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FISH SMOKERS AND POLYCYCLIC AROMATIC HYDROCARBON (PAH) RISKS IN SENEGAL

Technical Learning Note

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Overview

Smoked fish is widely traded and consumed in the entire West African region and is even exported internationally. In Senegal, artisanally-caught fish is typically processed by women's groups who use a variety of traditional processing techniques, most commonly smoking. Traditional smoking produces high levels of polycyclic aromatic hydrocarbons (PAHs) which are recognized as carcinogenic when consumed. Modern smoking ovens have been developed to reduce PAH levels in smoked fish, such as the Thiaroye model by FAO and the Ahotor oven model by the University of Rhode Island; however, these improved methods have not been widely adopted in many regions.

Business Drivers for Food Safety (BD4FS), a USAID-funded project implemented by Food Enterprise Solutions (FES), is engaging food businesses in Feed the Future countries to improve post-harvest processing, handling and transport practices for safer foods. In the Spring of 2020, BD4FS undertook a Food Safety Situational Analysis (FSSA) of the artisanal seafood sector in Senegal and confirmed that traditional smoking of fish remains a common practice.[1] To further investigate, BD4FS completed a desk review of the health risks associated with consuming smoked products, the different types of smokers and the levels of PAHs produced by each smoker, as well as costs and financing options for adopting modern smokers that produce lower PAH levels. The findings, summarized in this Technical Learning Note, are informing the next phase of research which will include (1) a survey to understand consumer demand and consumption levels of smoked fish and (2) focus groups with women fish processors to learn barriers to adopting modern smokers. Ultimately this research aims to identify implementable actions to help reduce PAH levels in smoked fish, contributing to the BD4FS mission of working with businesses towards safer foods.

[1] FES. (September 2020). "Summary of the Food Safety Situational Analysis of the Artisanal Seafood Sector in Senegal." Technical Learning Note. https://www.agrilinks.org/sites/default/files/media/file/FINAL%20FSSA%20Senegal%20%20Technical%20Note%209_23_20_0.pdf.

Introduction

Fish is one of the cheapest and most widely consumed animal proteins in the world. The FAO estimates that in 2017, approximately 17% of all animal proteins consumed was fish (FAO, 2020). In addition to being a great source of cheap protein, fish contains many other nutritious elements that are critical to human health and development such as iodine, vitamin D, omega 3's and omega 6 polyunsaturated fatty acids.

Although an excellent source of nutrition, one of the major challenges with fish is that it is extremely perishable and is prone to autolytic deterioration.[2] This perishable nature combined with poor storage and handling techniques at sea and on land often result in complete loss of the product. It is estimated that the world's fisheries suffer approximately 35% post-harvest loss each year (FAO, 2020). In areas where there is little or ineffective fisheries management and the status of fish stocks are poor or deteriorating, it is particularly important to minimize post-harvest loss.

Throughout the world there are many techniques used to reduce post-harvest loss, such as flash freezing, icing, refrigerating, canning, drying, salting, fermenting and smoking. Because of its relative simplicity, cost, and effectiveness, smoking of perishable items such as fish is a common process throughout Africa. It is widely estimated that in Africa, approximately 70-80% of fish that supplies the domestic markets is smoked (Adeyeye and Oyewole, 2015). The process of smoking foods for curing encompasses two steps. First, by reducing the moisture of the product, enzyme and bacterial action occurring within the product is slowed down (Kpoclou et al., 2014). Secondly, the process infuses antimicrobial compounds such as phenols to the product to further slow down enzymes and bacteria.

Although smoking can be a relatively cheap and effective way to process and preserve fish, it may pose risks to the consumer's health. As well as infusing the product with beneficial curing compounds like phenols, smoking produces chemicals such as acetic acids, aldehydes and polycyclic aromatic hydrocarbons which are deposited on the product (Essumang et al., 2013). Polycyclic aromatic hydrocarbons (PAHs) are a group of compounds that consist of two or more aromatic rings (Boehm, 1964). These compounds are naturally occurring, but their presence has been greatly exacerbated by anthropogenic activities such as pyrolysis and the incomplete combustion of organic materials such as coal, natural gas, woods, and oils (Boehm, 1964). While there are currently over 100 PAHs that have been identified, the Agency for Toxic Substances and Disease Registry (ATSDR) has identified the following 17 PAHs that are suspected to be more harmful to human health (ATSDR, 1995):

- acenaphthene
- acenaphthylene
- anthracene
- benz[a]anthracene
- benzo[a]pyrene
- benzo[e]pyrene
- benzo[b]fluoranthene
- benzo[g,h,i]perylene
- benzo[j]fluoranthene
- benzo[k]fluoranthene
- chrysene

[2] Autolytic deterioration is the destruction of cells through its own enzymes.

- dibenz[a,h]anthracene
- fluoranthene
- fluorene
- indeno[1,2,3-c,d]pyrene
- phenanthrene
- pyrene

In addition to being more harmful than others, the ATSDR has noted that humans have a higher likelihood of coming into contact with these 17 PAHs as they were found to be the most prevalent at waste sites (ASDTR, 1995). The most likely way of coming into contact with these PAHs is through the consumption of processed foods including grilled, dried, smoked, cured, barbecued or roasted foods (Tongo et al., 2016).

The formation of PAHs within food products is influenced by numerous different factors (Iko Afé et al., 2020). In 2009 the Codex Alimentarius commission identified ten variables that influence levels of PAHs within food products: (1) fat content of the food and where it goes during processing, (2) fuel type, (3) smoking method (hot or cold smoking), (4) smoke generation process and the temperature of pyrolysis, (5) airflow of the smoke, (6) distance between food and the heat source, (7) position of the food from the heat source, (8) smoking duration, (9) temperature during smoking, and (10) design of the smoker, cleanliness and maintenance of equipment (Codex Alimentarius, 2009).

When looking at these factors in relation to smoked fish in West Africa, one can easily understand concerns about high levels of PAHs in food and potential risks to human health. There are two mains methods for smoking meat and fish: hot and cold smoking. Cold smoking is defined as smoking products between the temperatures of 20-30 Celsius (Rørå et al., 2005) where the product is not cooked but simply infused with smoke to provide taste. Hot smoking is defined as 31-80 Celsius to cook and cure the product, and is the main curing process used to preserve fish. This method provides flavor of the smoke and is aesthetically pleasing to the consumer as it turns the flesh of fish a goldish color.

In West Africa, hot smoking is the predominant method of smoking largely due to the technology of the smokers. Up until recently and in many places still today, smoker technology has remained fairly simple, consisting of mud kilns, brick or cement ovens, and cut off barrel drums. A drawback to these types of smokers is that it is extremely difficult to regulate smoker parameters such as distance from the fire, dripping of fat, and temperature of the smoker (Essumang et al., 2013). Due to this, the traditional smokers often produce a product that far exceeds the 2 µg/kg and 12 µg/kg threshold for BaP[3] and PAH(4)[4] respectively which were set by the European Commission (EC) in 2014 (EC, 2006).

Reducing PAHs

In recent years, there have been numerous studies not only regarding the health impacts associated with the intake of PAHs, but on the synthesis of PAHs and how to prevent it. Studies have been separated into three different categories: (1) pre-processing, (2) processing, and (3) post-processing. Each of these categories has been studied at different intensities.

Research on the pre-processing of foods is a relatively new concept and has focused on utilizing techniques such as marinating with different herbs, spices, sauces and oils to prevent or reduce the

[3] BaP- Benzo(a)pyrene
[4] PAH(4) - Sum of four different polycyclic aromatic hydrocarbons; benz[a]anthracene, chrysene, benzo[b]fluoranthene, and benzo[a]pyrene.

formation of PAHs in the product. Examples of research that have been conducted in the preprocessing phase include a study by Farhadian et al. (2012) which found that the use of acidic marinades such as lemon juice have a significant effect on reducing the formation of PAHs in beef.

Of all the studies being conducted regarding the reduction/elimination of PAHs, the area of post-processing has been the least studied, presumably due to a lack of variables that can be manipulated. Studies in this area such as by Simko (2005) have focused on reducing PAH levels through the use of low density polyethylene (LDPE) and polyethylene terephthalate (PET). This study revealed that both plastic products can reduce PAHs in smoked meats. Although both LDPE and PET have shown a capacity to lower PAHs through the absorption processes, there are parts of the world where introduction or promotion of this material may exacerbate a plastic pollution problem due to a lack of proper waste disposal facilities. Besides, phthalates themselves represent a food health concern as some are known to contain reproductive and developmental toxins in animals and are believed to be endocrine disruptors in humans (Heudorf et al., 2007).

Probably the most heavily studied area of PAH reduction has been focused on the smoking process. There has been a wide range of studies looking at different variables that can be modified throughout the smoking process to reduce PAHs. Examples include those by Stumpe-Viksna et al. (2008) which have concluded that different wood types can have a significant impact on the amount of PAHs contained within the product. These findings were backed up by a later study by Hitzel et al. (2013) as the results of this study showed the higher lignin content in the wood directly correlated with PAH levels. Other studies such as those by Roseiro et al. (2011) and Skaljac et al. (2014, 2018) reported that modifying traditional smoking units can reduce PAH formation among smoked products (Iko Afé et al., 2020). Some of the modifications to smokers that that have led to a reduction of PAHs in products include: the addition of a ventilator which ensures even heating among the smoking chamber; trolleys which allow for hanging of the product at a desired height; filters that can cool the smoke, using an external combustion chamber for indirect smoking; and fat collection devices to prevent flaring while cooking (Iko Afé et al., 2020).

Today there are many different types of smokers in addition to the traditional barrel smoker that have come as a result of these scientific studies. Some of these smokers include the Chorkor, the Morrison, divine, the Altona, and the more recent Ahotor and FTT Thiaroye smokers.

Types of Smokers

Chorkor Smoker

Originally created in the 1970s as part of an FAO project in Ghana, the Chorkor smoker was designed to smoke a large amount of fish in a short period of time, while using very little fuel to save the processor money (Towers, 2014). The smoker design is fairly simple as it consists of a rectangular combustion chamber twice as long as it is wide and a smoking unit with a set of trays (Figure 1). The combustion chamber can be built out of either mud or brick (depending the processor’s budget), has a wall down the middle, and contains two stokeholes in front (Nunoo et al. 2018). The Chorkor operates with the smoking trays stacked on top of the

Figure 1: A single unit Chorkor smoker with 3 smoking trays on top (photo from Owusu et al., 2019)

smoker, acting like a chimney (Ajang et al., 2010). As the smoke and heat rise upwards, moisture within the product is removed. Due to its design and relative simplicity, the Chorkor smoker is not very effective at limiting PAH levels. Studies have shown that PAH levels for products processed with the Chorkor oven can range anywhere from 15 to 75 times higher than EC standards (Nunoo et al., 2018).

Morrison Oven

Created in Ghana in 2009 by Morrison Energy Limited, the Morrison oven (Fig. 2) was designed to be more user friendly and energy efficient (Pemberton-Pigott et al., 2016). Similar to the Chorkor smoker, the Morrison oven has noticeable differences that make it a safer and more efficient oven. The key differences include interlocking trays to hold the fish which prevent heat and smoke loss, and a built-in chimney that improves air quality for processors by allowing smoke to exit the smoking room (Pemberton-Pigott et al, 2016). Another notable difference with the Morrison oven is the additives in the clay to improve thermal properties. SNV tests showed that BAP and PAH(4) levels from products processed in the Morrison oven are 15 and 9 times, respectively, higher than the EC allowable level(Pemberton-Pigott et al., 2016). High PAH(4) levels produced by the Morrison oven could possibly be explained by a variety of factors; however, comparing the barrel smoker, the Chorkor, and the Morrison, smoke confinement is a major difference between the 3 types (Pemberton-Pigott et al., 2016).

Figure 2: A running Morrison oven with approximately 7 trays. The two metal chimneys above each stokehole allow for people to comfortably stand around the smoker while operating (photo from Pemberton-Pigott et al., 2016).

Altona Oven

Also known in various locations as the Altoona oven, or Altona kiln, the Altona oven is a common oven in West Africa (Fig. 3). The original oven was created in the 1970’s for use in Ghana by the German Volunteer Services and has since been adopted into many different areas throughout Africa (Hailu et al., 2019). The design of this oven differs from other ovens covered earlier, as this model is a vertical smoker which consists of a combustion chamber and an enclosed smoking chamber resting directly above (Degebassa et al., 2009). The standard dimensions of the oven is 170cm wide by 150cm deep by 202 cm tall. Other features of this oven consist of a stokehole on the front bottom, and a chimney atop the smoking chamber. Depending on the local adaptations of the basic Altona model, the smoke chamber can be

Figure 3: Front view of Altona oven in Ethiopia constructed of brick (photo from Hailu et al.,2019)

adjusted to either accommodate trays or rods to hang the fish from as they do in Ethiopia (Hailu et al., 2019). There is little to no scientific literature on the presence of PAHs in food that was cooked with the Altona oven. However, considering the factors that influence the creation of PAHs, the relative simplicity of this oven design suggests that PAH presence would be well above the EC limits.

Divine Oven

Figure 4: A double unit Divine oven used in Ghana (photo from Pemberton-Pigott et al., 2016)

Similar to the Altona, the Divine oven is a vertical oven that consists of two main components - a burner and a smoking chamber (Fig. 4). Created in 2004 by the Benvic Food Processing and Training company, the Divine oven was designed to address the rising cost of fuel as well as excessive smoke and heat (Pemberton-Pigott et al., 2016). The materials used to build the oven consist of aluminum, stainless steel and other lightweight metals. Rather than wood, the Divine smoker runs off of sawdust or rice husk that are packed into the combustion chamber by use of a PVC pipe (Pemberton-Pigott et al., 2016). A study conducted on PAH levels in three different species of fish (barracuda, sardinella and tuna) processed with the Divine oven showed that there is some potential for the reduction of PAHs, as tuna PAH levels registered below the EC limits. However, the other two species were above EC limits (Pemberton-Pigott et al., 2016).

Parpaing Oven

Figure 5: A double Parpaing oven with steel lids on top. (Photo from JV, 9/20/2020)

The Parpaing oven (Fig. 5), translated from French to English is simply, cinder block oven. Based on evidence provided from local contacts within Senegal, this is the most widely used oven in Senegal (JV, 11/23/20). The oven is used for numerous different processing techniques including the production of braised fish and smoked fish. At some sites such as Mbour and Joal, Parpaing ovens can be 8 meters long, and 1 meter wide with 4 stokeholes for burning (Ndoye et al., 2002). On top of the oven there is a mesh-style grate where the fish can be laid vertically and tightly packed (Ndoye et al., 2002). Additionally, some locations have metal lids that can be placed over the top to contain the smoke as seen in Figure 5. Information regarding the Parpaing oven is severely lacking. However, the oven shares similar attributes to the Chorkor oven, and in some cases also with the Morrison oven as when lids are used it has smoke confinement within the cooking chamber. Based on known information regarding the other two ovens, it seems likely that PAH levels for products produced in the Parpaing oven are also above the EC's thresholds.

FTT- Thiaroye Oven

Figure 6: People gathered around an FTT-Thiaroye oven (photo from Owusu 2019).

Created as a collaboration between FAO and the National Training Center for Fisheries and Aquaculture Technicians Training Institute in Senegal in 2008, the FTT-Thiaroye (FTT) smoker (Fig. 6) is widely considered to be the most advanced smoker when it comes to technology that reduces PAHs (Mindjimba, 2020). The FTT is a dual functioning smoker that can also serve as a dryer (Ndaye et al., 2014). The main goal of the FTT smoker was to build upon existing ovens to reduce or eliminate the synthesis of PAHs. To do this, designers took into account all of the variables mentioned earlier in this paper (Ndaye et al., 2014). Because of the recentness of the design and the increased expressed interest in PAHs, there have been ample scientific studies comparing the FTT to other smoking methods. Results from Ndiaye et al. (2015) along with independent studies have confirmed that the FTT does in fact reduce PAHs, as intended. For instance, studies by Bomfeh et al. (2019) found that BAP and PAH4 levels were 215-fold and 183-fold, respectively, lower than in the Chorkor smoker and 91-fold and 63-fold, respectively, lower than in traditional drums.

Ahotor Oven

Figure 7: A newly built Ahotor oven (photo from Owusu 2019)

Created in Ghana in 2016 as part of the URI Sustainable Fisheries Management Project (SFMP) funded by USAID, the Ahotor oven (Fig. 7) is a modified version of the Chorkor smoker. The objective of creating this oven was threefold: to reduce PAH levels in smoked fish, to improve the uniformity in the smoking process, and to reduce smoke exposure to the processors (Kwarteng et al., 2017).

The Ahotor oven consists of an outer shell comprised of sandcrete and cement, a combustion chamber made out of burnt bricks, a galvanized iron, a fat collector, a metal grate to elevate fuelwood, and smoking trays made out of wood and wire (Owusu, 2019). Two tests of the Ahotor oven showed that the oven does reduce BaP and PAH levels, and that the average of two trials produced BaP and PAH(4) levels of 0.95 µg/kg and 38.33 µg/kg, respectively (Kwarteng et al., 2017). Although still above the 12 µg/kg PAH levels instated by the EC, further modifications to the Ahotor oven can put PAH(4) levels in compliance with the EC standards. In a follow up study to help reduce PAHs, ash was spread throughout the fat collector to prevent the fats from dripping onto the fat collector and burning. The addition of ash reduced the BaP and PAH(4) levels to an average of 0.6 µg/kg and 10.9 µg/kg, respectively, thus putting the product in compliance with European standards (Etsra and Avega, 2018).

Adoption of a New Smoker

There is little to no scientific literature on the smokers currently being used in Senegal. Based on local knowledge, the FTT-Thiaroye and Parpaing smokers are used there, with Parpaing being the most popular (JV, September 2020). Of these two smokers, only the FTT has been proven to produce products with BaP and PAH(4) levels allowable by the EC.

Evidence has shown that the FTT and the Ahotor oven are both viable options for use in Senegal when it comes to reducing PAH levels. However, when it comes down to the introduction and adoption of a smoker, adoption of a new technology should not be forced; it needs to be properly diffused throughout the community. Diffusion is defined as the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2010). Diffusion of innovation is a much more complicated concept than it may seem, as the novelty of an object or idea will bring ambivalence to the person or societal group considering adoption (Beran, 2018). To add to the complexity, each individual has their own perceived risks based on social and cultural factors. These risks may be reduced if given the access to information (Rogers, 2010). In addition to this, proper training regarding the optimum use of a technological innovation can reduce uncertainty within the early stage of diffusion (Beran, 2018). Evidence of this can be seen in a 1992 thesis on the diffusion and adoption of the Chorkor smoker in Tema, Ghana. Results showed that amongst other things, meetings and demonstrations conducted for fish processors regarding the new Chorkor smoker helped fuel better perspectives of the smoker (Buadi, 1992).

One of the hardest concepts regarding the predictability of the diffusion of innovation is that there is no single contributing factor that can be used to model whether an innovation takes off or not (Meade and Islam, 2006). When it comes to the diffusion of smoker technology in Africa, numerous factors have been identified with only a few commonalities. Buadi (1992) found that influence of the community and the size of the smoking business played a role in the adoption of a new smoker; however, the largest contributing factors to adoption were savings on fuelwood and the time it takes to process the fish. A more recent study conducted in Ghana by Beran (2018) found that the adoption of a new smoker (Ahotor) was hindered by the complexity of the smoker during the construction phase as only a few artisans were trained on how to assemble the smoker. In addition to this, results of the study also revealed that the largest barrier to adoption of the Ahotor was cost. An analysis of the strengths, weaknesses, opportunities and threats (SWOT) study conducted by Mindjimba et al. (2019) found that fish processors believed that the introduction of the FTT smoker into Cote d'Ivoire came with more positives than negatives when comparing it to the traditional smokers (unknown type). Some strengths of the FTT smoker include: the equipment can be easily installed, it is usable in all weather conditions, the hoods provide protection against contamination from bugs, it increased revenue, and the technology has a longer kiln life lasting more than 15 years for the frame and 3-12 years for the parts. Weaknesses and threats for the adoption of the FTT identified by processors included that it was difficult to use and the investment cost required to assemble the smoker was high ($1,419-$4,709 USD). An additional threat identified was that there may be less consumers able to pay a higher price for FTT products (Mindjimba et al., 2019).

Of these three studies, two commonalities can be seen. The first commonality is complexity, which is one of the five main factors that influence the adoption of innovation described by Rogers (2010). In two of the three studies complexity of a new innovation was directly mentioned as a barrier for adoption. The third study may not have had this issue as the Chorkor smoker is not the most complex of smoking technology, or it is possible that the meetings and discussions to educate the processors may have reduced the complexity of the new smoker.

The second commonality that can be seen in these studies is the issue of cost. Many processors have identified cost as one of their factors preventing adoption of a new smoker. This commonality is in line with Rogers' theory of diffusion in which high cost is listed as a disadvantage to the adoption of a new innovation (Beran, 2018).

Cost

Three main variables influence the cost of smokers: the complexity of the oven, availability of construction items, and labor. Cost is typically higher with more complex ovens (eg, ovens that require more pieces to construct). When construction items are not locally available, importing items will cause added expenses. This was seen in the SFMP project in Ghana where fish processors had trouble purchasing certain construction materials as they had ever-increasing costs (Owusu, 2019). Labor costs may be higher if only a few people know how to construct the oven as this can make the oven a novelty item.

Table 1. Cost to build different types of single unit smokers in Ghana; based on reports by Owusu, 2018 and Pemberton-Pigott, 2016.

Oven Type	Cost in Report	USD Cost
Chorkor	400 GHS	$70
Morrison	1200-2000 GHS	$200-$345
Divine	3800 GHS	$655
Ahotor	1,768 GHS	$305
FAO FTT	5600 GHS	$980

Financing

The Action plan for the development of African Fisheries and Aquaculture (2005) and Tietz and Villareal (2003) identified that small and medium sized fish producer enterprises face a lack of adequate financial services to help develop their businesses (Kleih et al., 2013). In general fish processors have three ways to access financing to help fund their businesses: their personal savings, credit from friends or family, or credit from financial institutions (Owusu, 2018). In some situations, small business grants may be able to help alleviate some of the financial burdens on the processors.

Personal Savings

If processors have the ability to do so, they may save at home or with financial institutions. However, many coastal regions in West Africa are seeing low profit margins, declining fish stocks, and high post-harvest losses. Hence, savings tend to be minimal (Owusu, 2018).

Family and Friends

Borrowing money from friends and family members is another way of obtaining money. Oftentimes, processors can borrow money from them and pay them back over time using the profits generated from their business ventures. The pros of this financing strategy are that unlike with financial institutions the processor will avoid interest rates that are commonly charged. Cons of this strategy are that the money may not be readily available like with a financial institution and funds may not be sufficient to cover the required investment.

Rotating savings and credit associations are one of the most popular informal credit agreements within developing countries (Handa & Kirton, 1999). These informal credit groups work by members, usually close friends and family, contributing a small amount of money to a predetermined pot at each meeting. When the pot is full, the lead member, called the banker, will choose a member to take the money (Handa & Kirton, 1999). These meetings will occur over a period of time so that every member of the rotating savings and credit association will have had a chance to take the pot of money home. Pros of this strategy are that there is no interest or fees like with a financial institution and that members are helping each other out. A major con of this strategy is that it requires trust in other members as they could leave the rotating savings and credit association, hence leaving the other members at a financial setback.

Financial Institutions

Loans- In many places due to the risk and uncertainty of the fishing industry, microfinance institutions will not facilitate loans to fishermen and individual fish processors (Kleih et al., 2013). Fishermen and processors are more likely to obtain a loan when they are affiliated with an organization. In a survey of 21 members of The Women Fish Traders and Processors Cooperative of Abidjan, 16 members believed that they were granted microfinance loans because of their structure and organization (Mindjimba, 2020). This survey also revealed that in a span of two years, 10 members of the cooperative received approximately $5,960 in microfinance loans whereas before becoming a member, only 1 had ever received a loan (Mindjimba, 2020). Microfinance loans for individuals, as opposed to those affiliated with an organization, are often disadvantageous with high interest rates and the processor's credit is often linked to unfavorable terms of trade creating an exploitative relationship (Kleih et al., 2013).

If institutional credit agreements are not in place, optimum utilization and allocation of human and marine resources, as well as capital within the fisheries sector are obstructed (Tietze and Villareal, 2003). In the case of the SFMP mentioned earlier, three financial institutions were contracted to directly finance the construction of ovens. In order for a processor to obtain credit from these financial institutions they were required to have an account with that institution for a minimum of 3 months, and must have at least 20% down payment for the loan (Owusu, 2018). In order to have an effective loan program in which the processor can pay back, the loan and credit must be available immediately due to the nature of the industry i.e. fishing seasons, weather, regulations etc. (Tietze and Villareal, 2003).

Grants

Grants can also be used as a strategy for processors to obtain new smokers, and this may be more advantageous if trying to diffuse a smoker technology throughout the community. Since credit is not required for a processor to participate, a large number of individuals can participate in a grant program. Another advantage of using grants to extend smoker technology is that certain criteria can be added during the search process to help with the study. An example of this is the program created for the Ahotor oven in Ghana which targeted individual fish processors. This program offered 141 fish processors to have 88% of the smoker cost covered by grant money if they would in return agree to pay the other 12% for a fat collector, receive proper training on the use and maintenance of the Ahotor, and keep records of the value of the oven to their business (Owusu, 2018). The down side to this style of financing method is that it is essentially a free handout and there is the possibility that the oven will not be used. In the case of the SFMP project, only 47 of the 141 fish processors were actively using the oven; the remainder were not using the ovens due to lack of fish available at landing sites (Owusu, 2018).

Conclusion

Based on just smoker information alone, it is difficult to conclude which smoker should be recommended for use in Senegal. The only real insight the information gathered can provide is that the FTT (and, under certain conditions also the Ahotor) oven has the ability to produce a smoked fish product containing PAH levels below the EC limits. When looking at the original building plans, both the FTT and the Ahotor ovens used pre-existing models in which modifications could be made; for the FTT this took place in Senegal using Senegalese ovens. The National Training Center for Fisheries and Aquaculture Technicians Training Institute in Senegal and FAO did an excellent job at reducing PAH levels to below EC limits by modifying local smokers to account for the factors that contribute to the creation of PAHs, as highlighted by the Codex Alimentarius. That being said, the goal of the project was to reduce PAH levels at a "reasonable price" making the cost target subjective and resulting in a technology that is too expensive for many processors to adopt. An important next step to increase the adoption of smoker technologies that reduce PAH levels is to take the FTT smoker design and find ways to make the smoker affordable to Senegalese processors.

First and foremost, before any work can be done with PAH levels and smokers in Senegal, a survey should be carried out with Senegalese fish processors to help identify business drivers pertaining to the adoption of a new smoker, including cost and financing barriers and needs. In addition to learning from processors, it would be beneficial to devise a parallel survey for consumers to learn about their preferences for smoked fish, consumption of PAHs, and knowledge regarding PAHs. Smoked fish produced from a low PAH-smoker will cost more for consumers, therefore their knowledge of PAHs and motivation to reduce PAH consumption is a critical driver for cleaner smoker technology.

Resources

Adeyeye, S. A. O., and O. B. Oyewole. "An Overview of Traditional Fish Smoking in Africa." *Journal of Culinary Science & Technology*, vol. 14, no. 3, 2016, pp. 198-215, Boehm, Paul.

Buadi, D. K. (1992). *Diffusion and adoption of the Chorkor Smoker in Tema U compound* (Doctoral dissertation, University of Ghana).

Beran, K. (2018). Value Chain Improvements in Small-scale Fisheries: Case Studies from West Africa (Doctoral dissertation, University of Rhode Island).

Boehm, P. D. (1964). Polycyclic aromatic hydrocarbons (PAHs). In *Environmental forensics* (pp. 313-337). Academic Press.

Bomfeh, K., Jacxsens, L., Amoa-Awua, W. K., Tandoh, I., Afoakwa, E. O., Gamarro, E. G., ... & De Meulenaer, B. (2019). Reducing polycyclic aromatic hydrocarbon contamination in smoked fish in the Global South: a case study of an improved kiln in Ghana. *Journal of the Science of Food and Agriculture*, *99*(12), 5417-5423.

CAC/RCP 68/2009. Codex alimentarius commission (CAC). Code of practice for the reduction of contamination of food with polycyclic aromatic hydrocarbons (PAH) from smoking and direct drying processes. Retrieved December 1,2020 from: http://www.codexalimentarius.org/download/standards/11257/CXP_068e.pdf.

Degebassa, A., Tigabu, Y., & Mohammed, A. (2009). Evaluation of Chorkor smoker and Altoona Oven for Smoking nile tilapia (*Oreochromis niloticus*) Fish at Ziway, Ethiopia. Paper presented at the *Ethiopian Society of Animal Production,* 137-142.

Essumang, D. K., D. K. Dodoo, and J. K. Adjei. "Effect of Smoke Generation Sources and Smoke Curing Duration on the Levels of Polycyclic Aromatic Hydrocarbon (PAH) in Different Suites of Fish | Elsevier Enhanced Reader." *Food and Chemical Toxicology*, no. 58, 2013, pp. 86-94.

Etsra, H.E, Avega, B. (2018).Documentation of the Pains and Gains of the Ahotor Oven Improvement Process. The USAID/Ghana Sustainable Fisheries Management Project (SFMP). Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and SNV Netherlands Development Organisation. GH2014_ACT235_SNV.25pp.

European Commission. "Regulation No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in food stuffs." *Official J. Eur. Union* 364 (2006).

FAO. 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome.https://doi.org/10.4060/ca9229en

Farhadian, A., Jinap, S., Faridah, A., & Zaidul, I. S. M. (2012). Effects of marinating on the formation of polycyclic aromatic hydrocarbons (benzo[a]pyrene, benzo[b]fluoranthene and fluoranthene) in grilled beef meat. *Food Control, 28*(2), 420-425. doi:https://doi.org/10.1016/j.foodcont.2012.04.034

Hailu, A., Abebe, A., Lema, A., & Geneti, T. (2019). Pre-scaling up of fish smoking technology in selected oromia water bodies, Ethiopia *International Journal of Fisheries and Aquatic Studies, 8*(1), 1-6. Retrieved from https://www.fisheriesjournal.com/archives/2020/vol8issue1/PartA/7-5-42-488.pdf

Handa, S., & Kirton, C. (1999). The economics of rotating savings and credit associations: evidence from the JamaicanPartner'. *Journal of development Economics*, *60*(1), 173-194.

Heudorf, U., Mersch-Sundermann, V., & Angerer, J. (2007). Phthalates: toxicology and exposure. *International journal of hygiene and environmental health*, *210*(5), 623-634.

Iko Afé, Ogouyôm H., et al. "Insight about Methods used for Polycyclic Aromatic Hydrocarbons Reduction in Smoked Or Grilled Fishery and Meat Products for Future Re-Engineering: A Systematic Review." Food and Chemical Toxicology, vol. 141, 2020, pp. 111372. PubMed, http://dx.doi.org/10.1016/j.fct.2020.111372, doi:10.1016/j.fct.2020.111372.

Kleih, U., Linton, J., Marr, A., Mactaggart, M., Naziri, D., & Orchard, J. E. (2013). Financial services for small and medium-scale aquaculture and fisheries producers. *Marine Policy*, *37*, 106-114.

Kpoclou, Euloge Y., et al. "Effect of Fuel and Kiln Type on the Polycyclic Aromatic Hydrocarbon (PAH) Levels in Smoked Shrimp, a Beninese Food Condiment." *Food Additives & Contaminants: Part A*, vol. 31, no. 7, 2014, pp. 1212-1218, https://doi.org/10.1080/19440049.2014.916422, doi:10.1080/19440049.2014.916422.

Kwarteng, E.,Nketia, S., Manu S. D., Etsra, H., Abbey, L., Amponsah, S., Morrison, A. (2017). Continuous Technology Development for the Low PAH Stove –Ahotor Oven The USAID/Ghana Sustainable Fisheries Management Project (SFMP). Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and partner name where relevant. GH2014_ACT097_SNV. 29pp.

Meade, N., & Islam, T. (2006). Modelling and forecasting the diffusion of innovation–A 25-year review. *International Journal of forecasting*, *22*(3), 519-545.

Mindjimba, K. (2020). *Study on the profitability of fish smoking with FTT-thiaroye kilns in cote D'ivoire.* Rome: FAO. Retrieved from https://search.proquest.com/docview/2394536662/fulltextPDF/9C07318CE0A54ADFPQ/1?accountid=28991

Ndiaye, O., Sodoke Komivi, B. and Diei-Ouadi, Y. 2014. Guide for developing and using the FAO-Thiaroye processing technique (FTT-Thiaroye). Rome, FAO. 67 pp

Ndoye, F., Moity-Maïzi, P., & Broutin, C. (2002). Le poisson fumé sur la Petite Côte sénégalaise: de la pirogue au plat.

NEPAD. Action plan for the development of African fisheries and aquaculture;2005. Available at/http://siteresources.worldbank.org/INTARD/Resources/ACTION_PLAN_endorsed.pdfS; 2011 [accessed 10.11.11].

Nunoo, F. K. E., Tornyeviadzi, E., & Asamoah, E. K. (2005). Effect of two fish smoking ovens on the nutritional composition and PAH content of smoked fish. *J pub health catalog. 2018; 1 (1): 5-10. J pub health catalog 2018 Volume 1 Issue*, *1*, 208.

Owusu, D. (2019). Final Report on Ahotor Oven Market Development and Financing Outcomes and Lessons Learned. The USAID/Ghana Sustainable Fisheries Management Project (SFMP). Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and Resonance Global. GH2014_ACT242_RESONANCE.24pp.

Pemberton-Pigott, C., Robinson,J., Kwarteng, E., Boateng,L. (2016). Low PAH Improved Fish Smoking Stove Design Development Report.The USAID/Ghana Sustainable Fisheries Management Project (SFMP). Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Islandand Netherlands Development Organisation.GH2014_ACT063_SNV46pp.

Rogers, E. M. (2010). *Diffusion of innovations*. Simon and Schuster.

Roseiro, L. C., Gomes, A., & Santos, C. (2011). Influence of processing in the prevalence of polycyclic aromatic hydrocarbons in a Portuguese traditional meat product. *Food and Chemical Toxicology*, *49*(6), 1340-1345.

Šimko, P. (2005). Factors affecting elimination of polycyclic aromatic hydrocarbons from smoked meat foods and liquid smoke flavorings. *Molecular Nutrition & Food Research, 49*(7), 637-647. doi:10.1002/mnfr.200400091

Škaljac, S., Petrović, L., Tasić, T., Ikonić, P., Jokanović, M., Tomović, V., ... & Škrbić, B. (2014). Influence of smoking in traditional and industrial conditions on polycyclic aromatic hydrocarbons content in dry fermented sausages (Petrovská klobása) from Serbia. *Food Control*, *40*, 12-18.

Škaljac, S., Jokanović, M., Tomović, V., Ivić, M., Tasić, T., Ikonić, P., ... & Petrović, L. (2018). Influence of smoking in traditional and industrial conditions on colour and content of polycyclic aromatic hydrocarbons in dry fermented sausage "Petrovská klobása". *LWT*, *87*, 158-162.

Tietze U, Villareal LV. Microfinance in fisheries and aquaculture: guidelines and case studies. FAO Fisheries Technical Paper no. 440. Rome: FAO; 2003.Available at /http://www.fao.org/DOCREP/006/Y5043E/Y5043E00.HTMS;2011 [accessed 09.10.11].

Towers, L. (2014, December 09). A Guide to Smoking for Fish Preservation. Retrieved August 17, 2020, from https://thefishsite.com/articles/a-guide-to-smoking-for-fish-preservation