoking process, both values were increased due to heat treatment and activity of some thermostable enzymes. Such a rise did not occur across the permissible levels of both parameters, **Table 2**. Generally, the data in **Table 2** showed that meats of fresh female and cold smoked by sawdust smoke had higher levels of TVB-N and TMA-N than the meat of male and hot smoked by liquid smoke ones. Results of **Turan *et al*. (2007) and Turan *et al*. (2008)** showed that TVB-N and TMA-N were 11.83 and 1.07 mg/100g respectively, in smoked mussel meat.

TBA: As seen from **Table 2,** fresh meat of female had higher value of TBA than male one. This may be due to the higher level of lipid in female meat and its content of unsaturated fatty acids. Generally, the value of TBA in this study were less that found by **Zhou *et al*. (2019)** in fresh meat of *Mytilus edulis* mussel (0.89 mg MDA/kg sample). **Varlik *et al*. (1993), Aubourg *et al*. (2005), Regost *et al*. (2004) and Kaya and Baştürk (2015)** classified food according to its content of TBA, into very good with <3 mg MDA/ kg and good with ≤5 mg MDA/kg. According to this classification, the quality of both fresh and smoked products in this study is considered very good. Generally, the smoking process led to a significant rise in the level of TBA, especially in the cold-smoked one and that treated by sawdust smoke. Repeat liquid smoke spraying several times through smoking process may be behind the low levels of TBA in its smoked products. According to **Varlik *et al*. (1993),** the presence of phenolic compounds in smoke lowered from fat oxidation.

3.2.2. Microbiological:

Results in Table 3 showed that TVC counts of fresh and smoked mussel meat products in this study were less than 5 log CFU/g, the value reported by **ICMSF (1986)** to differentiate between fresh and spoiled mussel meat. Results of **Kacar (2011)**, **Berber and Avsar (2014)** and **Stratev *et al*. (2017)** showed that mussel TVC counts ranged from 4.02 to 6.83 log CFU/g, according to season. Both hot and cold smoking process by sawdust and by liquid smoke reduced the TVC and *Staphylococcus aureus* counts and inhibited coliform growth (Table 3). Such changes were obvious in sawdust hot-smoked products than liquid hot-smoked ones and also those prepared by cold smoking. This may be attributed to the heating regime followed during hot smoking process. **Xin *et al*. (2021)** found that dipping mussel meat in liquid smoke decreased its TVC counts from 3.65 to 3.03 log CFU/g. As shown from Table 3, both fresh and smoked mussel meat products were free from *E. coli*. **Kocatepe *et al*. (2016)** found that fresh mussel (*Mytilus galloprovincialis*) was ranged from 3.09- 3.69 log CFU/g Coliform bacteria and 0.39-0.59 log CFU/g *E. coli*.

Table 2. Physicochemical properties of hot and cold smoked male and female mussels (*Brachidontes pharaonis*)meat by sawdust and liquid smoke.

Mussels' products	pH	Salt content %	TVB-N mg/100g	TMA-N mg/100g	TBA mgMDA/kg
Fresh					
Male	6.32±0.12[a,b]	0.96±0.14[c]	9.89±0.42[e]	1.33±0.11[d]	0.39±0.15[e]
Female	6.46±0.19[a]	0.83±0.12[c]	10.99±0.57[d]	1.51±0.09[c,d]	0.47±0.07[e]
Hot smoked male by					
Sawdust	6.08±0.23[b,c,d]	3.52±0.31[b]	16.67±0.33[b]	1.77±0.21[b,c]	1.85±0.22[b,c]
Liquid smoke	5.73±0.14[e]	3.34±0.24[b]	14.52±0.72[c]	1.55±0.17[c,d]	1.28±0.18[d]
Hot smoked female by					
Sawdust	6.15±0.26[a,b,c]	3.39±0.19[b]	16.01±0.61[b]	1.80±0.19[a,b,c]	1.92±0.21[b]
Liquid smoke	5.82±0.13[d,e]	3.28±0.16[b]	13.87±0.28[c]	1.63±0.12[c,d]	1.58±0.17[c,d]
Cod smoked male by					
Sawdust	6.25±0.11[a,b]	6.77±0.32[a]	19.69±0.31[a]	2.13±0.23[a]	2.73±0.26[a]
Liquid smoke	5.89±0.09[c,d,e]	6.83±0.28[a]	16.55±0.46[b]	1.85±0.15[a,b,c]	2.01±0.13[b]
Cold smoked female by					
Sawdust	6.22±0.23[a,b]	6.56±0.18[a]	19.36±0.22[a]	2.09±0.27[a,b]	2.91±0.23[a]
Liquid smoke	5.78±0.15[d,e]	6.50±0.31[a]	15.98±0.13[b]	1.79±0.20[a,b,c]	2.17±0.11[b]

[a–e] Letters denote significant difference in the same column (P < 0.5).

Table 3. Microbiological quality of hot and cold smoked male and female mussels (*Brachidontes pharaonis*) meat by sawdust and liquid smoke.

Mussels' products	TVC	*S. aureus*	*E. coli*	Coliform
Fresh	**Log CFU/g**		**(MPN Index/100g)**	
Male	4.88±0.07[a]	2.43±0.14[a]	ND	125±20[b]
Female	4.96±0.15[a]	2.34±0.22[a,b]	ND	175±35[a]
Hot smoked male by				
Sawdust	2.98±0.10[d]	1.65±0.11[d,e]	ND	ND
Liquid smoke	3.04±0.03[d]	1.85±0.25[c,d]	ND	ND
Hot smoked female by				
Sawdust	2.95±0.11[d]	1.34±0.15[e]	ND	ND
Liquid smoke	3.34±0.14[c]	1.40±0.09[e]	ND	ND
Cod smoked male by				
Sawdust	3.81±0.21[b]	2.10±0.26[a,b,c]	ND	ND
Liquid smoke	3.94±0.27[b]	2.15±0.13[a,b,c]	ND	ND
Cold smoked female by				
Sawdust	3.92±0.16[b]	2.00±0.21[b,c]	ND	ND
Liquid smoke	3.95±0.19[b]	2.10±0.17[a,b,c]	ND	ND

[a–e] Letters denote significant difference in the same column (P < 0.5).

3.2.3. Organoleptic properties: According to **Figs. 3** and **4** and the data in **Table 4**, the prepared hot and cold male and female mussel meat products in this study were very acceptable by panelists. The acceptability score of colour, taste, texture and overall acceptability was more than 8. The same observation was noticed for the odour of all products except the hot-smoked male mussel meat by liquid smoke, which had slightly less score for this property.

Fig. 3: Hot and cold smoked male and female (MHT and FHT; MCT and FCT, respectively) black mussel (*Brachidontes pharaonis*) meat using sawdust smoke.

Fig. 4: Hot and cold smoked male and female (MHL and FHL; MCL and FCL, respectively) black mussel (*Brachidontes pharaonis*) meat using liquid smoke.

Table 4. Sensory properties of hot and cold smoked male and female mussels (*Brachidontes pharaonis*) meats by sawdust and liquid smoke.

Sensory characteristics	**Hot smoked male by**		**Hot smoked female by**		**Cold smoked male by**		**Cold smoked female by**	
	Sawdust	**Liquid**	**Sawdust**	**Liquid**	**Sawdust**	**Liquid**	**Sawdust**	**Liquid**
Colour	8.13±0.24^{a}	7.96±0.67^{a}	8.47±0.44^{a}	8.09±0.32^{a}	8.31±0.38^{a}	8.12±0.22^{a}	8.55±0.42^{a}	8.26±0.12^{a}
Oduor	8.20±0.41^{a,}	7.87±0.21^{b}	8.42±0.26^{a,b}	8.02±0.37^{a,b}	8.45±0.27^{a,b}	8.22±0.34^{a,b}	8.55±0.12^{a}	8.31±0.32^{a,b}
Taste	8.50±0.14^{a}	8.11±0.39^{a}	8.60±0.25^{a}	8.24±0.52^{a}	8.58±0.26^{a}	8.20±0.21^{a}	8.60±0.25^{a}	8.37±0.24^{a}
Texture	8.34±0.14^{a}	8.15±0.23^{a}	8.44±0.42^{a}	8.27±0.29^{a}	8.45±0.31^{a}	8.19±0.15^{a}	8.49±0.28^{a}	8.24±0.30^{a}
Overall acceptability	8.27±0.22^{a}	8.02±0.37^{a}	8.47±0.22^{a}	8.18±0.44^{a}	8.39±0.34^{a}	8.15±0.20^{a}	8.52±0.33^{a}	8.31±0.18^{a}

$^{a–b}$ Letters denote significant difference in the same row ($P < 0.5$).

3.3. Presence and qualitative of PAHs residues: As mentioned above, these compounds were qualified only in cold and hot smoked female mussel meats by sawdust and liquid smoke using GC-MS technique. This type of meat was selected because it had a higher level of lipids (**Table 1**), the popular phase of PAHs accumulation according to their presence probability. As shown from **Table 5**, 7 compounds of PAHs were identified. These compounds differed in their molecular weight and molecular formula. The presence of these compound was completely absent in hot smoked product by sawdust. Meanwhile some of these compounds were detected in some products and disappear from the others. Therefore, this point needs more deep investigation in future study.

Table 5. Probability, presence and molecular properties of PAHs in hot and cold smoked female mussel meat by sawdust and liquid smoke.

Polycyclic aromatic hydrocarbons (PAHs)	Smoked female mussels' meat				probability	Molecular Weight	Molecular Formula
	Cold smoked by		Hot smoked by				
	sawdust	liquid	sawdust	liquid			
Nephthoside 1,2',3',4'-Tetraacetate	+	-	-	-	73.8%	696	$C_{40}H_{56}O_{10}$
Dodecachloro-3,4-benzo phenanthrene	+	-	-	-	18.43%	636	$C_{18}Cl_{12}$
Pyrano [4,3-b] benzopyran-1,9-dione, 5a-methoxy-9a-methyl3-(1-propenyl) perhydro	-	+	-	-	30.77%	308	$C_{17}H_{24}O_5$
Phenanthro [1,2-b]oxire ne-4-carboxylic acid, tetradecahydro-1b,9-di hydroxy-4,7a-dimethyl9a-(1-methylethyl)-, methyl ester, [1ar-(1aà,1bá,3aá,4á,7a à,7bá,9á,9aà)]- (CAS)	-	+	-	-	33.43%	366	$C_{21}H_{34}O_5$
3,5-Diphenyl-3,5-(9,10 -phenanthylene)tricyclo [5.2.1.0]decane-4-one-8 -exo-9-endo-dicarboxylic acid	-	-	-	+	56.41%	708	$C_{44}H_{36}O_9$
2,9-Bis(5-tert-butyl-2-m ethoxy-3-pyridylphenyl) -1,10-phenanthroline	-	-	-	+	71.56%	658	$C_{44}H_{42}N_4O_2$

Conclusion

The above results indicated the successful production of new female and male hot and / or cold smoked mussel meat products using either sawdust and/ or liquid smoke. These new products are rich in protein, ash, considerable level of lipids and carbohydrates, with good physicochemical properties, very good overall acceptability and bacteriological safety, cold smoked products had lower moisture content than hot one, therefore they can store for long period while hot one can use as a snack foods.

REFERENCES

Aaraas, R.; Hernar, I. J.; Vorre, A.; Bergslien, H.; Lunestad, B. T.; Skeie, S.; Slinde, E. and Mortensen, S. (2004). Sensory, histological, and bacteriological changes in flat oysters, *Ostrea edulis* L., during different storage conditions. Journal of Food Science, 69, 205–210.

Alçiçek, Z. (2011). The effects of thyme (*Thymus vulgaris* L.) oil concentration on liquid-smoked vacuum-packed rainbow trout (*Oncorhynchus mykiss*) Walbaum, 1792) fillets during chilled storage. Food chemistry, 128(3), 683-688.

Alcicek, Z. and Atar, H. H. (2010). The effects of salting on chemical quality of vacuum-packed liquid smoked and traditional smoked rainbow trout (*Oncorhyncus mykiss*) fillets during chilled storage. Journal of Animal and Veterinary Advances, 9(22), 2778-2783.

Alçiçek, Z. and Balaban, M. O. (2015). Characterization of green lipped mussel meat. Part II: Changes in physical characteristics as a result of brining and liquid smoke application. Journal of Aquatic Food Product Technology, 24(1),15–30. https://doi.org/10.1080/10498850.2012.760188

Alomirah, H.; Al-Zenki, S.; Al-Hooti, S.; Zaghloul, S.; Sawaya, W.; Ahmed, N. and Kannan, K. (2011). Concentrations and dietary exposure to polycyclic aromatic hydrocarbons (PAHs) from grilled and smoked foods. Food control, 22(12), 2028-2035.

Antonacopoulos, N.; Bergner, K. G.; Grau, R.; Haller, H. E.; Kiermeier, F.; Lillelund, K.; Linke, H.; Meyer, V.; Meyer-Waarden, P. F.; Möhler, K. and Rauch, W. (1968). Handbuch der Lebensmittelchemie, Bd Ш/2. Springer, Berlin, pp 1493-1501.

Antonacopoulos, N. (1973). Bestmmung des flüchhtigen basensticktoofs. 224-225. In: Ludorf W, Meyer V (Eds), Fische und fischerzeugnisse. 1th ed. Aulage Verlag Paul Parey Press, Berlin und Hamburg.

AOAC (2000). Official Methods of Analysis.17th ed. Association of Official Analytical Chemists, Gaithersburgh. Maryland, USA.

Aubourg, S. P.; Pineiro, C.; Gallardo, J. M. and Barros-Velazquez, J. (2005). Biochemical changes and quality loss during chilled storage of farmed trout (Psetta maxima). Food Chem., 90: 445-452.

Maturin, L. J. and Peeler, J. T. (1995). Aerobic plate count in: Food and Drug Administration Bacteriological Analytical Manual. 8th ed. Arlington, Va.: AOAC International. p 1-10.

Balachandran, K. K. and Prabhu, P. V. (1980). Technology of processing mussel meat.

Berber, I. and Avsar, C. (2014). Investigating some microbial pollution parameters of seawater and mussels (*Mytilus galloprovincialis*, Lamarck 1819) of Sinop Black Sea Coastal Zone, Turkey. Sains. Malays. 43: 1835–1842.

Chesbrough, M. (2000). District Laboratory Practice in Tropical countries Part 2, (lower Price Edition). Edinbough Building U.K. 152- 154.

Conway E. J. and Byrne A. (**1933).** An absorption apparatus for the micro-determination of certain volatile subStances. I. The micro-determination of ammonia. Biochem. J. 27, 419-429.

Erkan, N. (2005). Changes in quality characteristics during cold storage of shucked mussels (Mytilus galloprovincialis) and selected chemical decomposition indicators. Journal of the Science of Food and Agriculture, 85(15), 2625-2630.

EUMOFA (European Market Observatory for Fisheries and Aquaculture Products) (2019). Fresh Mussel in the EU. Case study.

FAO (2020). The state of World Fisheries and Aquaculture 2020. Sustainability in action. DOI: 10.4060/ca9229en.

Goulas, A. E.; Chouliara, I.; Nessi, E.; Kontominas, M. G. and Savvaidis, I. N. (2005). Microbiological, biochemical and sensory assessment of mussels (Mytilus galloprovincialis) stored under modified atmosphere packaging. Journal of Applied Microbiology, 98(3), 752-760.

Holley, R. A. and Patel, D. (2005). Improvement in shelf-life and safety of perishable foods by plant essential oils and smoke antimicrobials. Food microbiology, 22(4), 273-292.

Huss, H. H. (1995). Quality and quality changes in fresh fish. FAO Fisheries Technical Paper No. 348, p. 195, FAO, Rome, Italy.

ICMSF (1978). Microorganismsin Food 4: Application of Hazard Analysis Critical Control Point (HACCP), System to Ensure Microbilogical Safety and Quality. International Commission on Microbiological Specification for Food. Black Wel Scientific Publication Oxford, London, U.K.

ICMSF (1986). International commission on microbiological specifications for foods. Sampling plans for fish and shellfish. In: ICMSF, Microorganisms in Foods. Sampling for Microbiological Analysis: Principles and Scientific Applications. Vol. 2, 2nd ed. ICMSF. Toronto, Canada: University of Toronto Press.

Kacar, A. (2011). Some microbial characteristics of mussels (*Mytilus galloprovincialis*) in coastal city area. Environ. Sci. Pollut. R. 18: 1384–1389.

Kaya, G. K. and Baştürk, Ö. (2015). Determination of some quality properties of marinated sea bream (Sparus Aurata L., 1758) during cold storage. Food Science and Technology, 35, 347-353.

Kocatepe, D.; Taskaya, G.; Turan, H. and Kaya, Y. (2016). Microbiological investigation of wild, cultivated mussels (Mytilus galloprovincialis L. 1819) and stuffed mussels in Sinop–Turkey. Ukrainian food journal, (5, Issue 2), 299-305.

Kyriazi-Papadopoulou, A.; Vareltzis, K.; Bloukas, J. G. and Georgakis, S. (2003). Effect of Smoking on Quality Characteristics and Shelf Life of Mediterranean Mussel (Mytilus galloprovincialis) Meat under Vacuum in Chilled Storage. Italian journal of food science, 15(3), 371-382.

Lawless, H. T. and Heymann, H. (2010). Sensory evaluation of food: Principles and practices (2nd ed.). New York: Springer Science and Business Media.

Ledesma, E.; Rendueles, M. and Díaz, M. (2017). Smoked food. In Current developments in biotechnology and bioengineering (pp. 201-243). Elsevier.

Maga, J. A. (2009). The flavor chemistry of wood smoke. Food Reviews International, 9129 (1987), 139–183. https://doi.org/10.1080/87559128709540810

Maga, J. A. (2018). Smoke in food processing. CRC Press.

Mahugija, J. A. M. and Njale, E. (2018). Effects of washing on the polycyclic aromatic hydrocarbons (PAHs) contents in smoked fish. Food Control, 93, 139–143. https://doi.org/10.1016/j.foodcont.2018.05.050

Martinez, O.; Salmeron, J.; Guillen, M. D. and Casas, C. (2004). Texture profile analysis of meat products treated with commercial liquid smoke flavourings. Food control, 15(6), 457-461.

Mercogliano, R.; Santonicola, S.; De Felice, A.; Anastasio, A.; Murru, N.; Ferrante, M. C. and Cortesi, M. L. (2016). Occurrence and distribution of polycyclic aromatic hydrocarbons in mussels from the gulf of Naples, Tyrrhenian Sea, Italy. Marine pollution bulletin, 104(1-2), 386-390.

Mittendorf, K.; Hollosi, L.; Ates, E.; Bousova, K.; Philips, E. and Huebschmann, H. J. (2010). Determination of polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons in fish by GCMS/MS. Method : 51991, Thermo Fisher Scientific, pp: 1-8.

Park, S. Y.; Yoo, S. S.; Hu, J.; Euv, J. B.; Lee, H. C.; Kin,Y. J. and Chin, K. B. (2007). Evaluation of lipid oxidation and oxidative products as affected by pork meat cut packaging method and storage time during frozen storage (-10oC). Journal of Food Science, 72, 114- 119. doi: https://doi.org/10.1111/j.1750-3841.2006.00265.x

Petridis, D.; Zotos, A.; Kampouris, T. and Roumelioti, Z. (2013). Optimization of a steaming with liquid smoke smoking process of Mediterranean mussel (Mytilus galloprovincialis). Food science and technology international, 19(1), 59-68.

Regost, C.; Jakobsen, J. V. and Rora, A. M. B. (2004). Flesh quality of raw and smoked fillets of Atlantic salmon as influenced by dietary oil sources and frozen storage. Food Research International, 37: 259-271.

Ruiz-Capillas, C.; Morales, J. and Moral, A. (2003). Preservation of bulk-stored Norway lobster at 1° C in controlled and modified atmospheres. European Food Research and Technology, 217, 466-470.

Rusmore-Villaume, M. L. (2008). Sea shells of the Egyptian Red Sea. The American University in Cairo Press. 307pp

Şengör, G. F.; Guen, H. and Kalafatoğlu, H. (2008). Determination of the amino acid and chemical composition of canned smoked mussels (Mytilus galloprovincialis, L.). Turkish Journal of Veterinary & Animal Sciences, 32(1), 1-5.

Sikorski, Z. E.; Kolakowska, A. and Burt, J. R. (1990). Post-harvest biochemical and microbiological changes, in Seafood: Resources, Nutritional Composition and Preservation, ed. by Sikorski ZE. CRC Press, Boca Raton, FL, p 71.

Stołyhwo, A. and Sikorski, Z. E. (2005). Polycyclic aromatic hydrocarbons in smoked fish–a critical review. Food Chemistry, 91(2), 303-311.

Stratev, D.; Popova, T.; Zhelyazkov, G.; Vashin, I.; Dospatliev, L. and Valkova, E. (2017). Seasonal changes in quality and fatty acid composition of black mussel (Mytilus galloprovincialis). Journal of Aquatic Food Product Technology, 26(7), 871-879.

Tosun, Ş. Y.; Alakvuk, D. Ü. and Ulusoy, Ş. (2018). Quality changes of thermal pasteurized mussels (Mytilus galloprovincialis) during refrigerated storage at 4±1 C. Aquatic Sciences and Engineering, 33(4), 117-123.

Turan, H.; SÖNMEZ, G.; Çelik, M. Y.; Yalcin, M. and Kaya, Y. (2007). Effects of different salting process on the storage quality of Mediterranean mussel (Mytilus galloprovincialis L. 1819). Journal of Muscle Foods, 18(4), 380-390.

Turan, H.; SÖNMEZ, G.; ÇELİK, M. Y.; Yalcin, M. and Kaya, Y. (2008). The effects of hot smoking on the chemical composition and shelf life of Mediterranean mussel (Mytilus galloprovincialis L. 1819) under chilled storage. Journal of Food Processing and Preservation, 32(6), 912-922.

Van den Burg, S. W. K.; Termeer, E. E. W.; Skirtun, M.; Poelman, M.; Veraart, J. A. and Selnes, T. (2022). Exploring mechanisms to pay for ecosystem services provided by mussels, oysters and seaweeds. Ecosystem Services, 54, 101407.

Varlık, C.; Özden, Ö.; Erkan, N.; Alakavuk, D. Ü. (2007). Su Ürünlerinde Temel Kalite Kontrol. İstanbul Üniversitesi Su Ürünleri Fakültesi Yayınları. 975-404-771-5. 202 pp

Varlik, C.; Uğur, M.; Gökoğlu, N. and Gün, H. (1993). Principles and methods of quality control in seafood. İstanbul: Food Technology Association, 174.

Vine, P. (1986). Red Sea Invertebrates. 224 pp., London.

Xin, X.; Bissett, A.; Wang, J.; Gan, A.; Dell, K. and Baroutian, S. (2021). Production of liquid smoke using fluidised-bed fast pyrolysis and its application to green lipped mussel meat. Food Control, 124, 107874.

Zhou, X.; Zhou, D. Y.; Liu, Z. Y.; Yin, F. W.; Liu, Z. Q.; Li, D. Y. and Shahidi, F. (2019). Hydrolysis and oxidation of lipids in mussel Mytilus edulis during cold storage. Food chemistry, 272, 109-116.