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ORIGINAL ARTICLE

Effects of smoking and sun-drying on proximate, fatty and amino acids compositions of Southern pink shrimp (*Penaeus notialis*)

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Abstract Traditional techniques of smoking and sun drying were investigated to understand their effects on nutritional qualities of Southern pink shrimp against present human dietary needs. Shrimps subjected to hot smoking at 71 °C and sun drying at ambient temperature of 31 °C treatments were compared to fresh samples. Proximate composition dry weight basis showed that smoked product were highest in protein and carbohydrate ($P<0.05$) while fat was raised in sundried products ($P<0.05$). The monounsaturated fatty acid (MUFAs) were highest ranging from 35.87 to 40.35 % in all products. Oleic acid (18:1) had highest value of 24.26 % in the smoked. Eicosapentanoic acid (C20:5 n-3) was highest in the sundried while Docosahexaenoic acid (C22:6 n-3) predominated in the fresh. The shrimp protein had Glutamate as the most abundant amino acid in the three forms. Both preservation methods significantly ($P<0.01$) raised the values of tyrosine, histidine and leucine. The Ω-3/Ω-6 ratios showed that prawn is rich in omega 3. The highest arginine/lysine ratio (1.54) was obtained in sundried. The EAA/NEAA ratios ranged from 0.72 to 0.80 while index of atherogenicity (IA) and index of thrombogenicity (IT) ranged from 0.71 to 0.82 and 0.21 to 0.30 respectively in all forms. All products forms showed different advantages with respect to quality and nutrition, smoked samples however, offered the best benefits. Information provided is the first detailed study on the impacts of smoking and sun-drying on the nutritional qualities of a shrimp with tremendous economic and nutritional importance.

Keywords Quality · Southern pink shrimp · Preservation · Fatty acids · Amino acids · Product form

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Introduction

Food preservation is critical in meeting the twin issues of balancing between the quantities of food required to meet increasing world population and quality underpinned by eating rightly for the sake of healthy life. Solar driers have been constructed in Bangladesh, Indonesia, Rwanda, the Philippines, and Papua New Guinea while many kilns such as the Chorkor (commonly used in West Africa) and smoke chamber developed in the Philippines are popular amongst the small scale fishers across the globe. Different designs are available worldwide and able to exclude rain, insects, animals, and dirt; produce temperatures high enough to reduce the possibility of mould or bacteria spoilage.

Aside the safety concern accentuated by issues of hygiene and qualities of physical products forms from traditional process techniques often adopted by small scale fishers (which often limit the acceptance by consumers) there is increasing attention on impacts of preservation on nutritional qualities of dietary fish. Fish products, particularly sea foods have attracted considerable attention as important sources of nutrients such as amino acids, peptides, protein and other useful nutrients in the human diet (Sriket et al. 2007).

Fish or seafood consumption frequency has been used as surrogate for the intake of the principal n-3 fatty acids found in fish/seafood, docosahexaenoic acid (DHA, 22:6n-3) and eicosapentaenoic acid (EPA, 20:5n-3) in cross national and sectional epidemiological survey of both major depressive order (MDD) and bi polar disorder (BD) (McNamara 2009). World Health Organisation (2000) projected that by 2020 MDD will be the second most important cause of disability worldwide (after ischemic heart disease).

Makrides (2009) supported the view that n-3 LCPUFA supplementation in pregnancy using high doses of fish oil that was higher in eico sapentaenoicacid (EPA,20:5n-3) than DHA produced better result with pregnancy leading to increased

duration of pregnancy, higher birth weight and a lower incidence of pre-eclampsia. The role of omega rich fish and seafood diets in the prevention and treatments of cardiovascular diseases have been well documented (Gogus and Smith 2010). The consumption of foods containing long-chain n -3 fatty acids, such as EPA and DHA, is associated with decreased risk of coronary heart disease and cancer with great impact on brain, neural and visual development among other health benefits.

Penaeus notialis is a widely consumed shrimp that support both artisanal and industrial landings of many countries. It is important for economic, ecological and dietary item of many developing countries. This study is the first to offer a holistic information on the impact of the two commonest traditional processing methods on the nutrient composition of this species. In West Africa, sun drying and smoking are frequently employed in keeping shelf life, diversity of product forms and ensure distribution and marketing of the product far and wide from coastal states where they support the artisanal fisheries. The objective of this study was to provide in qualitative terms information that answer question of effects of these traditional means of processing on the proximate, fatty and amino acids composition as well as nutritional quality of a widely consumed shrimp.

Materials and methods

Sample collection and processing

Penaeus notialis weighing 64.46–301.21 g were collected in February 2011 from shrimp trawlers (Karflex Jetty Kirikiri Town, Apapa, Lagos) with otter-trawl net (15 mm mesh size at the sides and 12 mm at its end). The trawlers fishing ground was FAO zone 34,100 nautical miles of the Nigerian coast. Shrimp samples collected were iced (shrimp and ice in the ratio of 1:1) immediately in a plastic ice box and transported within 30 min to Nigerian Institute for Oceanography and Marine Research (NIOMR) Lagos for processing in the laboratory.

The shrimps were washed, blotted dry and weighed. Afterwards, heads, shells, tails, legs and intestines were removed and weights of the samples taken using the weighing balance (Pioneer TM Ohaus corp pine brook weighing machine with Max cap of 4,100 g and Readability of 0.01). Afterward, samples within the same weight range were separated to three clusters: (i) fresh samples were stored at −40 °C for 2 h and used as control (ii) subjected to smoking (iii) sun drying.

Smoking

The smoking treatment adopted was the “hot smoke drying”. Shrimps were laid out on a platform of wire mesh supported by a semi-circular frame work of perforated metal drum measuring 0.846 m^2 for 2–3 h process of smoking. The base of the drum was filled with sharp sand up to 10 in. Six fire wood sticks of average length of 0.6 m and 0.05 m thick and firewood chips were used to make fire that was allowed to heat up for about 15 min. An average temperature of 160 °F (71 °C) was recorded during smoking with mercury in glass thermometer.

Sun drying

The shrimps were placed in a circular clean aluminium tray that was covered with a mosquito net to prevent access by flies and other insects. Samples were sun dried from 8 am to 4 pm at an average ambient temperature of 31 °C. The average internal temperature of the tray was 30 °C. The tray was always kept indoors after 4 pm in a room with an average ambient temperature of about 29 °C for 2 days. Shrimps were turned over every 3 h and on the third day sundried from 10 am to 1 pm after which they were taken to the laboratory.

Proximate composition

The proximate compositions were determined following the AOAC (2006) methods. The moisture content was determined by method no 934.01, protein and ash contents were done according to methods 984.13 and 942.05. Both fat and fiber were according to method 920.39 (A). Carbohydrate was calculated by difference.

Chemical analyses

Analyses of fatty acid

Oil extraction

The fat of the grinded sample from the control (fresh) and experimental (smoked and sundried) were extracted with redistilled n-hexane for the recovery of the undiluted oil using soxhlet arrangement. The crude oil extract was made to be free of filtering through the anhydrous sodium sulphate salt. The hexane was removed from the oil/hexane mixture by using rotatory evaporator at 71 °C under atmospheric pressure.

Fatty acid methyl ester analysis

Fatty acid profile- saturated, mono-and polyunsaturated analyses were carried out by following the modified AOAC (1990) and (2005) official methods. 50 mg of the oil sample were saponified (esterified) for 5 min at 95 °C with 3.4 ml of 0.5 M KOH in dry methanol. The

mixture was neutralized by using 0.7 M HCl 0.3 ml of the 14 % boron triflouride in methanol and heated for 5 min at the temperature of 90 °C to achieve complete methylation process. The fatty acid methyl esters were thrice extracted from the mixture with redistilled n-hexane. The content was concentrated to 1 ml for gas chromatography analysis and 1 μl was injected into the injection port of GC/MS.

The fatty acid methyl esters were analysed using HP 6890 powered with HP Chem Station Rev. A 09.01 [1206] Software equipped with a HP INNOWax capillary column, (30 m× 0.25 mm×0.25 μm). Nitrogen was used as the gas carrier and furnace temperature was 60 °C. The injection temperature was 250 °C with split ratio: 20:1. Oven program were as follow: first ramping @ 12 °C for 20 min and maintained for 2 min; second ramping @ 15 °C for 3 min and maintained for 8mins. The flame-ionization detector (FID) temperature was held at 320 °C.

Fatty acid identification

The fatty acids methyl esters were identified by comparing the retention time of the samples against C19:0 (10 mg/l concentration) that was used as fatty acids esters internal standard. The relative percentage of the area obtained by using the following equation: Area % FA_x = $[A_x/A_R] \times 100$, where: FA_x = fatty acid to be identified, A_x = area of the methyl esters X and A_R = total area of the chromatogram. Peak areas lower than 0.1 % of total area were not considered.

Indices of lipid quality

Index of atherogenicity (IA) was determined based on the relationship between the sum of the main Saturated Fatty Acid (SFA) and that of the main Unsaturated Fatty Acid (UFA). The former being considered pro-atherogenic (favouring the adhesion of lipids to cells of the immunological and circulatory systems), and the latter anti-atherogenic (inhibiting the aggregation of plaque and diminishing the levels of esterified fatty acid, cholesterol, and phospholipids, thus preventing the appearance of micro and macro coronary diseases) (Ulbritcth and Southgate 1991).

$$IA = [(12:0 + (4 \times 14:0) + 16:0]/ \left[\sum \text{MUFAs} + \sum \text{PUFA}{-}\text{n6} + \sum \text{PUFA}{-}\text{n3}\right]$$

Index of thrombogenicity (IT) shows the tendency to form clots in the blood vessels. This is defined as the relationship between the pro-thrombogenetic (saturated) and the anti-thrombogenetic FA (MUFA, PUFA-n6 y PUFA-n3) (Ulbritcth and Southgate 1991).

$$IT = [(14:0 + 16:0) + 18:0]/ [\{0.5 \times \sum \text{MUFAs} + 0.5 \times \text{PUFA}{-}\text{n6} + 3 \times \sum \text{PUFA}{-}\text{n3} + (\sum \text{PUFA}{-}\text{n3}/\sum \text{PUFA}{-}\text{n6})]$$

Analysis of amino acid

Amino acid extraction was achieved by modified AOAC (2006). It is noteworthy that tryptophan was not determined with this hydrolysis procedure. Dried and pulverized samples were made to be free of water by ensuring constant weight for a period of time in the laboratory. Ten grams of the sample were weighed into 250 ml conical flask capacity. Samples were defatted by extracting the fat content with 30 ml of the petroleum spirit three times with soxhlet that was equipped with thimble. The extract was hydrolysed using 6 M of hydrochloric acid (HCl) at 110 °C for a day to achieve complete hydrolysis in a sealed vial. The amino acid content of sample was recovered by extraction with 30 ml of the methylene chloride three times before been concentrated to 1 ml for gas chromatography analysis.

Gas chromatography was carried out using HP 6890 powered with HP ChemStation Rev. A 09.01 [1206] software and the capillary column HP 5 (30 m×0.25 mm×0.25 μm). Hydrogen was used as the gas carrier with furnace temperature at 60 °C. Injection temperature was 250 °C with split ratio: 20:1. Oven program was as follow: first ramping @ 8 °C for 20 min and maintained for 2 min; second ramping @ 12 °C for 6 min and maintained for 2mins with Pulsed Flame Photometry Detector (PFPD) at 320 °C. The results were expressed as g of AA per 100 g Southern pink shrimp flesh.

Amino acid score

Essential amino acid scores in the treatments were calculated with respect to the FAO/WHO reference amino acid pattern of the preschool child (2–5 year) (FAO/WHO/UNU 1985).

$$\text{Amino acid score} = \text{Sample amino acid}/\text{Reference amino acid} \times 100$$

Protein digestibility corrected amino acids score (PDCAAS)

The PDCAAS was calculated for each product form by multiplying the lowest uncorrected amino acid score by the food protein's digestibility (FAO 1991).

AAS X true digestibility.

Statistical analyses

All of the extraction and composition analyses were conducted in triplicates from three independent experiments conducted for this study. Results were expressed as mean values ± standard deviation (SD). The differences between the mean values of *Penaeus notialis* meat in fresh, smoked and sundried samples were calculated using one-way analysis of variance (ANOVA), and statistically significant differences were reported at $P<0.05$ and $P<0.01$ when high statistics significance were observed. The Least Significant Difference (LSD) was conducted for independent sample *t* test as may be required between two treatments. Data analyses were done with the use of SPSS 15.0 software.

Results and discussion

Proximate composition

The proximate composition of the fresh, smoked and sundried shrimp is shown in Table 1. Moisture value of 77.24 % in fresh *P. notialis* was similar to that of *Ostrea spp* (77.73 %) but lower to values found in *Sepia officinalis* (83.68 %), *Metapenaeus affinis* (79.47 %) and *Anadara granosa* (78.94 %) according to Nurnadia et al. (2011). Moisture loss on the accounts of both processing methods were approximately one quarter and one-third in smoked and sundried products compared to the fresh samples. The strength of both smoking and sun-drying was their abilities to reduce the moisture content or water activity in a product thus extending the shelf life by inhibiting the growth of spoilage bacteria.

Table 1 Proximate composition (% on a dry weight basis) of *Penaeus notialis* subjected to smoking and sundrying processes

Proximate characteristics (%)	Fresh	Smoked	Sundried
Moisture	$(77.24\pm0.40)^{a,b,c}$	$(57.86\pm0.33)^{a,b,d}$	$(52.40\pm0.60)^{a,c,d}$
Protein	$65.76\pm0.35^{a,b}$	$67.00\pm0.39^{a,b,d}$	$65.24\pm0.14^{a,d}$
Fat	$5.06\pm0.11^{a,b,c}$	$6.41\pm0.04^{a,b}$	$6.27\pm0.10^{a,c}$
Ash	12.29±0.12	14.42±0.11	12.23±0.27
Fibre	$13.67\pm0.13^{a,b,c}$	$10.59\pm0.37^{a,b,d}$	$12.68\pm0.23^{a,c,d}$
Carbohydrate	3.22 ± 0.20^{b}	3.85 ± 0.14^{b}	3.57±0.25

Values are given as means ± SD from triplicate determinations

[a] Values are significantly different ($p<0.05$) across the three product forms

[b] Values are significantly different ($p<0.05$) between fresh and smoked samples by the independent-sample *t* test from LSD

[c] Values are significantly different ($p<0.05$) between fresh and sun dried samples by the independent-sample *t* test from LSD

[d] Values are significantly different ($p<0.05$) between smoked and sun dried samples by the independent-sample *t* test

Protein and carbohydrate mean values of 67.00±0.39 % and 3.85±0.14 were significantly highest in smoked samples ($P<0.05$) indicating that smoking processes will increase the contents of these two important macronutrient components of food. This protein value obtained was higher (dry weight basis) compared to those reported in the muscle of *Penaeus monodon* (63.22 %), *Metapenaeus monoceros* (60.15 %) and *Macrobrachium scariculum* (56.75 %) (Snehalata and Sahu 2001; Dinakaran et al. 2010) but the carbohydrate value was lower to the 5.08 % in *Penaeus monodon* according to Snehalata and Sahu (2001). It is instructive to note that highest dietary protein and carbohydrate levels by smoking process as shown in this study will be a very useful practice towards increasing access per unit serve of protein in places where the cost of animal protein is prohibitive and dietary energy is required.

Meanwhile fat mean value of 6.41±0.04 % was highest in the smoked product ($P<0.05$) but not significantly different ($P>0.05$) from that of sun drying. Increased dietary fat content of the shrimp provided benefits of the medium for the absorption of fat-soluble vitamins, contributing to the palatability of food and crucial to proper development and survival during the early stages of life-embryonic development and early growth after birth, on through infancy and childhood (FAO 2008). It can be deduced from this present study and that reported for *P. monodon* (Akintola et al. 2013) that heat processing methods increases the value of crude fat in shrimps. In both studies, it was established that while in *P. notialis* values of crude fat and carbohydrate simultaneously increased with process of smoking, sun-drying produced simultaneously increased values of fat and carbohydrates. Therefore, it is speculated that increased fat levels in smoked and sundried samples in the present study may have resulted from metabolized glycogen from cell wall of the shrimp.

Ash contents were not significantly different ($P>0.05$) in all the products. The highest value obtained in the smoked samples (14.42±0.11 %) was adduced to moisture loss. Selmi et al. (2010) reported increased ash contents in fresh silverside (1.96 %) during solar (6.21 %) and experimental drying process (5.13 %) occasioned by water evaporation. Ash is not known to be of nutritional importance. Fibre value of the fresh (13.67±0.13 %) was highest ($P<0.05$) in the products. Both heat processing methods in this study lowered the fibre values ($P<0.05$) in the samples of *P. notialis* indicating that heat treatments resulted in the loss of cell wall of shrimps. In the light of this finding fresh shrimp offers better dietary advantage of helping to reduce constipation.

Non-polar fatty acid concentration

Thirteen fatty acids were identified in fresh, sundried and smoked muscles of Southern pink shrimp as shown in Table 2. The MUFAs were found as the most dominant accounting for

Table 2 Fatty acid profile of fresh, smoked and sundried muscle of *Penaeus notialis*(%)

Fatty acid	Fresh (n=3) Mean ± std	Smoked (n=3) Mean ± std	Sun-dried (n=3) Mean ± std
Saturated fatty acid (SFA)			
C 10:0 capric decanoic	0.31±0.05[c]	0.34±0.30	0.02±0.02[c]
C 12:0 lauric dodecanoic	0.05±0.01	0.13±0.19	0.04±0.05
C 14:0 myristic tetradecanoic	9.19±1.01	7.64±1.79	8.14±1.30
C 16:0 palmitic hexadecanoic	20.01±0.98	19.05±1.03[d]	20.86±0.28[d]
C18:0 stearic octadecanoic	1.54±0.40 [a,b]	3.11±0.37 [a,b,d]	3.78±0.04 [a,d]
∑ SFA	31.09±2.44	30.27±3.68	32.83±1.69
Monounsaturated fatty acid (MUFA)			
C16:1 n-7 palmitoleic cis-9-hexadecenoic	10.68±0.46 [c]	10.98±1.09[d]	9.08.54±0.11[c,d]
C18:1 n-9 oleic cis-9-octadecenoic	22.32±0.33 [b,c]	24.26±0.72[b]	23.68±0.61[c]
C22:1 n-9 erucic cis-13-docosenoic	6.65±0.61[c]	5.12±0.78[d]	3.12±0.39 [c,d]
∑ MUFA	39.65±1.40	40.35±3.21	35.87±1.11
Polyunsaturated fatty acid (PUFA)			
C18:2 n-6 linoleic 9–12,octadecadienoic	0.29±0.38[a,*]	2.08±0.13 [a,*]	0.98±0.22 [a, *]
C18:3 n-6 gamma linolenic cis-6,9, 12-octadecatrienoic	0.16±0.20[b,c]	1.06±0.06[b]	0.99±0.32[c]
C20:4 n-6 arachidonic cis-5,8,11, 14-eicosatetraenoic	0.21±0.27 [b,c]	1.26±0.18[b]	1.57±0.69[c]
C20:5 n-3 eicosapentaenoic cis-5,8,11,14, 17-eicosapentanoic	15.56±0.12[a]	14.71±0.58[a]	18.50±0.42[a]
C22:6 n-3 docosahexaenoic cis-4,7,10,13,16, 19-docosahexaenoic	13.05±0.26*[b,c]	10.26±0.94*[b]	9.26±0.61[c]
∑ PUFA	29.26±1.23	31.46±2.25	27.49±1.22
DHA/EPA	0.84	0.70	0.50
∑n-3 PUFA	28.61	24.97	27.75
∑n-6 PUFA	0.65	4.40	3.25
ω-3/ω-6	44.02	5.67	8.53
IA	0.82	0.71	0.80
IT	0.21	0.30	0.30

N. B No significant difference between replicate * Significantly different at $P<0.05$, $P<0.01$

[a] Values are significantly different ($P<0.05$) across treatments

[b] Values are significantly different ($p<0.05$) between fresh and smoked samples by the paired t test from LSD

[c] Values are significantly different ($p<0.05$) between fresh and sundried samples by the paired t test from LSD

[d] Values are significantly different ($p<0.05$) between smoked and sun dried samples by the paired t test

40.35 %, 39.65 % and 35.87 % in control and experiments respectively. Both saturated fatty acids (SFAs) and polyunsaturated fatty acids (PUFAs) were approximately equal with means of 31.09 % and 29.26 % in the fresh, 30.27 % and 31.46 % in the smoked specimen. The mean values for sundried were 32.83 % and 27.49 %. Similarly, the MUFAs (49.81 %) were the most dominant in Chinese mitten crab in the findings of Chen et al. (2007). However, some studies concluded that SFAs were the most abundant fatty acids in some shrimps (Mura et al. 2000; Zhou et al. 2007) while PUFAs were reported being most abundant in white shrimp and freshwater prawn (Lin et al. 2003) and in both black tiger shrimp and white shrimp (Sriket et al. 2007). Fatty acids compositions in invertebrates are known to be influenced by geographical variation, diets, biochemistry and reproductive status.

Capric Decanoic (C10:0) was the only medium chain SFA observed in this study; in similar vein Akintola et al. (2013) first reported the presence of this SFA in *P. monodon*. In view of the fact that previous works on shrimps from other countries (Chedoloh et al. 2011; Tsape et al. 2010) did not report any medium chain SFA, it is proposed that the presence of capric acid in the shrimps was related to geographical factor as alluded to by Budge et al. (2002). Preservation by sunlight reduced significantly ($P<0.05$) the concentration of the capric acid (0.02 %) compared to both fresh and smoked products. This observation in light of this study indicated the UV (hourly UV index in Lagos, Nigeria ranged between 3.8 and 10.8 :http://www.uvawareness.com/uv-info/uv-information.php) filtering attribute of the decanoic acid and shows the usefulness of sundried shrimp as anti-inflammatory diets and represents a typical option for a Mediterranean–style diet. The fresh and smoked products (0.31 and 0.34 %) with higher concentrations may be useful as antiviral against HIV when converted by the body to monocaprin (Thormar et al. 1994; Neyts et al. 2000), restrictive diets by obese individuals (Tvrzicka et al. 2011).

Palmitic hexadecanoic (C16:0) was the most dominant in all the product forms accounting for 64 % of the SFAs and was

similar to values reported in *P. monodon* (22.2 %) and *P. vannamei* (21.8 %) (Sriket et al. 2007) and approximate with values for various shrimps (14.4–26.4 %) according to Li et al. (2011). Statistically significant differences ($P<0.05$) was established for smoked and sundried samples with values ranging between 19.05 and 20.86 % respectively. Smoked product offered the lowest value of palmitic acid known to elevate total and low density lipoprotein (LDL)-cholesterol levels (Stanley 2009). This offers consumers a better choice since long-chain SFAs are known to increase levels of cholesterol, namely low density lipoprotein (LDL)-cholesterol, connected with increased coronary heart disease (CHD) mortality.

Other Long chain (saturated) fatty acids (LCFA) namely lauric (12:0) and myristic (14:0) produced no statistically significant difference ($P>0.05$). The values of Stearic Octadecanoic (18:0) were raised approximately by 102 % and 146 % in both smoked and sundried ($P<0.05$) compared to the fresh samples. The observed rise of stearic acid in both treatments cannot be explained separately from the results of thermal oxidation of the MUFAs as observed in *P. monodon* (Akintola et al. 2013). This implies that consumption of smoked and sundried shrimp will lower the risk for cardiovascular disease since stearic acid unlike other forms of SFAs produces a neutral effect on blood total and LDL cholesterol levels (Mensink 2005). Also, German and Dillard (2004) reported that the percentage content of both very-long-chain n-3 fatty acids and stearic acid is inversely associated with the risk of myocardial infarction.

Among the MUFAs, Oleic cis-9-Octadecenoic (C18:1 n-9) was the most dominant fatty acid. Li et al. (2011) reported similar finding among the seven shrimps (10.7–17.3 %) studied. The amounts of oleic acid in all the products in the present report were higher than those reported and may be due to geographical differences. The amount of oleic acid in the fresh sample was raised ($P<0.05$) by both treatments significantly; such change was rather small between 6 and 9 %. It nevertheless holds a lot of positives since oleic acid have similar influence on the blood total and LDL cholesterol as produced by stearic acid. Tvrzicka et al. (2011) stated that this fatty acid has anti-atherogenic and anti-thrombotic properties as it increases the high density lipoprotein, HDL-/LDL-cholesterol ratio and decreases aggregation of thrombocytes. All the product forms offer a diet richer when both stearic and oleic are summed producing a greater influence on the dreadful palmitic acid.

Erucic cis-13-Docosenoic (C22:1 n-9) was found in the Southern pink shrimp in this study. Literatures on the fatty acid composition on the species that would have provided needed comparison were rare. Erucic acid was not found in *P. monodon*, *P. vannamei, N. norvegicus* (Sriket et al. 2007; Tsape et al. 2010) and six of the seven shrimps except mantis shrimp (Li et al. 2011). It is apt to say that the acid is rarely found in shrimps and it occurrence as reported in *P. monodon* (Akintola et al. 2013) may be alluded to among and within species fatty acid signature variations in invertebrates as reported by Budge et al. (2002). In the present study, both preservation methods reduced significantly ($P<0.05$) the levels of erucic acid with the highest impact noticeable in sundried product form. This showed that sundried specimen is preferable, offering consumers a lower level. Stockler et al. (1997) stated that in human, dietary erucic acid was found to reduce the number of platelets and their membrane anisotropy. Palmitoleic cis-9-hexadecenoic (C16:1 n-7) values were significantly raised by smoking but significantly reduced by the impact of the sun drying ($P<0.05$). In both processes these changes were small although statistically significant. The values in all the product forms were higher than those reported in widely consumed shrimps in the Mediterranean and China (Tsape et al. 2010; Li et al. 2011).

Among the PUFAs, the Linoleic 9–12, octadecadienoic (C18:2 n-6) is considered one of the essential fatty acids for human. Sun drying and smoking impacted greatly on it concentration. Both processes returned significantly higher values ($P<0.01$) compared to the values in the fresh but smoking produced a greater impact raising the values from 0.29 to 2.08 %. Consumption of lipid emulsions rich in omega 6 PUFAs according to Tvrzicka et al. (2011) leads to increased cholesterol synthesis and increased activity of LDL-receptors. Accounts of Gogus and Smith (2010) indicated that it results to an increased amount of dienoic prostaglandin E2 (PGE2), thromboxane and leukotriene hence the immunosuppressive properties and the generation of free oxygen radicals associated with omega 6 PUFAs. Therefore, fresh samples (with the lowest value) provided a better choice as recipe in a diet.

Alpha Linolenic cis-9, 12, 15-Octadecatrienoic (C18:3 n-3) considered the second essential fatty acid was not observed in wild stock used for this study but gamma Linolenic cis-6, 9, 12-Octadecatrienoic (C18:3 n-6) was observed. Personal experience and previous studies on *P. monodon* showed the likelihood of α-LA and γ-LA to be mutually exclusive in the wild stocks of shrimps. In farmed shrimps both fatty acids were observed (Sriket et al. 2007; Li et al. 2011) whereas for the wild samples presence of α-LA and absence of γ-LA was reported in *Penaeus kerathurus* (Tsape et al. (2010) and *Penaeus monodon* (O'Leary and Matthews 1990; Sriket et al. 2007). The value of γ-LA in this study was significantly raised by both processing methods ($P<0.05$).

The arachidonic cis-5, 8, 11, 14-Eicosatetraenoic (C20:4 n-6) value in the fresh samples was raised significantly ($P<0.05$) by both processes of smoking and sun drying. Although, arachidonic acid (AA) has been implicated as inflammatory agent, according to Gogus and Smith (2010) its supplementation has also been shown to prevent epidermal water loss as it is retro converted to C18:2 n-6. Le et al. (2009) underscored the importance of AA and DHA supplementation in the form of fish oil in the prevention and amelioration of essential fatty

acid diseases (EFAD) as well as prevention and attenuation of parenteral nutrition (PN) which induced cholestasis in human. Smoked and sundried specimen could be useful ingredients in the emulsion rich in AA since Le et al. (2009) also suggested AA as a sole FA demonstrated similar results. .

Among the omega series, both Eicosapentaenoic cis-5,8,11,14,17-Eicosapentanoic, EPA (C20:5 n-3) and Docosahexaenoic cis-4,7,10,13,16,19-Docosahexaenoic, DHA (C22:6 n-3) have received a lot of research attentions and reviews because of their ability to promote health and prevent diseases in human. In this study, EPA was significantly raised by sun drying from 15.56 % in the fresh to 18.50 % while smoking reduced the value significantly statistically, the percentage was small hence the opinion that this may be as a result of oxidation due to heat from smoking. Lipids subjected to processing are known to undergo hydrolysis and oxidation. DHA demonstrated highest level of oxidation with both sun drying and smoking significantly reduced by approximately 30 % and 21 % respectively.

In the Ω-3, EPA dominated over the DHA in all the product forms. The highest value of the EPA was obtained in the sundried while the fresh specimen had the highest concentration of DHA. The ω-3/ω-6 were in favour of the omega 3. The highest ratio was found in the fresh specimen with the lowest found in the shrimp subjected to smoking process. This suggested that muscle of the shrimp regardless of forms is good for consumption coming from the fact that the PUFAs of the omega 3 produces anti inflammation unlike the omega 6 which is pro inflammation and thus supports a lot of health benefits.

Index of atherogenicity (IA) and Index of thrombogenicity (IT) determined for the control and treatments for the shrimp ranged from 0.71 to 0.82 and 0.21 to 0.30 respectively (Table 2). This result compares approximately with values reported for Brown shrimp (*Cragon cragon*) by Turan et al. (2011). IA values were higher in *Penaeus notialis* based on finding for this study than that reported for Red shrimp (*Aristeus antennatus*), pink shrimp, (*Parapenaeus longirostris*) and Norway lobster (*Nephrops norvegicus*) (Rosa and Nunes 2004) but in IT compares favourably. Smoked shrimp when consumed will be the most than other product forms due to its lowest IA value of 0.71 while fresh shrimp is the most antithrombogenic with lowest value of 0.21.

The composition of the amino acids in fresh, smoked and sundried muscles of *Penaeus notialis* is presented in Table 3. Glutamate was the most abundant in all product forms. In the fresh, glutamate, aspartate, proline, lysine, arginine, and glycine were the six most abundant and their sum consisted more than 50 % of the total amino acids. Zlatanos et al. (2009) reported similar findings for *Penaeus kerathurus*. In both processing methods leucine displaced lysine while both cysteine and alanine featured amongst the big six. The values of glycine, alanine, serine, aspartate, valine and phenylalanine were significantly raised ($P<0.05$) by both processing methods but such changes were considered small to have any impact on the shrimp composition and may be due to individual and size differences in the shrimp. In the same vein, values of glutamate, arginine, isoleucine, threonine and proline were significantly lowered ($P<0.05$) statistically but the author considered such changes largely below 10 % as not being strong enough to impact on the biologic nutritive value of the shrimp. This view was supported by the favourable protein scores of the shrimp.

The highest concentration of leucine (102 mg/g protein) was obtained in the smoked product. Leucine concentrations were raised highest in the four marine fin-fishes subjected to boiling and roasting but were reduced in fried samples (Oluwaniyi et al. 2010). In spite of the increased leucine levels occasioned by the heat treatments used in this study, it is worthy to note that the values were less than 110 mg/g protein, considered excess and results in the development of pellagra from sorghum consumption and maize (FAO 1995; Ghafoorunissa and Rao 1973). It is very instructive to evaluate and choose careful the product combination that gives the total leucine that must be below 110 mg/g protein when shrimps are added to maize/sorghum in the popular local formulation of complementary foods for infants and growing children. The strongest odour (olfactory perception) by the smoked product suggested the process of Strecker degradation (a Maillard-type process) which amino acids such as leucine are known to initiate through formation of Strecker aldehyde as described in Kerler et al. (2010). Erkan et al. (2010) indicated that leucine regulates the blood sugar levels therefore, the smoked form may be recommended in diabetes treatment. Although phenylalanine values were elevated in the treatments (7–17 % rise) and may have contributed in the Maillard-type reaction, it is suggested that the impact of leucine was higher.

Histidine value (35 mg/g protein) was highest in the smoked samples of *P. notialis* and perhaps offered better deal when in quest for growth and repair of tissue as well as in the production of blood cells (Erkan et al. 2010). In *P. monodon* sundried samples produced the highest concentration (Akintola et al. 2013) suggesting that impacts of both sun-drying and smoking processes may also be related to muscle structural differences among shrimp species. Nevertheless, it is apt that this study confirmed the tendency of histidine to be raised when subjected to sunlight because of its scavenge of free radicals (Fang et al. 2002) produced during exposure to ultra violet radiation from the sun. Sundried samples when consumed will provide functions such as prevention of seafood allergy and according to Fang et al. (2002) dietary foods functioning as antioxidant prevent many human diseases including cancer, atherosclerosis, stroke, rheumatoid arthritis, neurodegeneration, and diabetes. Importance of histidine in

Table 3 Amino acids composition in fresh, smoked and sundried muscle of *Penaeus notialis*

Amino acids	Content in fresh muscle (n=3)		Content in smoked muscle (n=3)		Content in sundried muscle (n=3)	
	(g/100 g) mean ± SD	(mg/g protein)	(g/100 g) mean ± SD	(mg/g protein)	(g/100 g) mean ± SD	(mg/g protein)
Glycine	4.20±0.16	64	4.57±0.01	69	4.65±0.15	69
Alanine	3.29±0.00	50	4.07±0.01	61	3.96±0.18	59
Serine	3.02±0.14*	45	3.49±0.00	53	3.35±0.24*	50
Proline	4.97±0.01	75	4.69±0.00	71	4.49±0.35	67
Valine	2.75±0.01	42	3.07±0.01	46	2.97±0.16	44
Threonine	3.82±0.01	58	3.30±0.01	50	3.44±0.25	51
Isoleucine	2.40±0.01	36	2.20±0.01	33	2.09±0.18	31
Leucine	4.62±0.01	70	6.76±0.01	102	6.43±0.57	96
Aspartate	5.96±0.06	90	6.39±0.01	96	6.10±0.49	91
Lysine	4.66±0.01	71	2.43±0.00	37	2.89±0.80	43
Glutamate	8.31±0.01	126	7.99±0.00	120	7.69±0.53	115
Methionine	3.81±0.00	58	2.31±0.01	35	2.26±0.07	34
Phenylalanine	1.80±0.01	27	1.93±0.02	29	2.12±0.33	32
Histidine	1.65±0.01	25	2.33±0.00	35	2.23±0.17	33
Arginine	4.58±0.02	69	3.36±0.00	51	4.21±1.47	63
Tyrosine	2.20±0.01	33	3.82±0.00	57	3.77±0.09	56
Cystine	4.00±0.01	61	3.74±0.01	56	4.32±1.02	65
Total	66.03	1000	66.44	1000	66.99	1000
Arginine/lysine	0.98		1.38		1.54	
∑ EAA	29.30		27.69		28.64	
∑ NEAA	36.73		38.75		38.35	
EAA/NEAA	0.80		0.72		0.75	

N.B Except otherwise stated means were significantly different (P<0.05) at 0.05 and 0.01 among treatments subjected to ANOVA and LSD

* Not statistically different (P>0.05)

infant and growing children have been emphasised (FAO/WHO/UNU 1985; Imura and Okada 1998).

Tyrosine values were increased approximately 70 % and 80 % respectively in the smoked and sundried samples. In the present study which compared with observation reported for *P. monodon* (Akintola et al. 2013) changes in the colouration of the shrimp from translucent to light brown in both processing (57 mg/g protein and 56 mg/g methods in smoke and sundried samples) may have been occasioned by the strong changes produced in tyrosine suggesting that it contributes the most to products' flavour. In light of the fact that both treatments produced increased level of carbohydrate and tyrosine, it is hypothesized that Maillard non-enzymatic browning processes were activated during processing and would continue upon storage in a real world situation beyond the study period wherein enzymatic browning becomes pronounced.

Tyrosine is the substrate for the enzyme tyrosinase (Loizzo et al. 2012) and the yield of ortho-quinone which drives enzymatic browning: one of the food industry's major problems especially for fruits, vegetables and seafood (Loizzo et al. 2012) leading to the search for natural and synthethic tyrosinase inhibitors. WHO (2007) stated that the lack of tyrosine causes hypothyroidism which could be treated by consumption of sundried and smoked samples of *P. notialis*. Investigation of the implications of high concentration of tyrosine in hot smoking and sun-drying of shrimps and attendant consumption of browning material therefrom on human health will be worthwhile. Lee et al. (1982) reported on the nutritional and toxicological effects of browning material in diet include severe diarrhea, enlarged cecums, enlarged kidney, damaged liver and others in an in vivo study using rat fed on browned diet (toxicity is evident over long period and cumulative).

In this study the reduction of available lysine from 71 mg/g protein in fresh to 43 mg/g protein and 37 mg/g protein sundried and smoked samples were due to the impact of heat on the muscle of the shrimp. Sannaveerapa et al. (2004) reported loss of lysine in milk fish subjected to salt and sun drying. Methionine values reduced from 58 mg/g protein to 35 mg/g protein and 34 mg/g protein indicating the impact of both processing methods. However, while the values for lysine and methionine in the two processes were able to meet the

Table 4 Amino acids score and protein digestibility corrected- amino acid score fresh, smoked and sundried meat of *Penaeus notialis*

Amino acids	Reference (mg/g protein)	Content in fresh muscle (n=3)			Content in smoked muscle (n=3)			Content in sun- dried muscle (n=3)		
		(mg/g protein)	Score	PDCAAS	(mg/g protein)	Score	PDCAAS	(mg/g protein)	Score	PDCAAS
Valine	35	42	120	1.1	46	131	1.3	44	126	1.2
Threonine	34	58	171	1.6	50	147	1.4	51	150	1.4
Isoleucine	28	36	129	1.2	33	118	1.1	31	111	1.1
Leucine	66	70	106	1.1	102	155	1.5	96	146	1.4
Lysine	58	71	122	1.2	37	64	0.6	43	74	0.7
Methionine + cystine	25	119	476	5.0	91	364	3.5	99	396	3.8
Phenylalanine + tyrosine	63	60	95	0.9	86	137	1.3	88	140	1.3
Histidine	19	25	132	1.4	35	184	1.8	33	174	1.7
Total	328	481			480			485		

Reference amino acid pattern of preschool children (2–5 years) FAO/WHO/UNU (1985) and FAO (1991) for Histidine

PDCAAS protein digestibility corrected- amino acid score at 95 %

30 mg/kg per day and 10 mg/kg per day recommended for adults lysine value was below the 69±9 mg/g protein found in human milk protein using the FAO/WHO/UNU (1985) standard hence may not serve the useful purpose intended when used as ingredient in baby formula. Use of processed shrimp is a common practice by nursing mother as dietary supplement for weaning children in Nigeria. Cysteine was highest in the sundried products and may be useful in dietary formulation for convalescing individual since cysteine is useful during the healing of wounds after surgical operations and in increasing the activities of white blood cells.

The cholesterolemic properties of proteins have been related to their amino acid content and the arginine/lysine ratio may be the most objective index (Unusan 2007). In this study, fresh muscle of the Southern pink shrimp presented an arginine/lysine ratio of 0.98. Larger ratio was calculated for the smoked (1.38) and in sundried (1.54). Based on this, the process of sun drying offered a better cardiosalutable product. The ratio of essential amino acid, EAA to the non-essential amino acid, NEAA was highest in the fresh (0.80). EAA/NEAA ratios for the smoked and sundried were 0.72 and 0.75 respectively. Sriket et al. (2007) reported ratios of 0.70 and 0.67 in black tiger shrimp and white shrimp respectively while Rosa and Nunes (2004) reported average of 0.89 and 0.91 for the red and pink shrimps. The EAA/NEAA ratio of many fish species is 0.70 on the average (Iwasaki and Harada 1985) hence the Southern pink shrimp fresh, smoked and sundried could be described as balanced with respect to EAA.

It is not entirely sufficient for a food item to be adjudged to have high quality protein, it is of equal relevance for a consumer to know if the amino acids are equally available or digestible. Digestibility of amino acids are known to be affected by such factors as protein conformation, binding to macronutrients (polysaccharides and lipids among others), anti-nutritional factors and thermal treatments. It is therefore imperative to calculate the digestibility of a food item which has been subjected to heat treatments. Protein degradation and Amino Acids Score (AAS) and Protein Digestibility Corrected- Amino Acid Score (PDCAAS) of fresh, smoked and sundried meat of *Penaeus notialis* is shown in Tables 3 and 4.

The limiting amino acid in the fresh shrimp was Phenylalanine + Tyrosine and in spite of this, fresh shrimp would meet 90 % of the requirements of 38 mg/g protein of an adult. In the muscle of the shrimp subjected to smoking and sun drying lysine was found limiting due to impact of the heat from the processing methods. Consumption of smoked and sundried products would only provide 60 % and 70 % of 45 mg/g protein. Cockerell et al. (1972) stated that free epsilon amino groups of lysine are particularly susceptible to heat damage, forming additional compounds with non-protein molecules (reducing sugars) present in the foodstuffs. Nevertheless, the proteins from Southern pink shrimp muscle were well-balanced in the three forms in their essential amino acid compositions, which indicated that it is a high quality protein source.

Conclusion

This paper present the first holistic study on the evaluation of the impact of smoking and sun-drying on the Southern pink shrimp. Proximate analyses showed that on dry weight basis smoking increased the protein and carbohydrate values while fat contents were not different between the two methods. Ash contents of fresh, smoked and sundried products were not different. Both treatment however reduced the fibre contents of the shrimp.

Palmitic acid was the most abundant of the SFAs with smoked samples offering the smallest concentrations. Oleic acid, the most dominant MUFA was raised by both treatments. In the PUFAs, linoleic acid values were increased by both heat treatment methods. Both EPA and DHA showed high degree of instability when subjected to smoking and sun-drying. The ratio of ω-3/ω-6 were in favour of the omega 3. The highest ratio was found in the fresh specimen with the lowest found in the shrimp subjected to smoking process. In spite of different impacts exhibited by both processing methods, positive values of Index of atherogenicity (IA) and Index of thrombogenicity (IT) were calculated for both inclusive of the fresh samples. Smoked shrimp when consumed will be the most anti-atherogenic than other product forms due to its lowest IA value while fresh shrimp is the most anti-thrombogenic with lowest value.

Glutamate was the most dominant amino acid and like arginine, isoleucine, threonine and proline the reductions by both smoking and sun-drying were considered not important. Maillard reactions lead to increased values of leucine, histidine, tyrosine and lysine leading to the browning observed in the smoked and sundried samples. Nevertheless, Protein degradation and Amino Acids Score (AAS) and Protein Digestibility Corrected- Amino Acid Score (PDCAAS) were positive indicating that the proteins from Southern pink shrimp muscle (fresh, smoked and sundried forms) were well-balanced in their essential amino acid compositions indicating that the shrimp is of a high quality protein source.

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