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Full Length Research

Cost benefit analysis and efficacy of smoking technologies in removing moisture content of *Mormyrus caschive* and *Oreochromis niloticus* in Terekeka-South Sudan

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ABSTRACT: Efficacy, cost and benefit of smoking fish using pit and *chorkor* technologies were investigated to inform decisions on economic sustainability and efficiency of the processing technologies in removing moisture content for quality assurance and extension of fish shelf-life. A total of 72 fresh fish; 36 (120 kg) *Mormyrus caschive* (Family: Mormyridae; common name: Elephant snout) and 36 (118 kg) *Oreochromis niloticus* (Family: Cichlidae; common name: Nile Tilapia) were bought from Sur-num fish landing site. From the procured fish, 12 (38 kg) samples were iced and used for fish moisture content analysis while the remaining 60 samples were divided into two batches for pit and *chorkor* smoking. Each batch contained 30 fresh fish samples with a total weight of 100 kg. Field experimental smoking was conducted twice in a completely randomized design. Moisture content in fish samples was determined using weight reduction method and cost benefit analysis using market price survey and interviews. Results revealed *chorkor* oven significantly reduce moisture content in *M. caschive* (10.0±0.83%) and *O. niloticus* (15.1±0.48%) more than pit kiln (15.3±0.57% and 17.3±0.42%), respectively. Although *chorkor* oven construction was expensive, the economic return was higher than for pit kiln due to short smoking time (6-8 hours, and twice in 24 hours) and utilization of small quantity of firewood (4 bundles/round). *Chorkor* oven is therefore, an efficient and economically viable technology for smoking fish. The study recommends its adoption for artisanal fisheries in South Sudan.

Keywords: Economic analysis, efficiency, fish species, kilns, moisture, sustainability.

INTRODUCTION

Fish and fisheries products play a significant role in people's livelihoods through provision of essential nutrients for healthy growth and development (Maxwell et al., 2014; FAO, 2018), enhancing food and nutrition security (FAO/WFP, 2014; Adeolu et al., 2017), and as source of income to fisher-folks (Golub, 2014; FAO, 2016a). However, fresh fish is the most perishable commodity of all food stuffs in the value chain (Getu and Misganaw, 2015). As such, processing and preservation methods are essential to extend fish shelf-life (Emere and Dibal, 2013; Famurewa et al., 2017).

Among the customary methods of salting, sun-drying and fermentation, smoking is the most widely used method of fish preservation in developing countries (Olopade et al., 2013; Huong, 2014). This is due to the fact that, smoked fish are highly accepted by the consumers in addition to technical and operational simplicity (Magawata and Musa, 2015).

Fish smoking is also commonly practiced in remote areas where delivery of fresh catches to distant markets is not permitted due to poor roads and lack of cold chain transport facilities (Adeyeye and Oyewole, 2016). The need to improve preservation technologies in such areas is of a paramount importance to reduce fish post-harvest losses (Diei-Ouadi and Mgawe, 2011; Adeolu et al., 2017). For fish processing technology to be adopted in commercial fisheries, factors such as cost and benefit, feasibility and acceptability of preserved fish have to be taken into consideration (Ndome and Ingwe, 2010; Namisi and Jiribi, 2013). As such, freezing as a preservation technique is not widely adopted in artisanal fisheries of South Sudan due to its need for electricity (UNIDO, 2015). Improved drying facilities and smoking technologies like solar panel and external smoke generators are not used by traditional fish processors in South Sudan due to lack of purchasing capacity (FAO, 2016b).

The quality and safety of processed fish are important aspects for adoption of a smoking technology (Yusuf and Hamid, 2017). Studies have shown that improved technologies produce better quality processed fish than traditional ones (Nguvava, 2013; Pemberton-Pigott et al., 2016). Abraha et al. (2017) compared the quality of Anchovy dried using open sun rack and solar tent methods and revealed that, the latter had better quality and sensory characteristics than the former due to effective removal of moisture content, and control of pests and microorganisms.

Similarly, Olukayode and Paulina (2017) assessed the effect of two traditional *chorkor* kilns and hybrid solar drier system in enhancing fish quality during storage and preservation, and observed that hybrid solar drier augmented fish shelf-life more than traditional drying systems due to effective removal of moisture. It is also worth noting that, high quality fish are accepted in the market at premium prices with resultant increase in profit margin that significantly improves fisher-folks' livelihoods (Muhame et al., 2020). Thus, increased marketing potential of smoked fish products is enhanced by extension of fish shelf-life (FAO, 2016b).

Indeed, fish shelf-life is extended by proper post-harvest handling techniques (Yusuf and Hamid, 2017), particularly where improved smoking facility is used coupled with good storage conditions (Olatunde et al., 2013; Baniga et al., 2017). However, cost of oven construction may limit adoption of improved processing technology in artisanal fisheries, depending on the quality of materials, and smoking capacity of the facility. Studies have shown that, the cost of constructing or fabricating a *chorkor* oven using locally available materials is lower than industrial materials (Ndome and Ingwe, 2010; Adeyeye and Oyewole, 2016). Ikenweiwe et al. (2010) investigated the performance of locally developed smoking *chorkor* over traditional kilns and reported that locally developed smoking *chorkor* oven is cost effective and can efficiently smoke fish more than the traditional kilns.

While studies revealed low cost of constructing *chorkor* oven (Ndome and Ingwe, 2010), little information is available in South Sudan regarding the cost and benefit of building kilns including *chorkor* oven. Lack of knowledge on cost and benefit of developing technologies can reduce fisher-folks' willingness to adopt any technical improvement endeavors. Additionally, the efficacy of traditional and improved smoking technologies in removing moisture in fish muscle has not been determined in South Sudan. This may lead to reduction in acceptability of technical improvement (Adeyeye and Oyewole, 2016). The current study therefore, determined the efficacy, cost and benefit of smoking fish using traditional pit and improved *chorkor* kilns to inform decisions on the effectiveness of preservation technologies for adoption in South Sudan.

MATERIALS AND METHODS

The study area

The study was conducted in the month of June, 2018 in Terekeka County of Central Equatoria State, South Sudan. Terekeka is located approximately, 52 miles north of Juba on the western bank of the Nile (Benansio, 2013). It lies within latitudes 5° 23'N and longitudes 31°48'E (FAO/WFP, 2019). The county has an estimated area of 10,538.232 km^2 and is occupied by an estimated population of 246,483 (South Sudan Centre for Census, Statistics and Evaluation, 2018). Terekeka has tropical climate with comparatively small seasonal changes in temperature, humidity and wind all year round (Climate-data.org, 2018). It receives rainfall from the months of March to May and August to November with an average annual rainfall of 907 mm. The area experiences dry periods between the months of December to February and June to July with average annual temperature of 27.7°C. It is within the dry season that most people are actively involved in fishing activities. However, plentiful periods of fish catch occur during the months of June to August particularly after flood recedes. It is within this period that majority of fish processors mainly women and children are actively involved in fish processing and preservation particularly, smoking of their catches.

The study design

The study was conducted in three phases; field experiment, laboratory analysis and market price survey. Field experimental smoking of the two fish species- *Mormyrus caschive (*Family: Mormyridae; common name: Elephant snout) *and Oreochromis niloticus (*Family: Cichlidae; common name: Nile Tilapia) using pit and *chorkor* technologies was conducted twice in a completely randomized design. Women fish group *chorkor* was used to represent improved smoking kiln. The *chorkor* was 2 m long, 1 m wide and 1m high with 3 trays attached after every 30 cm from base to top. This smoking kiln is made of unburnt bricks, interior plastered with clay soil and perforated flat iron sheets as roof. It has two inlets at the base for aeration and smoke production by burning firewood obtained from *acacia seyal*. Its smoking chamber has a movable door that remains closed except during monitoring periods. A traditional pit constructed alongside improved *chorkor* oven performance. The pit kiln measured; 1 m long, 0.5 m wide and 0.5 m high as practiced by fisher folks in the area. Four wooden planks are usually placed at the edges where a wire mesh sits. During fish smoking, flat iron sheet was used to cover the samples.

Moisture content was determined using weight reduction method in the laboratory to compare the efficacy of the two smoking technologies in removing water from fish tissues. Survey on market prices of pit and *chorkor* smoked fish was conducted through informal focus group discussions to determine and compare their costs and benefits.

Sampling, processing and analysis procedures

To investigate the efficacy of the two technologies in reducing moisture content, a total of 72 fresh fish; 30 (100kg) *M. caschive* and 30 (100Kg) *O. niloticus* were purchased from fishers at Sur-num landing site situated about 1 km East of Terekeka Town. Processing was done immediately after delivery. Fresh samples were kept in ice packed containers after being harvested at the fishing grounds. Purposeful smoking using improved *chorkor* and traditional pit was conducted at Terekeka landing site. The women fish group *chorkor* was used to represent improved smoking technology. A pit was constructed alongside improved *chorkor* to represent traditional smoking kiln. From the procured samples, 12 specimens (38 kg) from the two species (6 per fish species) were ice stored at 4ºC and transported by bus to the laboratory for reference moisture determination. The remaining 60 specimens were divided equally into two batches for pit and *chorkor* smoking. Each batch contained 30 fish samples (100 kg); 15 samples each of *M. caschive* and *O. niloticus*. All samples were prepared and processed following the traditional procedures (Abowei and Tawari, 2011). Processed fish samples were then immersed in freshly prepared salt solution (a mixture of 100 g salt in 10 L of clean water) for 15 minutes followed by draining for 15 minutes.

Fire was set in pit and *chorkor* kilns to generate smoke heat by burning *Acacia seyal* wood. The pre-treated fish samples were randomly loaded on the trays and wire mesh on top of *chorkor* and pit, respectively. The desired temperature range of 60 to 80ºC in *chorkor* kiln was maintained manually with a thermometer until fish were smoke dried. Then, smoked samples were cooled for 12 hours at ambient temperature of 20ºC. Samples were wrapped in aluminum foil, labeled for easy identification and packed in containers before delivery by bus to the laboratory in Makerere University Kampala, Uganda for analyses.

Market price survey

Survey on market prices of pit and *chorkor* smoked fish was conducted through informal focus group discussions. The discussion focused on the location of smoked fish sales, the prices of a kilogram of pit and *chorkor* smoked fish, reasons for the differences in cost and the duration of sales.

Statistical analyses

Data collected from the study was analyzed using R statistical package (R Core Team, 2018). A two-way analysis of variance (ANOVA) was used to test the difference in means of moisture content values to determine the efficacy of smoking technologies in removing moisture. Tukey's Honest Significant Difference Test was performed where the means of the two groups under comparison were significantly different. The level of significance was computed at $p \leq 0.05$. Descriptive statistics were used to compare the construction, maintenance and operation costs of pit and *chorkor* kilns. Benefits gained from sales of 100 kg of fish smoked using pit and *chorkor* technologies were established using the basic formula for determining profit (Profit = Selling Price – Buying Price).

RESULTS

Efficacy of smoking technologies in removing moisture content in fish

As expected, the study noted that the mean moisture of fresh *M. caschive* was significantly higher than pit and *chorkor* smoked fish, respectively ($p<0.05$, Table 1). With regards to efficiency, *chorkor* oven significantly reduced moisture in *M. caschive* (10.01±0.83%) more than pit (15.30±0.57%, $p<0.05$, Figure 1a). Similarly, the mean moisture content of fresh *O. niloticus* was significantly higher than pit and *chorkor* smoked fish ($p<0.05$, Table 1). In relations to the efficacy of smoking technologies in removing moisture, *chorkor* reduced moisture content of *O. niloticus* to 15.08±0.48% more than pit, 17.28±0.42% (Figure 1b).

Table 1. Summary analysis of variance with interaction for moisture content of the two fish species

Source	Df	Sum sq	Mean sq	F	Pr(>F)
Species	1	216	216	450.55	<2.00e-16***
Treatment	2	17086	8543	17791.83	<2.00e-16***
Species: Treatment	2	48	24	50.24	2.65e-10***
Residuals	30	14	0		

Species: *M. caschive* and *O. niloticus;* Treatment: Fresh fish, C*horkor* and Pit smoked fish

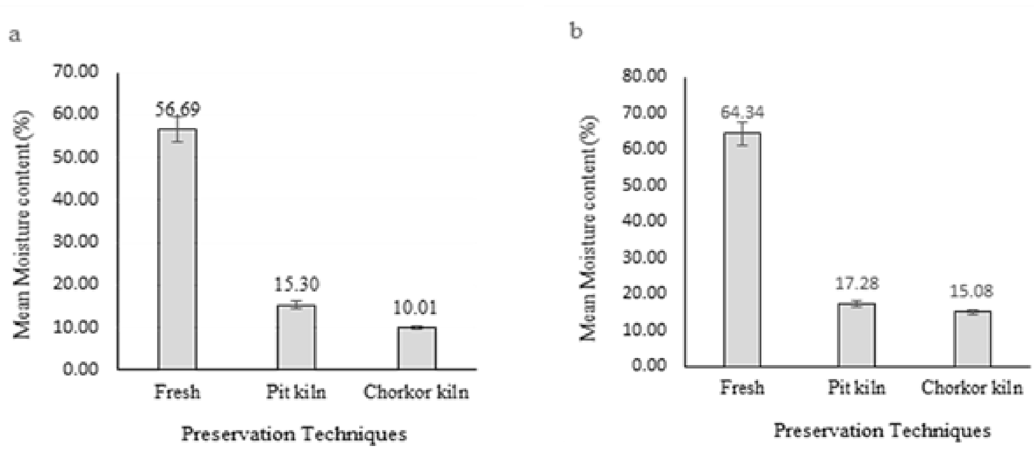

Figure 1. Efficacy of smoking technologies in removing moisture in *M. caschive* (a) and *O. niloticus* (b).

Economics of pit and *chorkor* smoking technologies

Concerning construction cost, the study noted that *chorkor* is more expensive than pit kiln. The investment cost of *chorkor* is more than that of pit kiln. *Chorkor* oven requires 40,700 South Sudanese Pounds (SSP) to construct while pit kiln requires 15,500 SSP (Table 2).

Considering smoking of 100 kg of fish (*M. caschive and O. niloticus*), investment cost incurred in smoking fish using pit kiln is more than that incurred in *chorkor* technology (Table 3). *Chorkor* kiln requires 4 bundles of firewood (with each bundle at 1,000 South Sudanese Pounds, SSP) to smoke 100 kg of fish while pit kiln requires 8 bundles (equivalent to 8,000 SSP). The operators spent 18-24 hours to smoke 100 kg of fish in a pit since the system takes on small batches of approximately 50 kg. The *chorkor* operators spent 8-12 hours and all the100 kg were smoked at once. Simple cost analysis showed that, to smoke 100 kg of fish, about 118,000 SSP was used in pit and 114,000 SSP in *chorkor* technology.

Cost benefit analysis of pit and *chorkor* smoked fish products

The weights of smoked fish recorded after smoking 100 kg fresh samples in pit and *chorkor* kilns were 85 and 78 kg (dry weight), respectively (Table 4). The market price of pit smoked fish during the study period was 2,000 per kilogram; and 85 kg of pit smoked fish equals 170,000 SSP. The profit earned from pit smoked fish was 36,500 SSP. For *chorkor* smoked fish, the market price was 2,600 per kilogram; 78 kg of smoked fish equals 202,800 SSP. The profit gained from the sales of *chorkor* smoked fish was 48,100 SSP. The profit gained from the sales of pit smoked fish products was less than that gained in *chorkor* smoked fish.

DISCUSSION

Efficacy of smoking technologies in removing moisture content in fish

Results of the study revealed a significant reduction of moisture in fish smoked using *chorkor* oven than pit kiln. Indeed, the ultimate aim of smoking is to reduce moisture content, which supports bacterial activities, oxidation and or rancidity leading to spoilage (Adeyeye and Oyewole, 2016). Studies noted that high moisture provides conducive environment for spoilage microorganisms to grow (Akintola, 2015). Smoke heat breaks down the hydrogen bond resulting in free molecules which eventually evaporate

Table 2. The cost of constructing pit and *chorkor* kilns.

Materials and Labor	Quantity	Unit price (SSP)	Amount (SSP)
Pit kiln			
Logs	4	400	1,600
Wire mesh	1 (2 meters)	1,500	1,500
Flat iron sheet	1	2,400	2,400
Labor	2 people	5,000	10,000
Annual maintenance		5,000 per year	5,000
Total			15,500 SSP
***Chorkor* kiln**			
Unbaked bricks	200	50	10,000
Clay mud	½ trip	2,000	2,000
Transport	Once	2,000	2,000
Water	200 liters	100 SSP per 20 liters Jerry can	1,000
Perforated iron sheet	3 (28 gauge)	2,400	7,200
Wood planks (Trays)	3 (2×1×1) meters	2,500	7,500
Nails	½ kg (4 inches)	2,000 per kilogram	1,000
Labor	2 People	5,000	10,000
Annual maintenance		2,000	2,000
Total			40,700 SSP

Table 3. The cost of smoking 100 kg of fish using pit and *chorkor* technologies.

Parameters	Quantity	Unit price (SSP)	Amount (SSP)
Pit kiln			
Fresh fish	100 kg	1000 per kg	100,000
Fire wood	8 bundles	1,000	8,000
Labor	2 People	5,000	10,000
Time	18-24 hours		
Total cost			118,000 SSP
***Chorkor* kiln**			
Fresh fish	100 kg	1000 per kg	100,000
Fire wood	4 bundles	1,000	4,000
Labor	2 People	5,000	10,000
Time	8-12 hours		
Total cost			114,000 SSP

on the surface of drying fish (Akintola, 2015). Excessive loss of moisture leads to decreased water activity in fish tissues (Olukayode and Paulina, 2017). Effective method of preserving fish should thus reduce moisture to the recommended level of less than 20% depending on the purpose and the desired dried fish product (FAO, 2016a).

In the current study, moisture was reduced to 10-15% and 15-17% for *chorkor* and pit smoked *M. caschive* and *O. niloticus*, respectively. In line with previous studies, smoke drying reduced moisture in the range of 81.49% to 84.33% in lean and fatty fish to 14.34% and 22.67%, respectively (Ahmed et al., 2011). With regards to the efficiency of the two technologies; *chorkor* oven effectively reduced moisture to 10% and 15% more than 15% and 17% for *M. caschive* and *O. niloticus* smoked using pit kiln, respectively. In line with Aba and Ifannyi (2013), Olopade et al. (2013), Omodara et al. (2016), Katola and Kapute (2017) and Olukayode and Paulina (2017), *chorkor* oven is an efficient technology for reducing moisture in fish muscles. Effective removal of moisture from fish is attributed to smoke-heat concentration (at a temperature range of 60 to 80^{o}C) associated with the construction

Table 4. Number, wet and dry weight (kg) of fish samples used for moisture and economic analysis.

Total number and weight of fresh fish samples			
Fish species	**Number of fish samples**	**Wet weight (kg)**	
Mormyrus caschive	36	120	
Oreochromis niloticus	36	118	
Total	72	238	
Number and weight (wet) of fresh fish for moisture determination			
Fish species	**Number**	**Weight (kg)**	
Mormyrus caschive	6	18	
Oreochromis niloticus	6	18	
Total	12	36	
Number of pit smoked fish samples used for moisture determination			
Fish species	**Number of fish samples**		
Mormyrus caschive	6		
Oreochromis niloticus	6		
Total	12		
Number of *chorkor* smoked fish samples used for moisture determination			
Fish species	**Number of fish samples**		
Mormyrus caschive	6		
Oreochromis niloticus	6		
Total	12		
Number and weight of fish samples used for economic analysis of the two species			
Smoked fish samples	**Number**	**Wet weight (kg)**	**Dry weight (kg)**
Pit smoked fish samples	30	100	85
Chorkor smoked fish samples	30	100	78
Total	60	200	163

materials and enclosed characteristics of *chorkor* oven. Similarly, effectiveness of *chorkor* kiln could be explained by the enclosed system leading to concentration of heat in the facility. Lower moisture recorded in fish smoked using *chorkor* oven therefore, entails longer shelf-life of smoked fish products. While moisture content of *chorkor* smoked products in this study was within the level considered acceptable for smoked fish to inhibit both bacterial and fungal growth (Msusa et al., 2017), relatively higher values recorded in fish smoked using pit technology signify exposure of products to microbial spoilage. Moisture also directly influenced the level of water activity in fish products (Omodara et al., 2016). Additionally, the type of smoking technology positively influenced the level of water activity that may impact on microbial growth (Reza et al., 2015). In the present study, fish smoked using *chorkor* oven had significantly reduced moisture and water activity than fish smoked using pit kiln. Effective removal of moisture content (<15%) in *chorkor* kiln may reduce water activity that may in turn inhibit the growth of microorganisms in the product (Immaculate et al., 2013) thus, suggesting fish products with extended shelf-life.

Economics of pit and *chorkor* smoking technologies

Although the cost of constructing *chorkor* oven is high due to relatively expensive building materials (unbaked bricks, clay, trays, nails and perforated iron sheets), the subsequent cost of smoking and kiln maintenance are lower than those for pit. Low cost of production is attributed to, firstly, the small quantity of firewood used in *chorkor* oven due to enclosed system leading to effective control of oxygen and temperature. Excessive oxygen increases combustion rate, and elevated temperature causes excessive consumption of firewood. Secondly, smoking of fish is conducted by only two people and completed within short period (6 hours on average) due to the control of combustion rate and smoking process, as air and temperature supplies were reasonably controlled in *chorkor* oven.

Fish processing is dominantly done by women and the average rate of fish smoking in South Sudan is 50 kg/person in 6 hours with a *chorkor* kiln but 20 kg/person in 12 hours with a pit kiln. Smoking fish in a *chorkor* oven therefore, helps women to smoke fish within short period (6-8 hours) and allow them to do other house hold activities including caring for their children which is not the case with those processing fish using traditional pit kiln. Indeed, smoking fish in a pit is more laborious than *chorkor* due to higher maintenance cost and regular monitoring of fish during smoking that could be done for a period of about 12 hours. Unlike *chorkor* oven that can last for at least five years, pit kiln requires yearly repair or construction yet smoked small quantity of fish with low-quality (UNIDO, 2015).

The cost benefit analysis of fish smoked using pit and *chorkor* kilns revealed higher profit gained from the sales of fish smoked using *chorkor* oven than with pit kiln. This is attributed to high quality smoked fish produced by *chorkor* which could be bought at higher prices in the market than pit smoked fish products (Abraha et al., 2017). High-quality fish obtained in *chorkor* oven is due to good handling practices and effective smoking which resulted into fish products with good sensory parameters particularly the uniformity of dark-brown colour that is one of the main attributes considered by consumers before buying at premium prices (Adeyeye and Oyewole, 2016).

Although the initial investment cost of *chorkor* kiln is higher than pit, it was extrapolated that the cost can be covered within short period due to higher profits gained from the sales of *chorkor* smoked fish products. While the lifespan of *chorkor* kiln ranges between five to eight years depending on the construction materials and seasonality (Pemberton-Pigott et al., 2016), pit kiln has shorter lifespan of less than a year depending on weather conditions, for example, pit can get flooded during rainy season making its use impossible. Flooding reduces the utilization of pit which subsequently result to higher post-harvest losses especially where modern facilities for preserving fresh fish are lacking. Consumers' acceptance and willingness to pay premium prices for smoked fish depend on the quality and sensory attributes of smoked fish (Olatunde et al., 2013; Adeyeye and Oyewole, 2016) which were noted to be higher in *chorkor* than in pit smoked fish products. This explains why the market prices for *chorkor* oven smoked products were higher than pit smoked fish products.

Conclusion

Cost benefit analysis and efficacy of smoking facilities in removing moisture content in fish were determined to inform decisions on effectiveness of preservation technologies for adoption in South Sudan. The study revealed that both smoking ovens reduced moisture in smoked fish. However, *chorkor* oven efficiently removed moisture content in fish more than pit kiln. Smoking parameters; temperature and time directly influenced the effectiveness of *chorkor* technology in removing moisture. Moisture was significantly reduced in *chorkor* oven within 6 to 8 hours at a temperature range of 60 to 80°C unlike the longer time (average of 12 hours) spent in smoking fish using pit kiln. The structural design of *chorkor* oven and standardization of the smoking process significantly increased the rate of heat retention. As such, *chorkor* oven was associated with shorter drying time than pit kiln. With regards to cost, *chorkor* oven is more cost-effective than pit kiln in terms of smoking time and quantity of fish smoked, which consequently resulted into higher profit returns hence, an economically viable technology for fisher-folks. However, smoke concentration levels and microbiological qualities of smoked fish will be studied to ensure quality and safety of fish for human consumption in South Sudan.

CONFLICT OF INTEREST

The authors declared no conflict of interest associated to this research work.

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