Comparative Evaluation of Rotary and NSPRI Model-B Smoking Kilns for Quality Assurance of Smoked Catfish

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Abstract

Fish is a perishable food product, making it easily susceptible to microbial attacks. Therefore, adequate drying becomes paramount to make fish shelf-stable. In the quest for food safety, the Nigerian Stored Products Research Institute developed a rotary smoking kiln to reduce product-human contact and contamination. This study, therefore, evaluated the performance of the new kiln and the existing model-B, concerning some quality attributes of smoked fish. Catfish (Clarias gariepinus) was used for the evaluation, and charcoal and gas were used as an energy source. Quality assessments were conducted on the fish products using standard methods. The proximate qualities of the samples in the two kilns were not significantly or negatively affected. The two kilns lowered the level of heavy metals in the fish within the global permissible limits. Additionally, the PAHs of the products from the two kilns, regardless of the energy source, were lower than the global permissible limit. Out of the total PAHs recorded in the fish dried in the rotary kiln powered with charcoal (8.43 µg/kg) and gas (18.08 µg/kg), only 0.42 and 0.26 µg/kg, respectively, were carcinogenic. Similarly, 0.40 and 0.26 µg/kg were carcinogenic out of the total PAHs recorded in the samples dried in the model-B kiln powered with charcoal (9.19 µg/kg) and gas (16.54 µg/kg), respectively. The products from both kilns received good overall acceptability. Therefore, considering the addressed challenge of opening the model-B kiln before trays could be changed, resulting in reduced risk of product contamination, the rotary kiln is an improved version/model of the NSPRI smoking kiln.

Keywords:
Fish drying, heavy metals, polycyclic aromatic hydrocarbons, proximate composition, smoking kiln

Introduction

Fish is known to be a major source of animal protein, supplying a reasonable proportion of the protein requirement in humans' diets (Peter & Coolborn, 2019; Selemin, 2024). In Nigeria, fish is consumed after being cooked or processed to enhance its quality and storage stability. It is a special delicacy known to people of different social status, faiths, age, and educational background (Adebayo-Tayo et al., 2008). The nutrient compositions include omega-3 long-chain polyunsaturated fatty acids, vitamin D, and minerals such as iron, calcium, iodine, and zinc (Snyder, 2023; Spandana, 2023; Selemin, 2024). Catfish (*Clarias gariepinus*) is a popular and preferred food delicacy worldwide, particularly in Nigeria, due to its palatability and great taste (van der Pijl, 2021).

Generally, fish is highly perishable, owing to its considerably high level of moisture content, which makes it susceptible to microbial spoilage and biochemical deterioration (Adeyeye, 2019; Oyewole et al., 2024[a]); hence, drying becomes paramount (Raji & Olanrewaju, 2015). Drying has been described as a known ancient and most efficient technique of fish preservation, primarily aimed at reducing the moisture content to a level that could hinder the growth of microbes and halt enzymatic reactions in food,

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thereby prolonging its shelf-life (Ajao et al., 2024). Smoke-drying is commonly used among other drying methods known for fish preservation, especially value addition of catfish (*Clarias gariepinus*), due to its ability to enhance flavour, texture, and microbial stability (Oparaku & Mgbenka, 2012).

The drying process may significantly affect the quality attributes of smoked catfish products, including nutritional composition, sensory properties, product safety and shelf stability**.** Studies have shown that drying temperature and duration (over-drying) can negatively influence the protein content, lipid oxidation, and overall acceptability of the final product from such a process (Omodara & Olaniyan, 2012; Falade et al., 2018; Oladejo et al., 2020). Excessive drying can cause undesirable changes such as increased hardness, case-hardening, shrinkage, and loss of essential nutrients, while inadequate drying may result in microbial contamination and spoilage (Oladejo et al., 2020). Additionally, lipid oxidation during drying can lead to off-flavours and reduced shelf-life, affecting consumer acceptability. More importantly, exposure to undesirable smoke composition can cause excessive deposition of polycyclic aromatic hydrocarbon contents (PAHs) on fish products being smoke-dried, and this could cause some acute and chronic health issues, among which are asthma, cancer of the bronchitis or lung (Zhang et al., 2019; 2020). Aside from PAHs, there are other contaminants, such as heavy metals, which are also of concern to human health and safety. Heavy metal contaminants, such as lead, arsenic, mercury, and cadmium, occur naturally as chemical compounds and are present in the environment (water bodies, soil, and even atmosphere). They could also be found in food as residues due to human activities through farming, food processing, or automobile exhaust. They could also be found in handling or storage facilities that are not made of food-grade materials. Human exposure to these contaminants in excess of the permissible level could pose detrimental health consequences (EFSA, 2025). Therefore, health and safety concerns should be prioritised in the development of food handling and storage facilities. Proper quality evaluation is necessary to affirm the integrity of such food processing technology.

Consequently, proffering solutions to these concerns has led the Nigerian Stored Products Research Institute (NSPRI) to the development of several models of smoking kilns, among which are a stationary metal model, a single unit model, model-A, model-C and model-B (Olayemi et al., 2013; Omodara et al., 2016; Oyewole et al., 2021). The NSPRI smoking kiln® consists of four major units: the smoke-drying compartment, drying trays, combustion compartment, and oil collection mechanism. The result from its performance evaluation with respect to efficient energy utilisation, drying rate, and quality of the finished product shows that it is efficient (Omodara et al., 2016; Ajao et al., 2024; Oyewole et al., 2024[a]; 2024[b]). However, the feedback from the users of NSPRI smoking kiln® calls for improvement of the value addition equipment to make it more user-friendly by reducing or eliminating the need for opening the kiln for changing trays and turning of fish, which exposes the product to contamination due to human contact and operator to burning hazard. Therefore, this identified challenge is a threat to food safety. To address this challenge, the existing model-B version of the NSPRI smoking kiln was modified to enhance its friendliness and reduce product contamination while using the NSPRI smoking kiln. This study, therefore, evaluated the impact of smoke-drying on the quality attributes with emphasis on nutrient retention, sensory attributes, and safety of the fish smoked in the modified NSPRI smoking kiln (Rotary smoking kiln). The study aimed to assess the new design's impact on the qualities of smoked fish products using a comparative approach.

Materials and Methods

Description of the NSPRI smoking kiln (Model-B)

The NSPRI smoking kiln (Model-B) comprises four major components: smoke-drying compartment, rack-trays arrangement, combustion compartment and oil collector (Figure 1). The smoke-drying compartment is cuboid-shaped and is constructed of two metal walls separated by 25 mm-thick polyurethane insulation. The chamber has other features such as a door situated in the front, an array of vents on top of the compartment, and four wheels that support the compartment at the base. The internal dimension of the compartment is 550 x 550 x 1150 mm. The racks are firmly joined to the inner side walls of the compartment. The trays, either square or rectangular, are removable, made of metallic pipe and expanded mesh, and have dimensions of 535 x 535 x 100 mm. The compartment for combustion is situated at the bottom of the rear end of the smoke-drying compartment. This detachable component accommodates the box and tray for charcoal loading and ash collection. The last major component collects the oil from the fish during the operation, and it is made of food-grade stainless steel for clean oil collection.

Description of modified components of the kiln

The modified components of the Model-B kiln that resulted in the rotary smoking kiln (Figure 2) include: drying trays, rack and smoke-drying chamber. The new design has convex-shaped trays with a cover that prevents fish from falling off during turning. Likewise, changing trays can be done without opening the drying chamber. The tray has a major diameter of 750 mm, a minor diameter of 640 mm and a length of 800 mm. The modified rack is cylindrical and pivoted on the two side walls for easy rotation. The rack has an extruded (external) handle for turning the rack-tray assembly. The rack's major and minor diameters and length are 710, 600 and 760 mm, respectively. As a result of the modifications, the size of the smoke-drying chamber was increased to accommodate the modified rack and trays. The modifications increased the dimension of the smoke-drying compartment to 850 x 850 x 1150 mm.

Collection and processing of catfish

The catfish used for this evaluation was sourced from a fish farm (in Ibadan, Nigeria) that adopts safe and standardised farming and harvesting practices. The assessment was carried out at the NSPRI Office in Ibadan, and the processing procedure used is presented in Figure 3. The two kilns were independently evaluated using charcoal and gas as a heat source, and samples were collected for quality assessments.

Quality assessments of the smoke-dried fish products

Quality assessments were carried out on the smoked fish obtained from the evaluation. Proximate composition, heavy metal profiling and polycyclic aromatic hydrocarbon analysis were considered for the study. Proximate composition analysis was conducted using a standard laboratory method (AOAC, 2010). The heavy metal profiling was carried out adopting the techniques of Bwala et al. (2023), while the determination of Polycyclic Aromatic Hydrocarbons (PAHs) was based on the method described by Adeyeye et al. (2015). This method involves four steps: homogenisation, extraction, purification, and analysis using Gas Chromatography with Flame Ionisation Detector (GC-FID).

Sensory evaluation

Samples of the dried fish produced from model-B and rotary smoking kilns were subjected to sensory evaluation to ascertain their acceptability. This evaluation covered taste, aroma, colour and texture. The sensory assessment was conducted using a palatability template designed on a 9-point hedonic scale as Olayemi et al. (2017) described. A twenty-five (25) panel was constituted and briefed to evaluate the product samples. The test template allowed the panellists to select from an array of alternatives ranging from 'like extremely' to 'dislike extremely', and the alternatives were allocated 9 to 1 marks respectively. Each of the panellists had access to a test template for each sample. Thereafter, the results were extracted and subjected to statistical analysis.

Data analysis

The data obtained for the quality parameters were analysed using analysis of variance in SPSS (version 20.0).

Figure 1: NSPRI Model-B Smoking Kiln

Figure 2: Pictorial View of Rotary Smoking Kiln

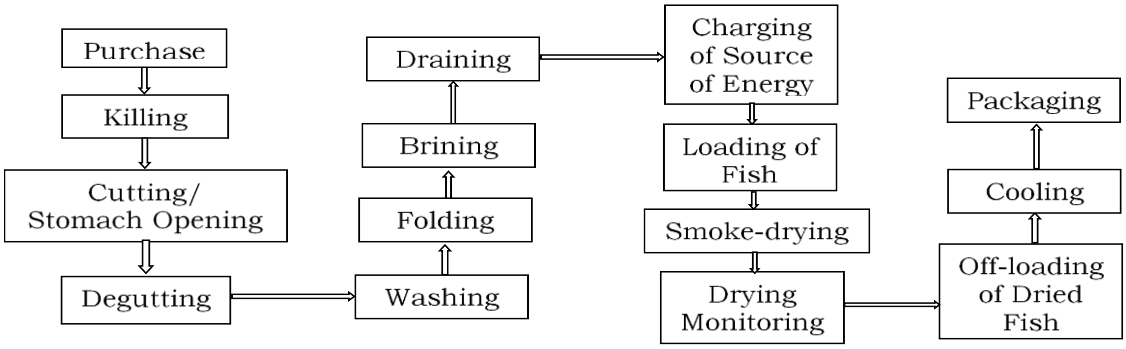

Figure 3: Flow Chart for Smoking of Fish

Results and Discussion

Effect of smoke-drying on proximate composition of the fish products

Moisture content of all dried samples from the charcoal-powered kiln ranged from 8.75±1.13 to 10.16±0.74% and that of the gas-powered kiln ranged from 5.26±0.93 to 5.26±1.15% (Tables 1 and 2). These values are within the value range reported by Omodara et al. (2016) (6.87%) and Tenyang et al. (2020) (13.31%). This makes it safer to effectively store the dried fish products for an extended period due to the low moisture level left in the products. There were no significant differences (P<0.05) in the moisture content and crude protein of fish smoked in the two kilns using charcoal, but there were significant differences in the means of the fresh and dried fish samples (P<0.05). Similar trends were observed in samples smoked in the gas-powered kilns. However, no significant differences were recorded in crude fat and carbohydrate contents of the gas-powered dried fish samples, unlike what was recorded in the fibre content of fresh samples compared to the dried samples from both kilns. Fat contents of samples from both kilns were significantly different from the fresh sample, with an increase (P<0.05). Fish samples dried in both kilns, regardless of the energy source, have higher protein content than fresh samples. The difference in the protein content could be attributed to the dry matter concentration due to the removal of moisture caused by the drying operation. Patterson et al. (2018) affirmed similar results in a study investigating the sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes.

Effect of smoke-drying on heavy metals profile of the fish products

Tables 3 and 4 show that all heavy metals tested were detected in all samples, although in minimal quantities. Also, it could be deduced from the results in Table 3 that smoke-drying using rotary and model-B smoking kilns caused difference (P<0.05) in mean contents of zinc (Zn), chromium (Cr) and nickel (Ni), whereas the average values of cadmium (Cd) and lead (Pb) in fish samples produced with charcoal as the source of energy were statistically the same. Zn dropped from 68.47±0.191 (fresh fish) to 48.57±0.335 mg/kg in the model-B kiln and to 53.17±0.36 mg/kg in the rotary kiln. The variation may be because the rotary kiln was used for the first time. However, the zinc levels recorded in the fish samples were generally lower than the allowable level of 288.2 mg/kg in fish and fish products (FAO/WHO, 1991). Similarly, this aligns with the findings of Javed et al. (2017). Cr content in the dried products ranged from 0.35±0.036 to 0.47±0.032 mg/kg, while the fresh sample had 0.75±0.04 mg/kg. The result indicates that the Cr contents were not statistically the same (P<0.05). The amount of Cr content recorded in the dried fish samples was below the maximum allowable quantity of 17.83 mg/kg in fish and fish products as reported by Javed & Nazura (2013). Cd ranged from 0.02±0.013 in the rotary smoking kiln to 0.04±0.033 in the model-B smoking kiln. No difference (P<0.05) was observed in the amount of Cd present in both fresh and dried samples. This implies that there is little or no emission of Cd metals to the product during the smoke-drying operation.

The Pb content of both wet and dried samples from both kilns ranged from 0.05±0.008 to 0.03±0.009 mg/kg. The result indicates that the Pb content of the samples is statistically the same (P<0.05). However, the Pb level was below the maximum allowable quantity set by the Food and Agriculture Organization (FAO/WHO, 1991). Meanwhile, it is essential to know that the accumulation of lead in the human body can result in gastrointestinal disorders, brain and kidney damage, and central nervous system malfunctioning (FAO/WHO, 1991). Ni in the dried fish samples was between 0.35±0.036 and 0.47±0.032 mg/kg, while the fresh sample was 0.75±0.04 mg/kg. The result indicates that the amount of Ni in the samples was not the same (P<0.05). The Ni levels in all the samples were below the maximum permissible quantity of 14.83 mg/kg in fish and fish products, as indicated by FAO/WHO (FAO/WHO, 1991; Javed et al., 2017; WHO, 2019). If Ni is ingested in large quantities, it may lead to gastrointestinal disorders, heart-related diseases, failure of the respiratory system and cancer (Javed & Nazura, 2013). Likewise, the levels of the heavy metals recorded in the samples showed that neither the kilns nor the source of energy has contributed to the levels in the samples (Tables 3 and 4). Instead, their impact during drying caused a significant reduction in the amount of the heavy metals present in the fresh fish sample. This reveals that the smoking process was responsible for the decrease in the metal level and that the kilns did not contribute to the levels present in the dried fish samples.

Effect of smoke-drying on the PAHs profile of the dried fish products

The smoking kilns (model-B and rotary) powered with charcoal produced lower total polycyclic aromatic hydrocarbons (PAHs), but higher carcinogenic PAHs, compared to the kilns powered with gas that produced higher total PAHs, but lower carcinogenic PAHs (Table 5). This could indicate that charcoal tends to produce a higher concentration of PAHs, notably heavier and more carcinogenic ones, with fewer but incomplete combustion (Zhang et al., 2022). According to Igwe et al. (2012), there may be increased concentrations of carcinogenic PAHs in the soot and particulate matter that settle on fish after charcoal smoking. In general, smoking with gas results in fewer particulate matter and, when it does, lighter and less hazardous PAHs are deposited (Abdel-Shafy & Mansour, 2016). Smoking fish, whether with gas or charcoal, affects the amount and makeup of PAHs in the finished product.

Table 1: Proximate composition of the fish products smoked in the two kilns powered by charcoal

Sample ID	Moisture (%)	Ash (%)	Fibre (%)	Fat (%)	Protein (%)	Carbohydrate (%)
Fresh	68.73±1.28^{a}	5.48±0.49^{a}	0.91±0.06^{c}	8.60±0.48^{c}	11.37±0.25^{b}	4.98±1.80^{c}
Rotary Kiln	8.75±1.13^{b}	2.42±0.14^{b}	1.41±0.12^{b}	30.51±1.78^{a}	45.79±5.63^{a}	11.12±5.50^{b}
Model-B Kiln	10.16±0.74^{b}	5.16±0.47^{a}	2.04±0.23^{a}	23.56±0.82^{b}	41.44±0.55^{a}	17.64±12.0^{a}

Average values ± standard deviation of three replicates. Average value that has the same superscript in the same column are statistically the same at P<0.05.

Table 2: Proximate composition of the fish products smoked in the two kilns powered by gas

Sample ID	Moisture (%)	Ash (%)	Fibre (%)	Fat (%)	Protein (%)	Carbohydrates (%)
Fresh	65.95±0.58^{a}	0.77±1.9^{a}	0.43±0.05^{c}	2.28±1.27^{a}	27.80±1.59^{b}	2.78±0.67^{b}
Rotary Kiln	5.26±1.15^{b}	0.68±0.16^{b}	2.01±0.38^{a}	3.61±1.29^{a}	42.87±2.53^{a}	45.57±3.43^{a}
Model-B Kiln	5.26±0.93^{b}	0.45±0.6^{c}	1.39±0.06^{b}	4.16±2.09^{a}	43.09±1.92^{a}	45.65±4.65^{a}

Average values ± standard deviation of three replicates. Average value that has the same superscript in the same column are statistically the same at P<0.05.

Table 3: Heavy metals profile of the fish products smoked with charcoal

Sample ID	Zn (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Ni (mg/kg)
Fresh	68.47±0.19^{a}	0.55±0.048^{a}	0.02±0.003^{a}	0.05±0.008^{a}	0.75±0.04^{a}
Rotary Kiln	53.17±0.36^{b}	0.26±0.03^{b}	0.02±0.013^{a}	0.03±0.009^{a}	0.47±0.032^{b}
Model-B Kiln	48.57±0.335^{c}	0.26±0.015^{b}	0.04±0.033^{a}	0.03±0.013^{a}	0.35±0.036^{c}

Average values ± standard deviation of three replicates. Average value that has the same superscript in the same column are statistically the same at P<0.05.

Table 4: Heavy metals profile of the fish products smoked with gas

Sample ID	Zn (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Ni (mg/kg)
Fresh	78.60±0.33^{a}	58.83±0.29^{a}	0.24±0.03^{a}	0.85±0.02^{a}	67.31±0.13^{a}
Rotary Kiln	53.71±0.36^{c}	20.49±0.13^{c}	0.06±0.01^{b}	0.14±0.02^{b}	28.88±0.17^{c}
Model-B Kiln	56.70±0.22^{b}	23.63±0.036^{b}	0.07±0.02^{b}	0.15±0.003^{b}	31.52±0.17^{b}

Average values ± standard deviation of three replicates. Average value that has the same superscript in the same column are statistically the same at P<0.05.

Due to partial combustion and soot build-up on the fish, smoking fish over charcoal often increases carcinogenic PAHs. However, with more effective combustion processes and distinct smoking settings, the use of gas produces fewer hazardous PAHs, even though the overall amount of PAHs produced may be larger.

The level of Benzo (a) pyrene (BaP) in smoked fish products has been identified by some scientific regulatory institutions as a means of measuring the safety of the product with respect to PAH contamination (Essumang et al., 2012).

In assessing the safety of smoked fish products due to PAHs contamination, the European Commission has indicated a maximum allowable BaP concentration of 5.0 µg/kg (E.C., 2006), while the Turkish Codex Regulation sets its maximum permissible limit at BaP of 2.0 µg/kg (Turkish Food Codex, 2008). Different studies have reported concentrations of PAH contamination in smoke-dried fish products. Wretling et al. (2010) reported BaP concentrations that ranged between 8.4 and 14.4 mg/kg; while BaP concentration of 2.4 - 31.2 mg/kg was reported in another study where a traditional smoking facility was adopted (Akpambang et al., 2009). The research outputs of this study revealed that the PAHs of the smoke-dried fish products obtained from the smoking kilns were far below the permissible quantity of 2-5 µg/kg recommended by E.C. (2006) and Turkish Food Codex (2008), irrespective of the charcoal and gas used as heat source. This could be attributed to the design configuration and unique features of the drying equipment used, which provides a separate compartment for combustion away from the drying compartment, preventing fish oil and water droppings from contacting the heat source. To minimise health concerns related to PAHs in smoked fish, it is imperative to comprehend these variations to enhance food safety and optimise smoking methods (Dzikunoo et al., 2021) by adopting a smoking facility that has provisions to minimise PAHs deposition on smoked fish products.

Results of the Sensory Evaluation of the Smoke-Dried Fish Products

None of the sensory attributes and overall acceptability considered in the study to evaluate the fish products from the two kilns show a significant difference in their means (Table 6). However, overall acceptability showed that sensory panelists preferred fish samples from the rotary kiln (7.44±0.10) 5.2% more than the model-B kiln (7.07±0.13).

Table 5: Polycyclic Aromatic Hydrocarbons (PAHs) profile of the fish products smoked with charcoal and gas in the two smoking kilns

PAHs Components	Rotary Smoking Kiln		Model-B Smoking Kiln	
	CPK (µg/kg)	GPK (µg/kg)	CPK (µg/kg)	GPK (µg/kg)
Naphthalene	0.01144	0.00889	0.02075	0.00817
Acenaphthylene	0.01254	0.01771	0.01218	0.01794
Acenaphthene	0.04549	0.05675	0.04572	0.05708
Flourene	0.05857	0.09396	0.03999	0.09451
Phenenthrene	1.24622	1.57022	1.18660	1.57221
Anthracene	0.67518	4.91466	0.55801	4.44365
Fluoranthene	4.56241	5.57267	5.50825	4.74008
Pyrene	1.34587	5.57567	1.34957	5.32923
Benzo (a) anthracene	0.08939	0.05889	0.08246	0.05888
Chrysene	0.02303	0.07274	0.02221	0.07306
Benzo (b) Anthracene	0.03179	0.01035	0.03366	0.01038
Benzo (K) Fluoranthene	0.03399	0.00632	0.03383	0.00773
Benzo (a) pyrene	0.22934	0.11226	0.21830	0.11747
Indeno (1,2,3-cd) anthracene	0.00877	0.00110	0.00836	0.00114
Dibenzo (a,h) Anthracene	0.04303	0.00738	0.05056	0.00738
Benzo (g,h,i) Perylene	0.01240	0.00495	0.01504	0.00449
Total PAHs	8.42946	18.08452	9.18549	16.5434
Total Carcinogenic PAHs	**0.41878**	**0.25759**	**0.40736**	**0.26452**

CKP – Charcoal powered kiln; GPK – Gas powered kiln

Table 6: Results of sensory evaluation of fish products smoke-dried with charcoal

Sample ID	Colour	Aroma	Texture	Taste	Overall Acceptability
Rotary kiln	7.36±0.10[a]	6.92±0.07[a]	7.44±0.06[a]	7.64±0.02[a]	7.44±0.10[a]
Model-B kiln	7.48±0.92[a]	7.01±0.06[a]	7.04±0.06[a]	7.52±0.13[a]	7.07±0.13[a]

Average values ± standard deviation of three replicates. Average value that has the same superscript in the same column are statistically the same at P<0.05.

Conclusion

The evaluation of the rotary and model-B smoking kilns, considering two sources of energy, has been able to establish the following facts about the kilns: The utilisation of the two kilns did not significantly affect the nutritional quality (proximate composition) of the smoke-dried fish products. The two kilns did not contribute to the level of heavy metals in the fish products; instead, they brought the levels down, which were within the global acceptable limit. The fish product from the rotary kiln received better overall acceptability than the model-B kiln-smoked fish product. Irrespective of the energy sources and the kiln, the PAHs levels were within the maximum permissible limit of international regulatory bodies. Therefore, considering the solution provided to the challenge of opening the kiln before trays could be changed and fish could be turned in the model-B kiln, resulting in reduced risk of product contamination through human contact, the rotary smoking kiln becomes an improved version/model of the NSPRI smoking kiln.

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