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Effect of Heat Transfer Kinetics on Nutritional Composition and Acceptability of Smoked Fish and Meat Products

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Abstract
In food processing engineering, heat and mass transfer problems are encountered and cannot be solved by thermodynamics reasoning alone but requires food analyses based on heat kinetics principles. The objective of this work is to determine the rate of moisture removal within specified machine capacity and the effect on nutritional composition and sensory attributes of various fish and meat products. Proximate composition of fresh and finished beef, Atlantic mackerel fish, chicken and herring fish was carried out. Sensory acceptability of the product was also considered. Moisture removal rate of the machine for fish and meat products was calculated to be 25.87 %/hr (Atlantic mackerel), 23.37 %/hr (herring fish); and 28.05 %/hr (beef) and 24.51 %/hr (chicken) respectively. The volumetric capacity was found to be 0.0048 m^3 (mackerel and herring fish), 0.0061 m^3 (beef) and 0.0095 m^3 (chicken). Proximate analysis showed that moisture content, crude protein, crude fat, crude fibre, ash content, and carbohydrate content of the smoked product ranged from16.41 to 22.67%, 36.78 to 59.00%, 14.42 to 26.64%, nil, 2.09 to 9.00% and 5.42 to 6.79% while that of fresh product ranged from 69.77 to 73.19%, 18.17 to 20.11%, 4.73 to 7.30%, nil, 1.20 to 3.57% and 0.85 to 4.02% respectively. At 5% level of significance, there was a significant difference in the proximate composition of fresh and smoked samples. Overall acceptability of the products was high and there was no significant difference ($p > 0.05$) in the sensory attributes considered for the products.
Keywords: heat; products; analysis; composition; evaluation; capacity

I. INTRODUCTION

Drying could be achieved by smoking, roasting, frying and so on. These are popular unit operations in food engineering commonly find in kitchen. It is designed to cook fish, beef, chicken, breaded vegetable, specialized pastries and French-fried potatoes among others. These processes influence many qualities of finished product such as flavor, texture and shelf life; and therefore making food palatable for human consumption [1]. In addition, dried food products are more convenient to transport as a result of reduced weight and the phenomenon involved the use of heated air to stimulate quality of food to cause some desirable physical and chemical changes [2[. The desirable attributes manifested in food product enhances marketability of the finished product and provision of raw material for both small and large scale processors. In fish, meat and dairy, food preservation is accomplished by temperature difference as driving potential of heat transfer kinetics [3]. It destroys micro-organism and reduces water activity at the surface of food.

In addition to heat transfer, there is mass transfer (concentration difference) in food composition as a result of surface dehydration to harness good nutritional and textural attributes of finished food product as expected by the consumers [4]. As heat is conducted to the material, the inner moisture is converted to steam, creating a pressure gradient [5]. The convective heat transfer causes boiling of free water, diffused in available fat and leached out of the product. The moisture vapourizes and creates capillary pore through which exchange of heat takes place [6]. The reaction occurs by the influence of oil uptake, crust formation, shrinkage and therefore inducing macro- and micro-structural changes.

The heating procedure determines effective way to maintain food product's quality. However, heating can promote protein denaturation in food products, resulting in a reduction in both nutritional and functional qualities [7]. To obtain a premium grade dried product, it is vital to optimize the time, temperature, and parameters in the drying procedure. Sensory evaluation (color, texture, odor, flavor, and overall acceptance); physicochemical assessment (pH level, VBN level, TBARS level, TMAO and fatty acid content); and microbial growth measurement also established qualities of fish products [8].

Fish is the most often smoked commodity in Nigeria, ranging from traditional open fire to mud brick, cylindrical drum, and brick [9]. In most regions of the world, fish processing via hot smoking has been practiced

for centuries. Due to a lack of suitable technology and infrastructure, Nigerian fish smoking procedures have not gained international recognition. Locally accessible technologies like mud bricks, stone, and firewood are commonly employed, but with negative impact on the quality of the finished product [10]. Market value declines owing to damaged and unappealing appearance of processed fish, while quality control and enhanced hygienic conditions are difficult to maintain [9]. Locally smoked products in Nigeria have been identified as mutagenic and carcinogenic, polycyclic aromatic hydrocarbons (PAHs). These are organic compound found in wood smoke and smoked foods which are potentially genotoxic and carcinogenic to human. PAHs are processed by enzymes in human body, resulting in promutagenic and carcinogenic DNA adducts [11-12]. The objective of this work is to determine the effect of heat application on nutritional composition and sensory attributes of fish and meat products using an improved smoking kiln.

II. MATERIALS AND METHODS

2.1 Procurement of Raw Materials

Samples (beef, Atlantic mackerel fish, chicken and herring fish) were obtained from Ota market; the samples were thoroughly washed and salted, and eviscerated to remove the impurities and intestine of the fish and meat product. The charcoal in the charcoal tray was first ignited with the help of kerosene, the ignited charcoal was allowed to burn for 10 to 15 minutes to allow the kerosene odor to be exhausted. More charcoal was added to the burning charcoal in the charcoal container and placed inside the smoking kiln before loading with fish or meat material. The exploded view of the machine is shown in Figure 1.

Figure1: Exploded view of the smoking kiln

2.2 Rate of Moisture Removal

The samples were weighed (Initial weight) and arranged on a rack before being placed in the smoking kiln. Smoking/drying continued until a final weight was achieved and hence the percentage moisture loss during smoking was determined from both the initial and final weight as shown in Table 1. The percentage moisture loss is calculated using the equation given by Ikenweiwe, [13].

Table 1: System evaluation

Samples	Time taken (hrs)	Initial weight (kg)	Final weight (kg)	Moisture loss (%)
Beef	2	5.85	2.57	56.10
Atlantic mackerel	2	5.20	2.51	51.73
Chicken	2	8.20	4.18	49.02
Herring fish	2	5.20	2.77	46.73

$$Moisture\quad loss\ (\%) = \frac{Initial\quad weight\quad - Final\quad weight}{Initial\quad weight} \times 100 \quad \text{.....} \quad ...(1)$$

Moisture removal rate (MR) of the smoking kiln is given as:

$$MR = \frac{Moisture\quad loss}{t} \text{..... .... (2)}$$

MR for Beef:

$$MR_{beef} = \frac{56.10}{2}$$

$$= 28.05\ \%/hr$$

MR for Atlantic mackerel:

$$MR_{mac\ ker\ el} = \frac{51.73}{2}$$

$$= 25.87\ \%/hr$$

MR for Chicken:

$$MR_{chicken} = \frac{49.02}{2}$$

$$= 24.51\ \%/hr$$

MR for Herring fish:

$$MR_{herring} = \frac{46.73}{2}$$

$$= 23.37\ \%/hr$$

2.3 Determination of System Capacity

The volumetric machine capacity was computed based on mass of each sample in the smoking kiln. The volumetric capacity is calculated as:

$$V = \frac{M}{\rho} \text{..... ....(3)}$$

Where V= Volumetric capacity of smoking kiln (m^3), M = Mass of each sample (kg) and ρ = Density of sample: Fish = 1080 kg/m^3), Beef = 955.25 kg/m^3) and Chicken = 865.64 kg/m^3) [14].

For Fish (Atlantic mackerel and Herring fish):

$$V_{fish} = \frac{5.20}{1080}$$

$$= 0.0048\ m^3$$

For Beef:

$$V_{beef} = \frac{5.85}{955.25}$$

$= 0.0061 \quad m^3$

For Chicken:

$$V_{chicken} = \frac{8.20}{865.64}$$

$= 0.0095 \quad m^3$

2.4 Determination of Nutritional Composition of Samples

2.4.1 Moisture Content Determination

The moisture content determination was determined by using the procedure described by AOAC [15]. Five grams of the sample was grinded, weighed into a previously dried crucible and heated in an oven at 105^{o}C for 1 hour. The crucible from the oven was removed and cooled in the desiccator and weighed. The samples were heated in the oven for a further period of 4 hours, cooled and weighed. This process was repeated until change in weight between the two successive observations did not exceed 1mg. The determination was carried out in duplicates.

$$MC_{wb}(\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad \text{.....} \quad \text{.....} \quad \text{.....} \quad \text{.....}(4)$$

Where W1 = Weight of empty crucible, W2 = Weight of sample and crucible before drying and W3 = Weight of sample and crucible after drying

2.4.2 Ash Content Determination

Five (5) grams of the sample was weighed out and put in a clean dried and weighed crucible. The sample was evaporated to dryness in an oven at 100^{o}C. The dried sample was placed in a muffle furnace and ignited at 550^{o}C for 3 hours. It was transferred into a desiccator to cool. Weight of the ash and crucible was taken as follows:

$$Ash\ content\ (\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad \text{.....} \quad \text{.....} \quad \text{.....} \quad \text{.....}(5)$$

Where W1 = Weight of crucible, W2 = Weight of crucible and dried food and W3 = Weight of crucible and ash

2.4.3 Crude Fat Determination

Crude fat was determined using Soxhlet method of AOAC [15]. One gram of each dried sample was weighed into fat free extraction thimble and plugged lightly with cotton wool. The thimble was placed in the extractor and fitted up with reflux condenser and a 250 ml Soxhlet flask which has been previously dried in the oven, cooled in the desiccator and weighed. The Soxhlet flask was filled to ¾ of its volume with N-Hexane and the Soxhlet flask. Extractor plus condenser set was placed on the heater. The heater was put on for 6 hours with constant running water from the tap for condensation of the solvent vapour. The solvent was left to siphon for about 10-12 times, then the content of the extractor was carefully drained into the ether stock bottle. The thimble containing sample was removed and dried on a clock glass on the bench top. The extractor, flask and condenser were replaced and the distillation continued until the flask was practically dried. The flask which contains the fat was detached, cleaned and dried to constant weight in the oven.

$$\%\ Crude\ fat = \frac{W_2 - W_1}{Weight\ of\ sample\ used} \times 100 \quad \text{.....} \quad \text{.....}(6)$$

Where W_1 = Initial weight of dried soxhlet flask, W_2 = Final weight of oven dried flask + fat

2.4.4 Protein Content Determination

The protein content was determined using KJECTEC 2200 distillation apparatus (Kjeldahl method) according to the procedure of AOAC [16]. Concentrated H_2SO_4 (12 cm^3) and 2 tablets of catalyst were put into a Kjeldahl digestion flask containing 5g of the sample. The flask was placed in the digestor in a fume cupboard and switched on and digestion took 45 minutes to obtain a clear colorless solution. The digest was received into a 4% boric acid, 40% sodium hydroxide solution and put in the KJECTEC 2200 distillation equipment until distillation was completed. The distillate was then titrated with 0.1M HCl until a violet formation indicating the end point. A blank was run under the same condition as with the samples tested. The total nitrogen content was then calculated according to the formula:

$$Crude\quad protein\quad =\frac{titre\quad of\quad (sample\quad -\ blank\quad)\times 0.01\times 14.007\quad \times 6.25}{10\ \times\ weight\quad of\quad sample}\ .....\quad .....(\quad 7)$$

2.4.5 Crude Fibre Determination

Three (3)g of the sample was weighed into a 250 ml beaker containing 200 ml 1.25% H_2SO_4. The mixture was heated for 2 hours in a steam bath at 90°C, and then chilled over a Backner funnel, the cooled mixture was filtered through a muslin cloth. The residue was rinsed three times in hot distilled water before being placed in a beaker with 200 ml potassium hydroxide. The mixture was heated for 2 hours at 90 °C. After filtering the solution through a muslin cloth over a Buckner funnel, the residue was rinsed three times with hot distilled water, then with petroleum ether and water. The final residue was put into a pre-weighed crucible, dried to constant weight at 120 °C in a convection oven. The oven-dried sample was placed in a crucible and ashed at 550 °C for 30 minutes in a muffle furnace. The crucible and sample were weighed after cooling. The samples' crude fiber was calculated as follows:

$$Crude\quad fibre\quad (\%)=\frac{W_3\ -\ W_2}{W_1}\times 100\ .....\quad .....\quad ..(8)$$

Where W1 = Weight of sample, W2 = Weight of sample after digestion and W3 = Weight of ash.

2.4.6 Carbohydrate Content Determination

The carbohydrate content was obtained by calculation:

Carbohydrate (%) = 100 – (% moisture + % protein + % fat + % fibre + % ash) … (9)

2.5 Statistical Analysis

Statistical analysis was conducted with the SPSS software version 25.0. The mean and standard deviation of duplicate of the parameters were calculated and differences between the means was evaluated using one way analysis of variance (ANOVA) with significant level being considered at 5%. The mean values were separated using Duncan's multiple range test (DMRT)

2.6 Sensory Evaluation

Sensory evaluation was carried out on the smoked samples using the 9-point hedonic scale where 9 represented "like extremely" and 1 represented "dislike extremely". The sensory evaluation was carried out by 20 panelists where they assessed the appearance, aroma, taste, texture and overall acceptability of the smoked products.

III. RESULTS AND DISCUSSION

3.1 Performance Evaluation of the Machine

Smoking is a complex process that involves simultaneous heat and mass transfer and results in a range of physicochemical changes in the smoked food. Volumetric capacity of the smoking kiln was calculated to be 0.0048 m^3, 0.0061 m^3 and 0.0095 m^3 for fish, beef and chicken respectively. Atlantic mackerel, herring fish, Beef, and chicken had percentage moisture loss of 51.73%, 46.73%, 56.10% and 49.02% respectively at 2 hours smoking time. Smoke drying was carried out at product temperatures of 90°C as measured with the aid of a thermometer. This temperature is in accordance with Rahman [17] who stated that required smoking temperature ranges from 80°C to 90°C to allow for optimum smoke penetration suitable for effective drying. As the product heats up, moisture is converted to steam and it migrates to the surface. The rate of moisture removal of the smoking kiln was calculated to be 25.87 %/hr, 23.37 %/hr, 28.05 %/hr and 24.51 %/hr for Atlantic mackerel, herring fish, beef, and chicken respectively. These values contradict Seraj [18] who reported low moisture removal 2.87 %/hr. This could be as a result of short resident time motivated by the lagging of entire smoking kiln with fibre glass insulator purposely to preserve the heat and prevent losses to the surrounding. Smoked chicken, Atlantic mackerel and herring fish are shown in Figure 2 to 4.

Figure 2: Smoked chicken products

Figure 3: Smoked Atlantic mackerel

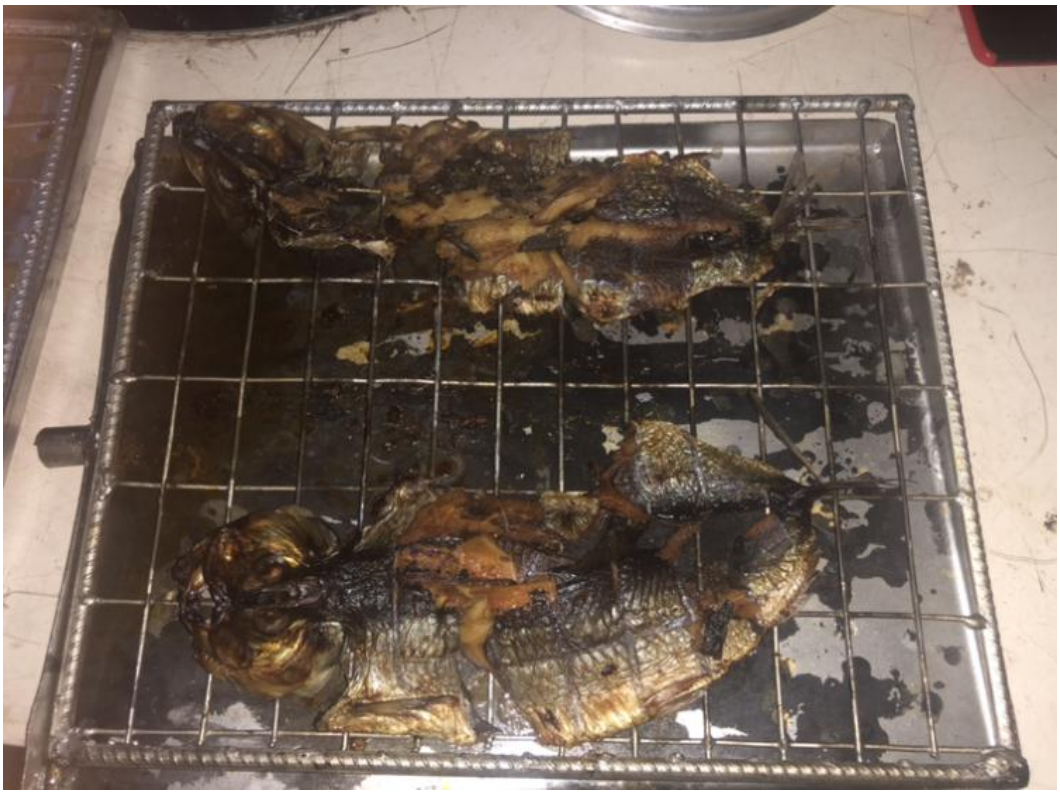

Figure 4: Smoked herring fish

3.2 Effect of Smoking on Proximate Composition of Smoked Products

The effect of the smoke-drying method on the proximate composition of smoked fish, beef, and chicken is shown in Table 2. The moisture content of the raw samples ranged from 69.77% to 73.19% while the processed samples ranged from 16.41% to 22.67%. The moisture content of the smoked samples is similar to a research carried out by Kwaghvihi [19] who reported moisture content 8.25% to 22.86% of various smoked fish purchased at various markets in Umahia. There was a significant difference in the moisture contents of both the fresh and smoked samples ($p<0.05$). The crude protein content of the raw samples ranged from 18.17% to 20.11% while the processed samples ranged from 36.78% to 59.00%. These values are not far from the results of Msuku and Kupute [20] whose values for smoked product ranged from 52.80% to 55.30%. At 5% level of significance, the crude protein content of smoked products was significantly different ($p<0.05$). As shown in table 4.2, the crude fat content of the raw samples ranged from 4.73% to 7.30% while the smoked samples ranged from 14.42% to 26.64%. Foline [21] developed a smoking kiln and fish smoked with this kiln had 12.50% fat content. This is relatively lower and could be as a result of variety of fish used. At 5% level of significance, the crude protein content of smoked products was significantly different ($p<0.05$). No crude fibre was detected in any of the fresh and smoked products. This is in accordance with Msuku and Kupute [20] who reported no presence of crude fibre in both fresh and smoked fish. However, Foline [21] reported 0.7% and 0.9% crude fibre in fresh and smoked fish respectively at 70^{o}C for 5 hours. This could be as a result of processing method. The ash content of the raw samples ranged from 1.20% to 3.57% and that of the smoked sample ranged from 2.09% to 9.00%. Ash content of fish by Msuku and Kupute [20] was recorded to be 10.57% and 12.96% for fresh and smoked product respectively. This is significantly different from the results obtained from this study which might be as a result of variables such as temperature, processing method and fish species. There was a significant difference in the ash contents of both the fresh and smoked samples ($p<0.05$). Nitrogen free extract (NFE) content of the samples ranged from 0.85% to 4.02% for the fresh samples and 5.42% to 6.79% for the smoked samples. Research carried out by Foline [21] showed NFE of 0.92% in fresh fish sample and 1.80% in smoked fish sample. The difference in the Nitrogen Free Extract of smoked samples could be as a result of the processing technique and source of the materials used. At 5% level of significance, the carbohydrate content of smoked products was significantly different.

Table 2: Effect of smoking on proximate composition of fish and meat products

Sample	Moisture (%)	Crude Protein (%)	Crude Fat (%)	Crude Fibre (%)	Ash (%)	NFE (%)
FMBF	73.19± 0.00^{g}	19.77 ± 0.01^{b}	5.00 ± 0.04^{a}	0.00± 0.00	1.20 ± 0.04^{a}	0.95 ± 0.02^{ab}
SMBE	17.92 ± 0.13^{b}	59.00 ± 0.16^{e}	14.42 ± 0.01^{d}	0.00± 0.00	2.09 ± 0.04^{c}	6.59 ± 0.01^{e}
FFTI	69.77 ± 0.42^{e}	20.11 ± 0.96^{b}	6.02 ± 0.19^{b}	0.00± 0.00	2.77 ± 0.04^{d}	1.35 ± 0.70^{b}
SFTI	16.41 ± 0.04^{a}	55.31 ± 0.06^{d}	18.72 ± 0.50^{f}	0.00± 0.00	9.00 ± 0.07^{g}	6.57 ± 0.23^{a}
FMCH	70.85 ± 0.17^{f}	18.75 ± 0.08^{a}	4.73 ± 0.22^{a}	0.00± 0.00	1.66 ± 0.03^{b}	4.02 ± 0.01^{c}
SMCH	20.67 ± 0.06^{c}	54.82 ± 0.40^{d}	15.61 ± 0.04^{e}	0.00± 0.00	2.12 ± 0.04^{c}	6.79 ± 0.43^{e}
FFSH	70.12 ± 0.15^{e}	18.17 ± 0.07^{a}	7.30 ± 0.05^{c}	0.00± 0.00	3.57 ± 0.04^{e}	0.85 ± 0.71^{ab}
SFSH	22.67 ± 0.13^{d}	36.78 ± 0.10^{c}	26.64 ± 0.15^{g}	0.00± 0.00	8.50 ± 0.05^{f}	5.42 ± 0.13^{d}

Values are means ± standard deviation of duplicate determinations. The mean values of the samples within a column with different superscripts (letters) are significantly different ($p < 0.05$).

Legend

FMBE: Fresh beef
SMBE: Smoked beef
FFTI: Fresh Atlantic mackerel fish
SFTI: Smoked Atlantic mackerel fish
SMCH: Smoked chicken
FFSH: Fresh herring fish
SFSH: Smoked herring fish
FMCH: Fresh chicken

3.3 Effect of Smoking on Sensory Evaluation

Results of the sensory evaluation are shown in Figure 4. The results implied that parameters tested for had no significant difference ($p>0.05$) except for the texture parameter ($p<.05$). Beef (SMBE), Atlantic mackerel (SFTI), chicken (SMCH) and herring fish (SFSH) had appearance attribute of 6.59, 7.50, 7.07 and 7.45respectively. There was no significant difference in the appearance of all samples. SMBE, SFTI, SMCH) and SFSH had 7.35, 7.75, 7.30 and 7.50 in aroma attribute respectively. There was no significant difference in aroma across the samples ($p>0.05$). The taste of the samples showed significantly difference within the values of 7.45, 7.95, 7.50 and 7.55 for SMBE, SFTI, SMCH and SFSH respectively. The texture of all the samples showed significant relationship at 7.10, 8.10, 7.40 and 7.45 respectively. There was no significant difference in overall acceptability of the samples with preference for Atlantic mackerel fish.

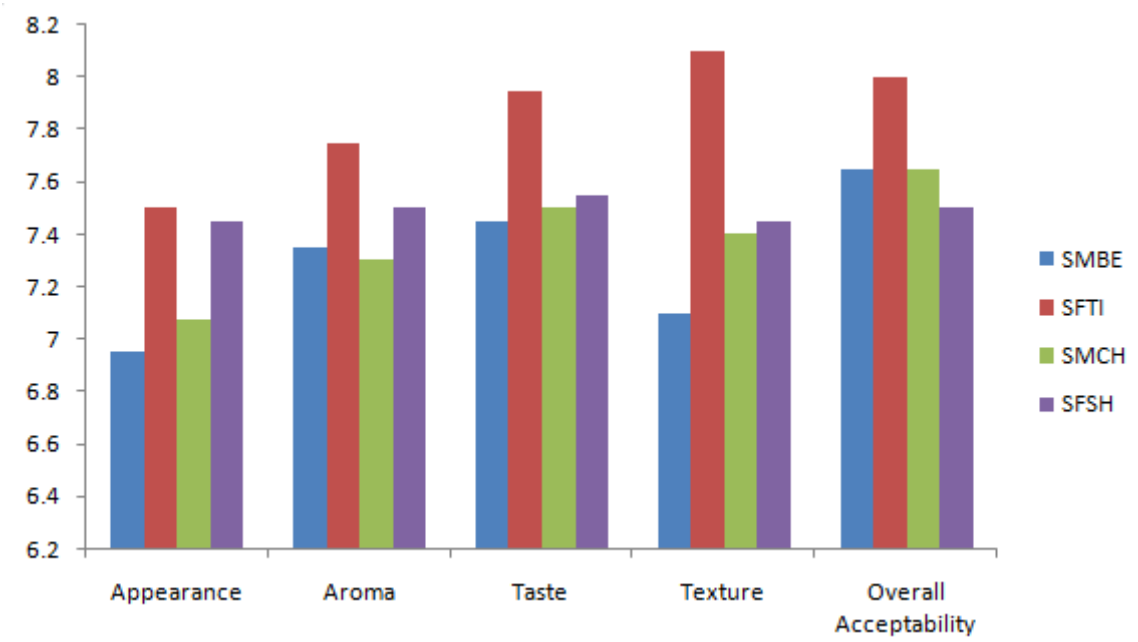

Figure 5: Effect of smoking on sensory attributes of fish and meat products

IV. CONCLUSION

A smoking kiln was evaluated and effect of heat transfer kinetics on nutritional composition and consumer's acceptability of selected smoked fish and meat products was determined. High rate of moisture removal of the machine depicts suitability for the purpose of upgrading rural technology for fish and meat smoked products. The machine is affordable and eliminates drudgery and contamination associated with local smoking. It was observed that heat source is not directly under the rack system of the kiln, as heat flows upward, the hot air floats and products at upper tray were noticed to dry faster. At 5% level of significance, there was a significant difference in the proximate composition of fresh and smoked products. However, consumer perception of the smoked products indicated that Atlantic mackerel fish was most preferred and acceptable to the panelist. A clear coloured with light consistency oil leached out from smoked products and collected through hose at the back of the smoking kiln call for further research.

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