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Solar Drying in Africa

Proceedings of a Workshop held in Dakar, Senegal, 21-24 July 1986

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ABSTRACT / RÉSUMÉ / RESUMEN

Abstract -- This book presents the proceedings of a workshop on solar drying in Africa attended by 24 participants involved with solar drying research relevant to the continent. Of the papers, 17 describe research activities on socioeconomic aspects, design and testing of solar dryers, and future research needs. In addition, a summary of the discussions held during the workshop to assess the state of the art of solar drying research in Africa are outlined, focusing on progress made and on possible research and collaborative activities that are needed to overcome the technical and socioeconomic problems that limit the development and introduction of improved solar dryers.

Résumé -- Voici le compte rendu d'un colloque sur le séchage solaire en Afrique auquel participaient 24 personnes effectuant des travaux de recherche propres à ce continent. Au nombre des communications, 17 décrivent les activités de recherche sur les aspects socio-économiques, la conception et l'essai des séchoirs solaires, ainsi que les besoins futurs de recherche. En outre,le lecteur trouvera un résumé des discussions sur l'état de la recherche sur le séchage solaire en Afrique, notamment les progrès réalisés et les activités de recherche coopératives nécessaires pour surmonter les problèmes techniques et socio-économiques qui entravent la mise au point et la diffusion de séchoirs solaires améliorés.

Resumen -- Este libro contiene los trabajos presentados en un seminario sobre secamiento solar en Africa, al cual asistieron 24 participantes del área de investigación en secamiento solar referida a este continente. Diez y siete de los trabajos versan sobre actividades de investigación en aspectos socioeconómicos, diseño y prueba de secadores solares y necesidades futuras de investigación. Se describe además la discusión sostenida durante el seminario para sopesar el estado de la investigación en secamiento solar en Africa, discusión que se centró en los progresos realizados y en las posibilidades de investigación y acciones colaborativas necesarias para superar los problemas técnicos y socioeconómicos que obstaculizan el desarrollo y la introducción de secadores solares mejorados.

CONTENTS

APPROPRIATE TECHNOLOGY FOR SOLAR FISH DRYING IN ARTISANAL FISHING CENTRES

Niokhor Diouf[1]

Abstract -- *An overview is presented of the improvements in the artisanal manufacturing technology chain for various types of dried fish using simple polyethylene solar dryers and appropriate techniques for pretreatment and preservation after processing. The paper also attempts to answer the question: is solar drying economical for local producers and consumers of dried fish? This question is particularly relevant because natural drying, notwithstanding the favourable climatic conditions, has resulted in some loss of productivity by the processors.*

Analysis of Technical and Socioeconomic Aspects of the Artisanal Fish-Processing Sector

Improvement of suitable technologies for the rural and urban communities is a priority in developing Africa. This priority has been clearly recognized by the Institut de technologie alimentaire, which, together with the Food and Agricultural Organization of the United Nations (FAO) and the U.S. Agency for International Aid (USAID), has sought ways of adapting solar drying to local production of dried fish in the artisanal fishing centres of Senegal and Gambia.

The artisanal fish-processing sector (Table 1) offers thousands of jobs and considerable revenues. The processor has become a true business person employing 3-5 people, or more, according to need, to gather fresh supplies of raw materials, to preprocess the fresh fish, monitor the drying operations, and package and market the finished product.

The processing and storage operations for dried fish are simple and basic. The work is performed with bare hands, often directly on the ground, using simple instruments that are barely in fit condition. The processing area is polluted[2] and the processors have no respect for basic hygiene and cleanliness. They also use a number of insecticides, particularly DDT and Propuxor, to protect the product from infestation. In addition, the processors experience many acute problems in marketing dried fish even though demand exceeds supply both locally and on the African continent as a whole.

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[1] Institut de technologie alimentaire, Dakar, Senegal.

[2] The pollution is due especially to fishing or production wastes, which permit insect pests that infest the dried fish to breed, and to the waste waters and refuse of all kinds that litter the ground.

Table 1. Fish processed artisanally in Senegal, 1977-1983.

End product	Quantity produced (t/year)						
	1977	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
Dried salt fish (saly)	953	988	707	758	528	477	640
Dried braised fish (kéthiakh)	7169	6002	5728	6014	7047	6458	7950
Smoked fish (métorah)	1387	1381	1027	698	680	657	560
Dried fermented fish (guédj)	3869	4232	3751	3403	3496	3436	3688
Whole dried fish (tambadiang)	3017	2894	3338	3928	939	713	3950
Toufa, yeet	1632	3580	5200	7403	2803	1567	925
Other end products (pagne, yokhoss)	1794	112	97	132	2272	4000	105
Total end products	19821	19189	19848	22336	17765	17308	17818

Source: Oceanographic and Maritime Fishing Service.

Note: The fraction of total end products of fish processed by artisanal processors varies between 30 and 60% when the full range of raw materials and processes is taken into account. Artisanal processing accounts for 45,000-60,000 t of fresh fish annually, including the amount consumed personally by the artisans.

In parallel with the development of artisanal fishing, artisanal processing has shifted from direct, consumption-oriented production to trade-oriented commercial production. However, the technology of dried-fish production has stagnated somewhat since 1960 following a governmental order prohibiting natural drying on the ground in the concessions in favour of natural drying on racks at the landing sites.

Two major attempts, 20 years apart, to improve dried-fish production were unsuccessful, at Saint-Louis and MBour. There were other unsuccessful attempts to introduce mechanical fish-drying factories in the fishing centres that were rich in high-demand species, notably at Kayar, despite the application of scarce resources (investment capital, currency, and energy).

Applied research on fish technology in the fishing centres has given relatively poor results, in particular because all the research and development (R&D) projects have focused, and still focus, on particular techniques to the detriment of an overall study of the improvements that are needed in the field of production of each type of dried fish. Thus, nature still exerts a predominant influence on the various techniques for producing dried fish. Operations to prepare the fish before drying are undertaken directly on the ground, and the natural heat of the sun is used for drying. The salt used is manufactured in an artisanal fashion by drying out salt lakes. The drying racks are made of wood, and reeds and palmyra creepers are used for wrapping fresh or dried fish.

After examining the present technological situation in dried-fish production in the artisanal fishing centres, it is clear that an integrated approach is needed to remedy the various technical, social, and economic deficiencies. This great vital sector could then enjoy a harmonious and integrated development.

Equipment and Methods

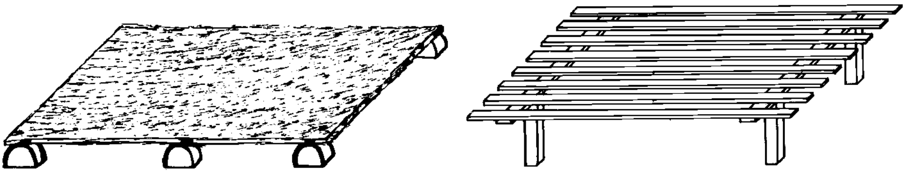
This study started during the phase of adapting solar dryers to the local conditions of dried fish production and proceeded with the installation of solar drying facilities in the fishing centres of MBour, Joal, Kayar, and Missirah.

Apart from the operations of scaling, gutting, and washing, the preparation of fresh fish for open-air drying (Fig. 1) or for drying in a solar enclosure includes various operations depending on the nature of the final product: kéthiakh (Fig. 2), guèdj (Fig. 3), saly (Fig. 4), and tambadiang (Fig. 5).

Each solar drying workshop (Fig. 6) has the appropriate equipment for producing these four types of dried fish. The preprocessed fish is dried in two ways: static drying on artisanal or improved racks (Fig. 1) and in Brace-type (Fig. 7) or house-type (Fig. 8) solar dryers; or drying by hanging in the dome dryer (Fig. 9).

Operation of Polyethylene Solar Dryers

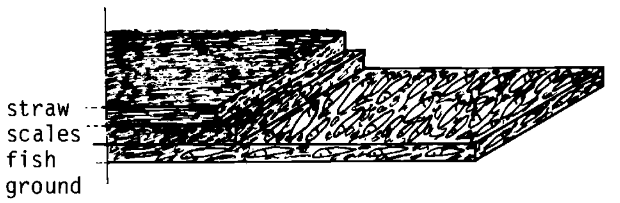
These three polyethylene solar dryers are direct heating systems that use only solar energy and in which the fish to be dried acts as the absorber. The frame is made from metal for the dome dryer and



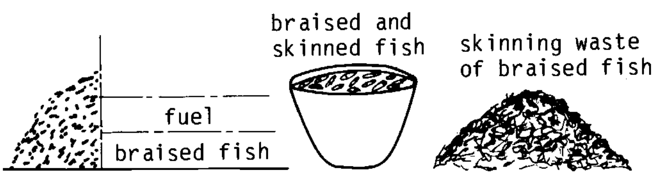
A. Artisanal drying rack

B. Improved drying rack

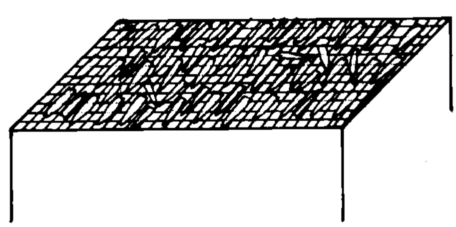
Fig. 1. Fish drying racks.



A. Before braising: preparation technique



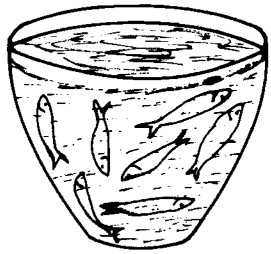
B. After braising: handling of braised fish



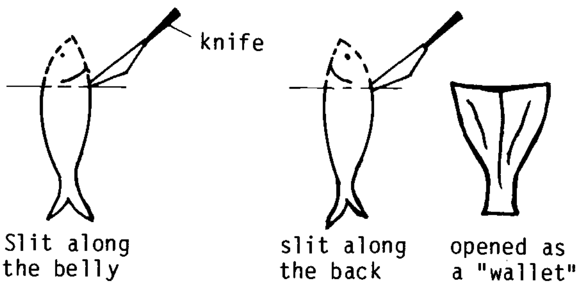
C. Natural drying of braised fish

Fig. 2. Artisanal technique for preparing kéthiakh (braised dried fish).

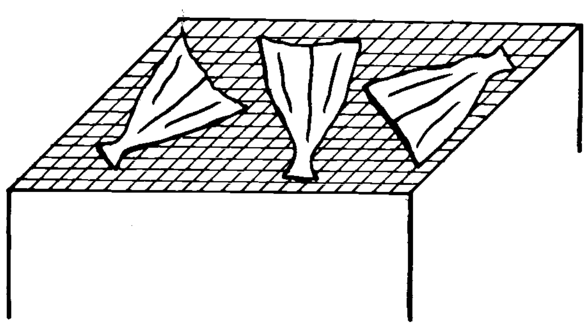
from wood for the other two. Solar radiation passes through the clear faces (transparent polyethylene of 180 μm) of the chamber but is absorbed by the blackened faces (black polyethylene of 300-350 μm).



A. Fermentation of whole fish in brine



B. Preparation of fermented fish



C. Drying fermented fish on a rack

Fig. 3. Technique of preparing <u>guédj</u> (dried fermented fish).

Drying air circulates as a result of vents above and below the installation. A door allows access by the processors. The site of the solar dryer installation must be well exposed to the sun all day, and the openings of the lower vents must be oriented toward the prevailing winds.

Solar radiation enters the installation through the transmissive surfaces and is then absorbed in the form of heat by the internal blackened surfaces. In turn, these blackened surfaces reemit radiation mainly in the infrared region, only a small part of which escapes

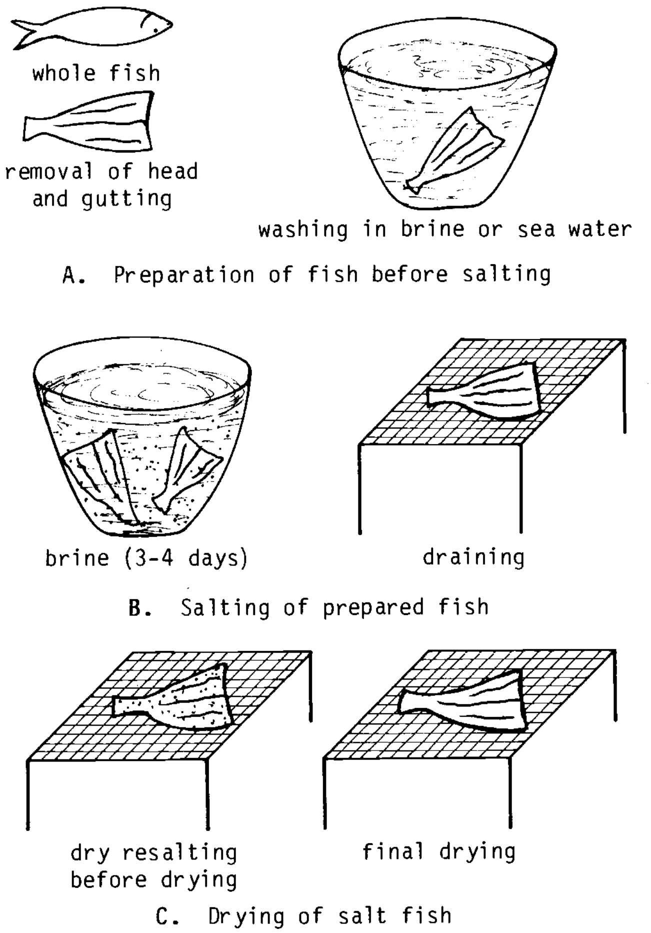
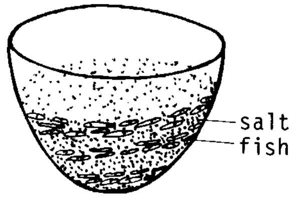


Fig. 4. Artisanal technique for preparing saly (dried salt fish).

through the transparent surfaces. Heat is, therefore, trapped through the greenhouse effect and is transmitted to the drying air by conduction and radiation, but mainly by convection. The heated air expands in the drying chamber, becomes laden with humidity from the product, and escapes through the air outlet. The lower air inlet allows the drying air to be replaced as it rises and escapes from the dryer.

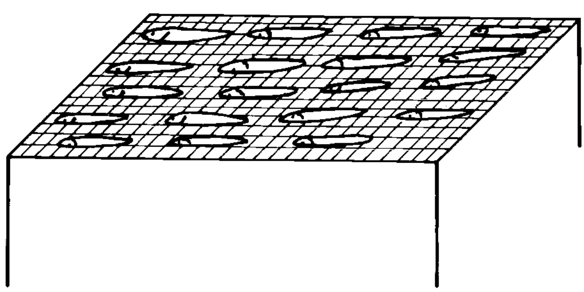
The supports used in rack fish drying operations cover all of the floor except for the part used as a walkway by the processors. These racks have an openwork structure to allow the drying air to pass through. The product to be dried is distributed uniformly along the rack, with small regular spaces left so that it can be turned over periodically. In this way, the degree of drying can be controlled.

The air vents are closed at night, or whenever rain threatens, to avoid any significant re-wetting of the product.



A. Fermentation of whole fish

B. Preparation of semifermented fish



C. Drying of whole semifermented fish

Fig. 5. Artisanal technique for preparing tambadian (whole dried fish).

Monitoring of Drying

To monitor the kinetics of drying and the changes that take place in fish quality during the preprocessing and the natural and solar drying phases, we measured the physical characteristics of the drying air using Ultrakurst telethermometers to measure temperature, Richard hygrometers to measure relative humidity, and anemometers to measure the airflow. Water activity was measured with the Aw-Value analyzer Model 5803. We analyzed the weight loss of the product during production and the changes in the chemical, microbiological, and organoleptic quality of both the product to be dried and the finished product.

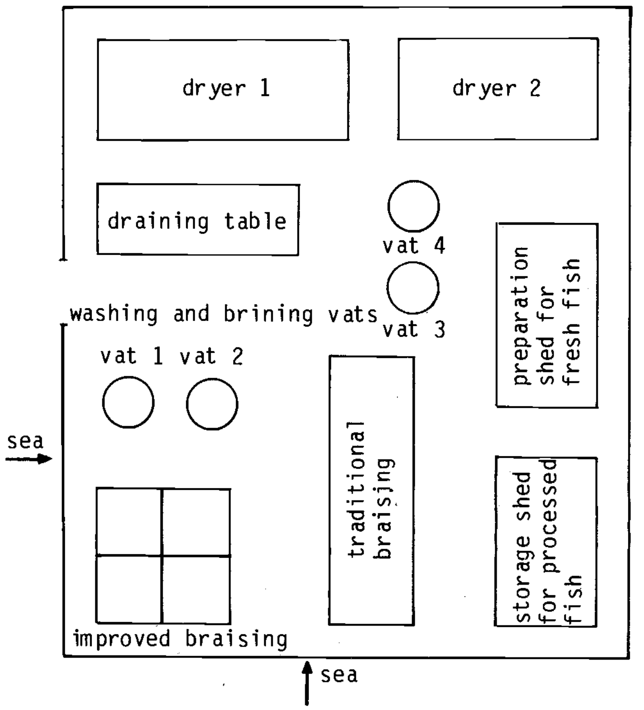


Fig. 6. Model solar dryer workshop at the Institut de technologie alimentaire, Senegal.

Results and Discussion

Preparation of Fish before Drying

Braising the pelagic species (gilt sardine and Ethmalosa finbriata) in a breezeblock oven (80-90 x 10^2 kcal/kg of fish) is more hygienic and reduces smoke production considerably. In addition, the moisture content of the fish drops by 9-15% during braising in an oven, compared with 5-10% during braising on the ground. This is equivalent to lowering the water activity from about 0.99 to 0.91 for fish braised on the ground and to 0.84 for the fish braised in an oven. Irrespective of the method of braising, the braised fish is cooked.

Fermentation of the fish whole, or gutted together with the guts, in vats of light brine (6-12° Beaumé) under good hygienic conditions produces a fermented product whose taste, appearance, and aroma are sought by the processors. In addition, the lactic flora of fermentation develops rapidly and reaches a stable level of 10^5-10^6, in contrast to the microbial flora of putrefaction that decreases appreciably. It should be noted that the Lactobacillus plantarum has a prominent influence on quality as well as quantity in the process of fermenting guédj.

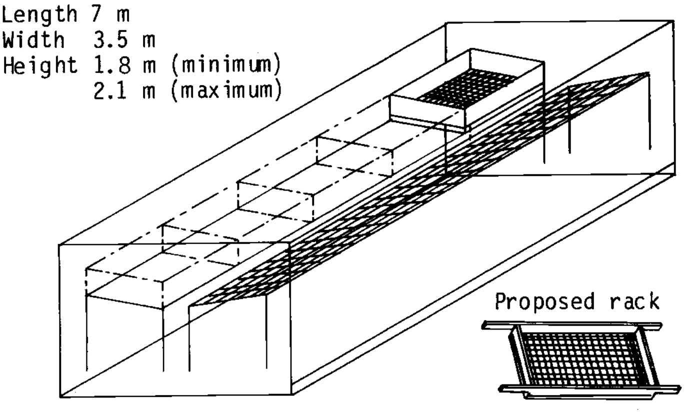


Fig. 7. Drying racks in the Brace-type solar dryer.

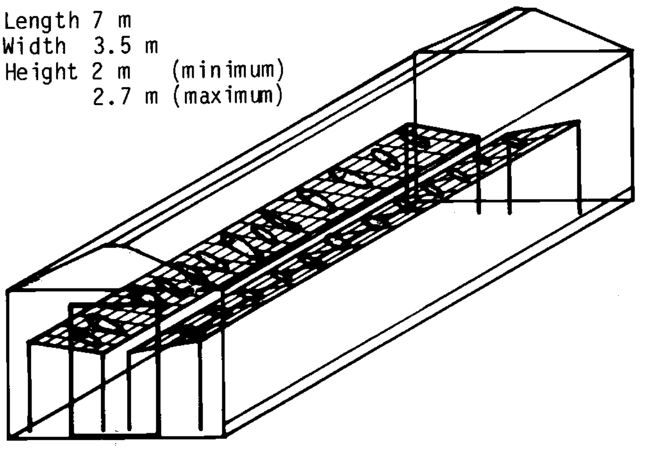


Fig. 8. Solar house dryer.

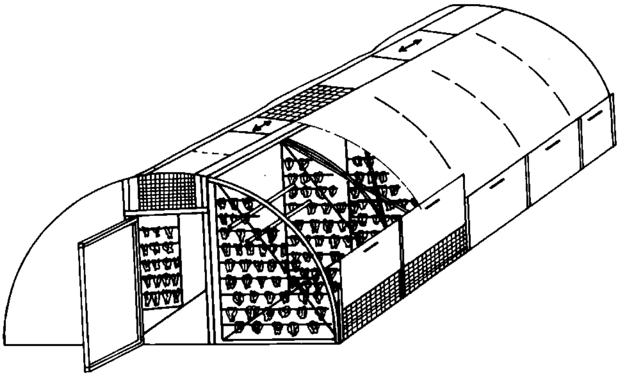


Fig. 9. Solar dome dryer with hanging fish.

Dehydration of fresh fish in dry salt is faster than in brine. For instance, after about 48 hours, the water activity of the Nile perch reaches about 0.85 in dry salt, compared with 0.90 in brine. However, the processors use a combination of dry salting and brining because the salting vats are not designed to allow the water exuded by the fish to drain off simultaneously. Deterioration of salt fish can be prevented by taking two precautions: avoiding trimming the fresh fish on the ground before salting to eliminate possible deterioration of the salt fish by moulds, and using salt that is free from hallophilic bacteria for salting by storing marine salt for 6-7 months before using it.

The preparation phase of fresh fish before drying is important because it allows, among other things, the temperature adjustment phase to be shortened. In addition, preprocessing the fish by salting or braising before drying increases the efficiency of the drying operation and results in products that match the particular tastes of the consumers.

Physical Characteristics of Drying Air

Between February and June at MBour and Joal, the temperature inside the dryers varies during the hours of sunshine between a maximum of 53°C and a minimum of 28°C (Fig. 10). Between 1200 and 1600 hours, the temperature is about 49-53°C. Relative humidity (RH) inside the dryers varies between 84 and 33%, with a level of 33-38% between 1200 hours and 1600 hours. Ambient temperature varies between 37 and 28°C without leveling off, and the atmospheric RH varies between 84 and 55%, again without leveling off. In addition, the circulation of the drying air in the dryer through natural convection is appreciable and amounts to about 25% of the speed of the ambient air (Table 2).

Mean daily total insolation measured with a solarimeter equipped with an integrator (Lintronic Ltd, 54-59 Bartholemew Close, London, U.K.) was about 15 MJ/m^2.

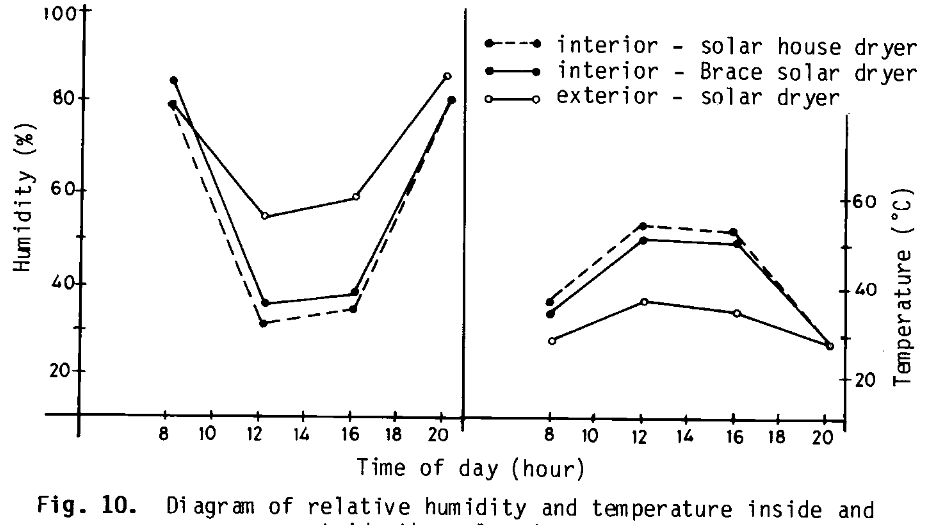


Fig. 10. Diagram of relative humidity and temperature inside and outside the solar dryers.

Table 2. Measurements of drying air speed.

Time of day (hour)	Ambient wind speed (m/sec)	Air speed in dryer (m/sec)	
		Inlet	Outlet
800	3.90	3.05	0.90
1200	3.20	2.88	0.80
1600	4.54	3.90	1.20
1800	3.80	2.87	0.86

Use of the solar dryer under these various conditions of temperature, RH, and drying air circulation make solar drying noticeably superior to artisanal drying. The effects of climatic conditions are less harmful than those for natural drying because the dryer is enclosed -- fish dried naturally are contaminated by atmospheric dust, which is intense in the dry season in the Sahel, and are rewetted by nocturnal humidity and rainfall. Losses due to larvae and larder beetles, which can be seen on the artisanal racks, are eliminated. Infestation by these insects is particularly intense during the rainy season.

Despite these clear advantages, the solar dryer remains subject to frequent variations of atmospheric air characteristics and solar intensity. This raises the question of how to "free" the solar dryer from variations in atmospheric conditions, as is the case for the heat pump.

Differences between Fish Dried Artisanally and in the Solar Dryer

Braised Fish

Predrying of the fish and temperature adjustment are partially or entirely completed during the braising operation (Table 3), according to the intensity of the fire. Thus, removal of surface water from the braised fish is completed after about the first 4-5 hours of exposure in the dryer (Fig. 11A). The accelerated solar drying phase for braised fish lasts about 30 hours (i.e., 18 hours of effective drying) after which the kéthiakh has a moisture content less than 28%, as opposed to more than 32% humidity for fish braised and dried on racks for about 45 hours or more. Interruption of drying during the night is beneficial because residual water migrates from inside the fish to the surface. This explains the marked improvement in the drying of braised fish during the first hours of the morning. However, this phenomenon becomes complicated for fish braised and dried on racks due to the amount of nocturnal condensation. Oven-braised fish dries more rapidly without salt in the dryer (about 14 hours of effective solar drying) than lightly salted fish braised on the ground (about 18 hours of effective solar drying). The temperatures reached in the solar dryer do not degrade either the colour or the taste of the kéthiakh produced. In addition, the final product has a firmer flesh, a much appreciated taste, a better appearance, and an almost total absence of the odour which characterizes artisanally dried kéthiakh.

Table 3. Fish quality during solar drying of _kéthiakh_ and _guédj_.

Product	Protein (%)	Total nitrogen (mg/100 g)	pH	Humidity (%)	Water activity	Flora			
						Aerobic	Putrid	Lactic	Hallophilic
Kéthiakh									
Fresh fish	21.9	24	5.95	65.7	0.99	1×10^5	<10	-	-
Braised fish	29.6	26	6.05	58.0	0.89	3×10^4	<10	<10	<10
Dried braised fish	62.0	27	6.20	24.0	0.70	4×10^4	<10	<100	<100
Guédj									
Fresh fish	18	35	6.30	72	0.98	6×10^5	10^2	<10	-
Fermented fish	23	60	6.70	68	0.94	5×10^6	<10	10^5	10^2
Dried fermented fish	59	58	6.72	28	0.75	4×10^5	<10	10^3	10^3

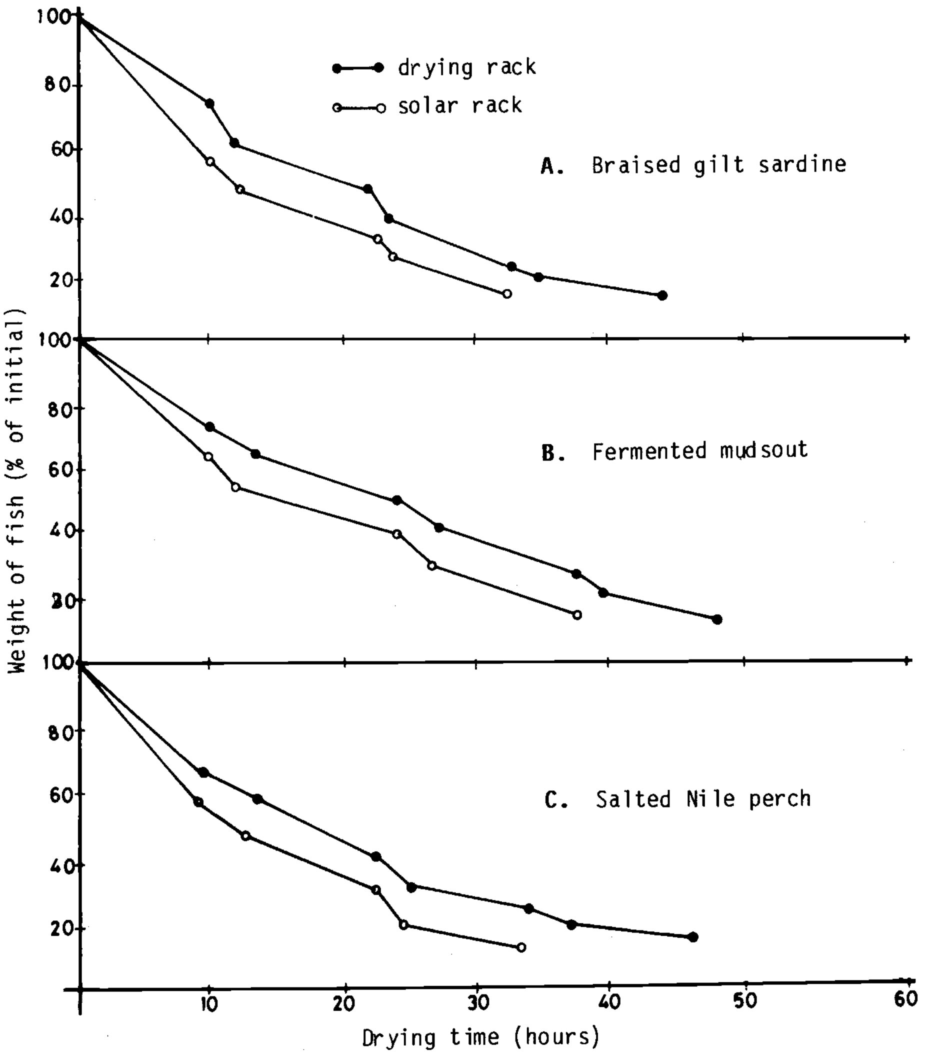


Fig. 11. Drying curves for braised (A), fermented (B), and salt (C) fish.

Fermented Fish

Solar pre-drying of fermented and trimmed fish for 4-5 hours with the access door open is necessary to avoid the formation of a crust on the surface of the product. To prevent crust formation on the surface of the fermented fish, drying temperatures should be below 42°C and drying air speed greater than 1 m/sec.

Loss of surface water from the fermented fish continues for about 8 hours, which coincides generally with the 1st day of solar drying.

By this time, the moisture content of the half-dried fermented fish is between 46 and 56% (Fig. 11B). During the following night, water migrates from the inside of the product to the surface and this occurs more rapidly if nocturnal condensation in the dryer is minimal. If fine salt is scattered on the slab, nocturnal condensation and rewetting have a negligible effect on the product and, the following day, the product surface is moist due only to migration of water from the inside of the fish to the surface.

The accelerated solar drying phase lasts about 10-20 hours depending on the type and thickness of the fermented fish. Migration residual water from the interior of the product accelerates drying during the early hours of the morning. This also accelerates the process of fermentation of the product, whose bacterial and lactic flora contents increase to stabilize at between 10^5 and 10^6 each night (Table 3).

The temperatures during accelerated drying of the fermented fish must not exceed 50°C to avoid degradation of the colour and taste of the final product.

Fermented fish cannot be dried by hanging in the dome dryer because it generally falls onto the slab before the end of drying, thus degrading the appearance of the final product.

Fish fermented and dried in the solar dryer (27-30% humidity after 32-38 hours) is much appreciated and has a good appearance, colour, and taste, as well as being less acidic than the guédj obtained by natural drying.

Salted Fish

Study of solar drying of salt fish is an on-going activity. The results obtained so far nevertheless indicate that solar drying accelerates the drying process (Fig. 11C) without recourse to conventional energy sources, solves the problem of infestation of drying or dried fish by insects, and yields a final product of better chemical, microbiological, and organoleptic quality.

The polyethylene solar dryer has some limitations:

° The solar dryer depends on the surrounding atmospheric conditions, even though, in contrast to the artisanal rack, the product is directly protected against the negative effects of nature.

° The dryer construction cost is high compared with the cost of an artisanal drying rack.

° The transparent polyethylene tears easily and must be replaced after each year of use.

° Processing capacity is inadequate according to the processors if the dryer is equipped with only one layer of drying racks.

Nevertheless, our investigations to improve the technical qualities of polyethylene dryers continue. Thus, to increase drying capacities, the dimensions of the access doors must be increased to allow drying racks (see Fig. 7, proposed rack) to be filled with fish outside and piled five to seven deep.

General Characteristics of Solar Drying Operations

The fish-processing community has rapidly assimilated the technological innovations for producing dried fish in the workshops, which are described in Appendix 1. These processors are producing all the types of fish dried in Senegal, depending on the availability of raw materials and customer demand, despite their previous specialization in only one product.

The use of preprocessing and solar drying structures in the facilities has resulted in rationalization of the production technology for the various types of dried fish. Dried fish production was characterized, among other things, by savings in drying time (1-2 days on average according to the size of the species and the needs of the customers) and in braising fuel.

Whatever type of fish is dried, the total production expenses cover the purchase of the raw materials (about 65-82% of the amount spent) and overheads. The cost of raw materials and overheads vary according to the types of fish dried and the fishing centres. The acquisition costs of raw materials can double depending on market fluctuations (Table 4).

Three channels are used to sell plant production:

° Direct sale to the wholesale fish merchants (intermediates between processors and consumers) who, because of their considerable financial resources, set the buying price from the processors;

° Sale in the major dry-fish marketing centres where the processors take their merchandise using rented vehicles; and

° Sale to the dried-fish exporters at a price negotiated at the time of signing the contract, which is prepared before production starts.

The last two forms of marketing the product are favoured by the processors who earn substantial profits in contrast to the first form where they can make either profits or losses according to the traditional laws of supply and demand.

Prospects and Recommendations

After a few months of operation of the facilities, the benefits are numerous and diverse. The following recommendations address the problems that still remain:

- Increase the drying capacity of each dryer by drying preprocessed fish in stacks of five to seven piled drying racks (Fig. 7);

- Improve the conditions for supply of raw materials to the processors (more precisely, equip the facility with isothermal containers for preserving fresh fish on ice) and, most

Table 4. Analysis of production costs of kéthiakh in Joal workshop (1 week of production)

	Costs (XOF x 10^3)[a]	Cost of production (%)
Production costs		
Raw materials (4 baskets of fish)	55.0	80.41
Products required for production		
Wood	4.5	
Salt	1.1	
Total	5.6	8.19
Labour cost		
Delivery of fresh fish in handcarts	4.0	
Oven loading	1.3	
Scaling of braised fish	2.0	
Lighting costs	0.5	
Total	7.8	11.40
Turnover at Joal[b]		
Total sales	124.2	
Profit	55.8	
Turnover in marketing centres[b]		
Cost of vehicle rental	27.8	
Cost of wrapping and sales	28.0	
Total costs	55.8	
Total sales[c]	224.2	
Profit	100.0	

[a] In 1986, 220 XOF (franc of the Communauté financière africaine) = 1.00 CAD (Canadian dollar).

[b] Total weight of kéthiakh = 1180 kg.

[c] The cost of kéthiakh made by braising on the ground was between 40 and 70 XOF/kg at Joal at the time when kéthiakh braised in the oven cost 90-130 XOF/kg. The kéthiakh is sold at 190 XOF/kg in most of the major marketing centres.

importantly, regularize plant production by having a minimum daily quantity of raw materials available;

- Improve the production and marketing of products by maintaining a staff of experts to promote the following aspects: team spirit; cooperative endeavours; credit structures; and business management and marketing;

- Improve production hygiene by taking the following actions: pave the inner yard to reduce the reproduction of destructive insects; recover the value from waste and by-products of processing; use cleaner water in the operations; and illuminate the plant with gas lamps so that the processors can work on the nightly arrivals of fresh fish in good and safe conditions;

- Improve the storage conditions of dried fish before marketing to minimize the qualitative and quantitative losses of the product due to insects and rewetting, particularly at night;

- Continue studies on the technological chain of production for dried fish, especially the fish fermentation process and the interplay between salting and drying; and

- Continue studies on the innovative and investment capacities of the processors by in-depth examination of the possibilities of subsidies or credit systems for processors.

Conclusion

Implementation and operation of solar drying facilities by fishery technologists and experienced processors represents real progress in applied research on artisanal fish technology in Senegal. That collaboration between technologists and processors has set a good example is shown by the activities of the processors. The processors have contributed greatly to better adapting these technological innovations to the local conditions of the fishing centres. Thus, these workshops allowed us to introduce team work into the corporate processor community, despite the individualistic character that predominates in that sector; to produce good quality dried fish in conditions of good hygiene; to initiate a study of rationalization of the artisanal dried-fish production chain; and to identify the other technical and socioeconomic problems that must be solved to accompany the introduction of solar dryers in the fishing centres.

The key thing is to continue working toward the improvement of solar fish drying. Close collaboration between scientists and processors can only be beneficial, because the processors demonstrate a potential for creativity and initiative that can help develop a more effective and less costly solar drying technology.

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