PARAMETERS INFLUENCING FUEL WOOD CONSUMPTION IN FISH SMOKING

E.J. Mushi[1] , B E.J. Mrindoko[2] , H.A. Mbise[2] and A. Omari[2]

[1] Mechanical Engineering Department, University of Dar es salaam, P .O. Box 35131, Dar es Salaam
[2] Ministry of Energy and Minerals, P.O. Box 2000, Dar es salaam

ABSTRACT

Factors influencing the consumption of wood fuel in fish smoking were investigated in an Altona type of kiln. Fire management including control of the air flow through the kiln were observed to have considerable impact on the wood consumption. The ratio of the weight of loaded fish to kiln capacity was another significant factor where the consumption increased intolerably for loads below 75%. Small size fishes required less wood per unit mass compared to large ones. Brining was found to have no impact on the wood consumption but did increase considerably the shelf life of the smoked fish.

BACKGROUND

Smoking is the main method of fish preservation practiced in Tanzania, with two main advantages. These are a preservation process in which the shelf life of fish is improved and the introduction of a special flavour from smoke impaction. Simple and energy inefficient kilns which are used today could be improved. Observations from existing practices, indicate that about 1 m^3 of solid wood is used to smoke 1 tone of fish (about 7 kg of wood per kg of drip dried fish).

The average annual fish production between 1985 an 1991 was 363.5 tones; of which about 218.1 tones (60%) were smoked. Using the average consumption of 1 m^3 of wood fuel to smoke one tone of fish, the average annual wood fuel consumption for fish smoking in Tanzania is about 218100 m^3.

Almost all fishing areas in Tanzania are experiencing acute wood fuel scarcity for fish smoking, consequently leading to large post-harvest losses. To minimize future losses, urgent efforts are required to institute efficient use of wood fuel in fish smoking and to explore other preservation methods within local people's economic capability and technical capacity.

Fish smoking provides employment and income to a large proportion of the rural population in Tanzania hence efforts to sustain energy supply to the industry is an important contribution to socio-economic development of Tanzania.

Most of the fishing areas in Tanzania are isolated due to poor road network, consequently making transportation of fresh fish to main consumption areas a critical problem. Freezing and other modern fish processing facilities like ice plants and cold rooms are not available to the artisanal fishermen, who account for over 99 percent of the fish produced in Tanzania.

The process of fish smoking is usually in three phases, starting with preliminary drying at 30 to 35^{0}C kiln cavity temperature for 30-60 minutes. Opaque smoke is supplied to the kiln for the duration of this phase thus imparting the smoke compounds into the fish flesh. This is accompanied by slow drying in which the skin is toughened to prevent breakages and ensures that the pores on the skin of the fish will remain open for further accelerated evaporation in the subsequent phases.

Preliminary drying is followed by partial cooking sometimes accompanied by smoking. The precise temperature and duration for this phase depend on the product desired and the type of fish. Table 1 indicates that the kiln temperature can range between 50 and 80^{0}C for the three sources indicated. During this phase, the fish tissue is partially cooked and sterilized while hydrogen bonds are broken to free water molecules for evaporation in the subsequent phases.

Finally the process ends with a cooking and drying phase. The temperature and duration for this phase depend on the desired product, fish species, size and the nature of the fish flesh.

Data presented in Table 1 indicates wide variation on the duration for

each phase and to a lesser extent on the kiln temperature. This may be attributed to the difference in the requirements to be met on the final product. One can conclude that the preliminary drying phase must be done at 30 to 35 ^{0}C with the duration adjusted to suit the required end product. Similarly the partial cooking phase may be performed at temperatures between 50 and 80 ^{0}C with 80 ^{0}C being favourable where higher degree of drying and cooking is required. The final phase may be at a temperature between 80 and 105 ^{0}C. The durations for the last two phases are to be adjusted in a similar manner to that of the first phase.

The rate of uptake of smoke is proportional to its concentration. It is also directly proportional to the rate of water evaporation from the fish, which in turn is dependent on the velocity and to some extent on the humidity of the smoke, (Storey, 1986). It follows from this that the smoke must have a certain velocity through the kiln or where recirculation is employed the smoke must be exhausted periodically. However, during the preliminary drying the rate of evaporation has to be selected to ensure proper toughening of the skin and prevent blockage of the skin pores.

Measurements made on the existing practice reveal that processing of a batch of fishes extends over two days. Table 2 shows the different identified stages and their measured duration. Initially the drip dried fish are carefully arranged on the wire gauze of the kiln such that one side will be in contact with the hot gases from the fire chamber Care is required to ensure that the loading does not block the passage of hot gases from the fire chamber past the fish. This is followed by loading of fuel wood into the fire chamber The amount is estimated such that it will last for the duration of the first drying. Firing is done using smoldering wood from other fires and small thin pieces of wood. This marks the beginning of the first drying stage.

Except for the overnight drying, flames in the fire chamber have to be kept below a height of 0.3m from the base of the fire chamber Control is achieved by spreading the burning fuel wood in the fire chamber thus reducing the flame height.

At the end of the first drying stage, flame is put off leaving smoldering wood in the fire chamber. This will provide convenience in turning the fish so that the other side faces the hot gases from the fire chamber Flames are then allowed after loading the fire chamber with fuel wood. The amount

loaded should be enough for the second drying stage.

Table 1 Temperature and duration for different smoking phases

Source	Prel. drying		Partial cooking		Cooking & drying	
	Temp (°C)	Time (min)	Temp (°C)	Time (min)	Temp (°C)	Time (min)
1	30	30 - 60	50	30 - 45	80	-
2	35	240	70	240	75 - 80	180
3	30	-	≥80	-	≥80	-
4	30	45 - 60	80	60	105	≥ 60

- indicates that information was not published

Source: 1 Torry advisory note no. 82, 2 Kirenga et.a.l 1983
3 Storey 1986 4 Kunduchi Fisheries College, 1994

Table 2. Existing Kiln operation stages

S/No	ACTIVITY	DAY	DURATION
1	Smoking and Pre-cooking (First drying)	1	90 ± 10 mins
2	Side Change	1	10 mins
3	Pre-cooking Final cooking (Second Drying)	1	90 ± 10 mins
4	Overnight Drying	-	10 ± 2 hrs
5	Third Drying	2	6.5 ± 1 hrs
6	Overnight Drying	-	7.5 ± 2 hrs
7	Fourth Drying	3	≥12 hrs
8	Fish cooling.		≥12 hrs

For all the overnight drying a smoldering log is placed in the fire chamber This is selected such that it will be enough for the duration of this stage. The selection of the log and its placement in the fire chamber depends on the experience of the operator.

On the second day there will be fresh fish to undergo first and second drying. Where space is enough the fresh fish are processed on one side of the kiln with separate fire while those from the previous day undego third drying on another side of the kiln. The duration shown on Table 2 is for such an arrangement. Where more than one kiln is available, the processing can be done separately. In cases of a small kiln the fish from the previous

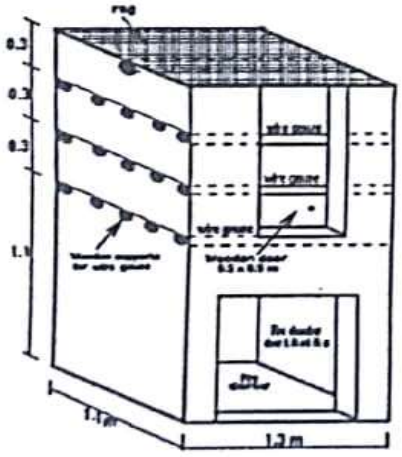
day are arranged on top of the fresh ones on the kiln and dried together

On the third day the fish are sorted to separate fully processed fish from partially dried ones. Those partially dried undergo the fourth drying stage while the rest are stored.

It is evident from the stages described that drying has more priority over smoke impaction. In some places, after the drying stage a batch of smoked fish is covered with sisal bags to trap more smoke which enhances darkish coloration.

Excessive heat treatment can impair the nutritional value of fish proteins. Besides, in dried fish lower moisture content has been observed to favour lipid oxidation which is a favourable process, while higher moisture content renders the fish susceptible to damage by blowflies and their lavae, a process which renders the fish inedible..

EXPERIMENTS



Parameters to be studied were selected following observations made on the current smoking practice. These are in three main categories. The first is process control which included fire management, phase durations, fish and gas temperatures and the fuel used. Fish preparation and handling formed the second category for which only two parameters namely brining and drip drying duration were studied.

Fig. 1: Fish smoking kiln

Parameters directly related to the fishes gave the third category These included the quality of the fish before and after smoking, fat content (fat/ lean), size of fishes, shelf life and customer preference.

Figure 1 gives a sketch of the kiln used in the study It is similar to the Altona type of smoker except for slight variation on the dimensions. It was selected because of its increased hot gas residence time and also

improved taping of the heat energy from the combustion products by passing them through successive layers of fish. It has a wall thickness of 15 cm, a length of 1.3 m, width of 1.1 m and a height of 2 meters. Other dimensions are as indicated on the sketch.

For the construction concrete blocks were used. The kiln had four trays of wire gauze on which the fish were loaded. Its capacity was 40 kilograms of fish (landed weight) or 28 kg of drip dried fish. This is equivalent to about 200 to 300 table size fishes.

Sisal bags were used to cover both the top and the kiln doors.

The use of sisal bags on the fire chamber door did pose a safety risk in that fire wood in contact with the bag as well as large flames close to the bag may ignite it with catastrophic results. This can be avoided by constant monitoring of the burning wood and control of the associated flames which is vital element of fire management.

Weights were measured using a spring balance with a range of 0 to 50 kg with a readout accuracy of 0.5 kg. Temperatures, wind speed and relative humidity were measured using a Testoterm 4510 anemometer with digital readout for temperature, relative humidity and wind velocity. Type K thermocouple probes were used for temperature measurement with a range of -120 to 1370 ^{0}C. A humidity probe with a range of 2.0 to 98% was used for the measurement of ambient relative humidity. A vane type of anemometer probe, which was part of the Testoterm 4510 was used for measurements of wind speed. This had a range of 0.4 to 40 m/s. Except for the thermocouples the other probes could not withstand the hazardous conditions inside the fish chamber thus preventing the measurement of gas velocity and relative humidity.

An immersion brinometer graduated at 1% and covering the range 0 to 100% was used for the preparation of brining solution. Wood moisture content was measured using a Bollmann wood moisture meter with digital readout.

The weight of fish was measured and recorded on landing, after dressing, after drip drying and finally after smoking. Gas and fish temperatures were measured 45 minutes after the start of each process phase. Measurements

were done at two locations, i.e at one corner and at the center Same locations were used for all the studies.

For each experiment, an amount of wood estimated to be more than enough was weighed and recorded prior to commencement of the smoking process. During the process all fuel wood requirements are met from this pile and on completion the remaining wood is weighed and recorded.The difference between the two was considered to be the weight fuel wood used.

EXPERIMENTAL RESULTS

Three experiments were conducted with emphasis on preventing flames and sometimes spreading the fire to reduce its intensity These resulted into an average wood fuel consumption of 2.0 kg per kilogram of drip dried fish. Existing technology had indicated an average consumption of 2.2 kg/kg. It was with this observation that it was decided to couple fire management and the recommended temperatures for each process phase.

The intensity of the fire was controlled by either spreading, reducing or increasing the amount of burning wood or sand quenching of flames, such that fish temperatures were within ±10°C of the recommended value. With this arrangement the average wood consumption was reduced to 1.14 kg of wood per kilogram of fish (drip-dried weight). Further, it was observed that with the mentioned fire management, whether the fire was spread over the fire chamber floor or concentrated at the central area of the same did not affect the fuel wood consumption. In addition to reducing the wood consumption the instituted fire management improved the quality of the product. This was reflected in the appearance and taste of the smoked fish.

While performing the above mentioned experiments, sisal bag covers were found to play a significant role. This initiated a need to asses their effect by having an experiment with conditions similar to those observed above but with all the covers removed from the kiln. This was done and wood consumption of 3.26 kg per kilogram of drip-dried fish was recorded.

Three drip drying durations of 30, 60 and 120 minutes were investigated. An immediate observation was that for the 120 minutes duration the fish tended to become stale before being loaded into the kiln for smoking. On table 3 some of the measurement are presented for a fixed process duration

of 4.5 hours (1 hour smoking, 1 partial cooking, 1 cooking and 1.5 hours drying).

Table 3 Results of experiments on drip drying duration

No	Drying [min]	Drip Dry [kg]	wt loss [kg]	% weight Loss	Wood Use [kg]	wood/ fish wt
1	30.0	20.5	12.0	58.5	27.0	1.32
2	60.0	22.5	12.7	56.4	30.2	1.33
3	120.0	16.3	10.2	62.6	24.0	1.48

The drip dried weights of fish are different and for the three runs the ratio of weight of wood used to the weight of drip dried fish is a measure of performance which takes into account this difference. Percentage weight loss which is a measure of the extent of evaporation is different for each experiment. To account for this it is assumed that the wood consumption is a linear function of the percentage weight loss between losses of 56 and 63 percent and one may take 56.4% as the reference. Using this to adjust the ratio of weights of wood to fish the new values will be 1.27, 1.33 and 1.33. It follows from this that dripping for 30 minutes reduces fuel consumption by 4.5% while durations of 60 to 120 minutes do not indicate a change in fuel consumption. This observation may be related to the change in the skin of the fish. If drip dried for long duration the skin tends to shrink (toughen) which reduces to small extent the rate of water evaporation from the fish flesh at the early stages of the process.

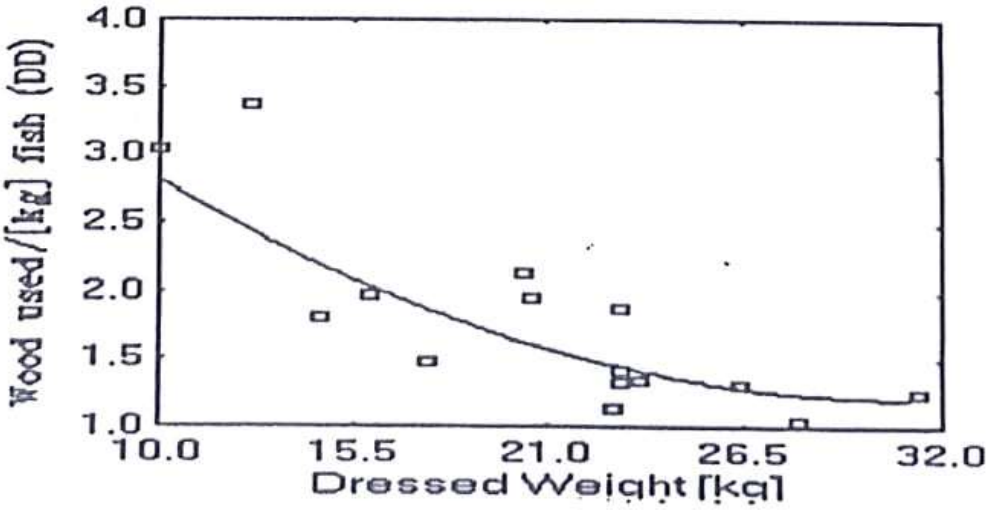


Fig 2: Wood used vs weight loaded

Analysis of the experimental results reveal that the performance of the kiln is highly sensitive to the weight loaded compared to the kiln capacity Figure 2 shows the observed wood per kilogram of drip dried fish as a function of the loaded weight. The experimental values are represented by the squares while the curve is a least square fit. Thirty (30) kilograms of dressed fish was the kiln capacity. As the loaded weight is decreased to 23 kilograms of dressed fish a slow increase in wood consumption is observed. Below 23 kg a rapid increase in fuel wood used with decrease in loaded weight is observed. This suggests that for efficient use of wood fuel this particular kiln must be operated with loads of dressed fish above 23 kg (above 76% capacity).

Figure 3 presents results of the variation of the wood used per kilogram of drip-dried fish with the number of fish pieces loaded into the kiln. Again the squares are the experimental values while the solid curve is a least square fit of the points. The figure indicates a linear decrease in the fuel wood used with increase in the number of fish pieces loaded. Since the kiln capacity is limited, a large number of pieces loaded is a direct indication that the individual pieces are small in size. Based on this and fig. 3 there is an indication of a decrease in fuel wood used with decrease in the size of the fish.

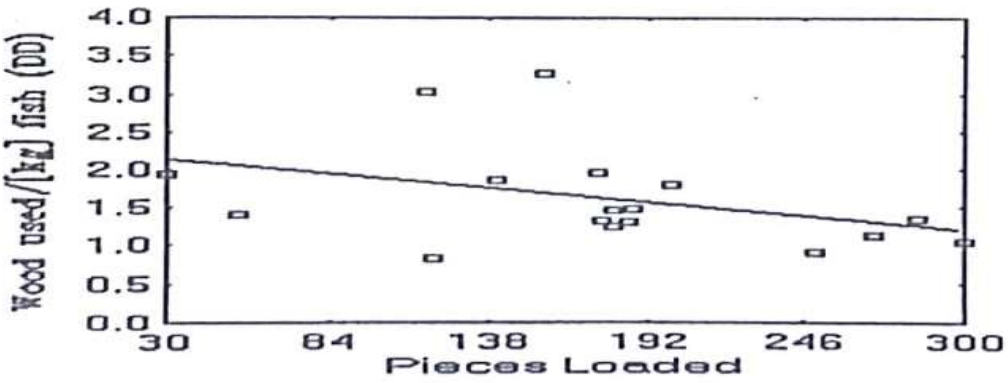


Fig. 3: Wood vs pieces of fish loaded

Normally lean fishes are the ones smoked. In this work fatty fishes were smoked to assess their impact on the amount of wood fuel used. The observed fuel wood consumption was 1.41 kg per kilogram (drip dried) of fatty fish, as compared to 1.05 kg/kg (drip dried) for lean fish. This difference supports the theory that fatty flesh tend to dry at lower rates compared to lean flesh thus requiring more time and hence more fuel.

The amount of wood used for the different phases of the process was measured for some of the experiments. Similarly the weight of a selected group of fishes were recorded. It was observed that the first three phases i.e smoking, partial cooking and cooking each consumed twenty percent of the total fuel wood used for the whole process while the drying phase consumes the rest. Further, 15.7% weight loss occurred during the smoking phase, 17.3% in the partial cooking phase, 11.6% in the cooking phase and 19.7% in the drying phase. Although the first three phases use equal amount of fuel wood, 24.4% of the drying was observed to occur during the smoking phase, 26.9 percent during partial cooking, 18 percent in the cooking phase and 30.6 percent in the drying phase.

Through fire management the process duration, (from start of smoking to end of drying), was reduced to 4.5 hours without alteration of the process phases. It was observed in one run that the partial cooking was at temperatures as high as those of the cooking phase but the quality of the end product was still very good. From this observation an experiment was designed in which the partial cooking and the cooking phases were combined and performed at the cooking temperature. A period of one hour was found to be adequate for the combined phase with the same result. This observation resulted in a further reduction in the process time to 3.5 hours.

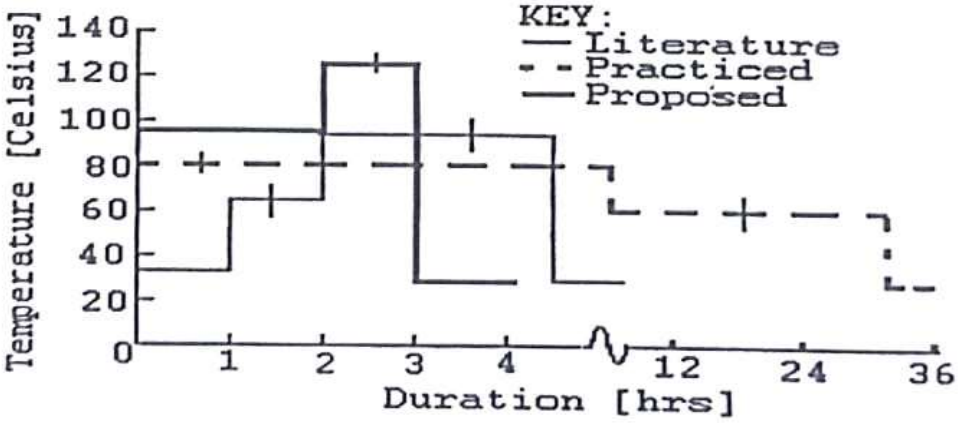


Fig. 4 Processing cycles

Further reduction was achieved through a critical assessment of the drying phase. A large portion of this phase is accompanied by the falling rate of evaporation. This implies that the moisture content of the final product is not very sensitive to drying duration. It was decided to perform an

experiment in which the drying duration was reduced by 30 minutes from 90 to 60 minutes. The result was an average percentage weight loss of 64% which is close to 65.2% the maximum recorded in measurements carried out on selected fish smokers. From this observation the drying duration was reduced to 60 minutes. The final durations for the different phases are 60 minutes for smoking, 60 for combined partial and final cooking and 60 minutes for the drying phase. Figure 4 compares the different processing cycles indicating the average gas temperature and the duration for the different phases.

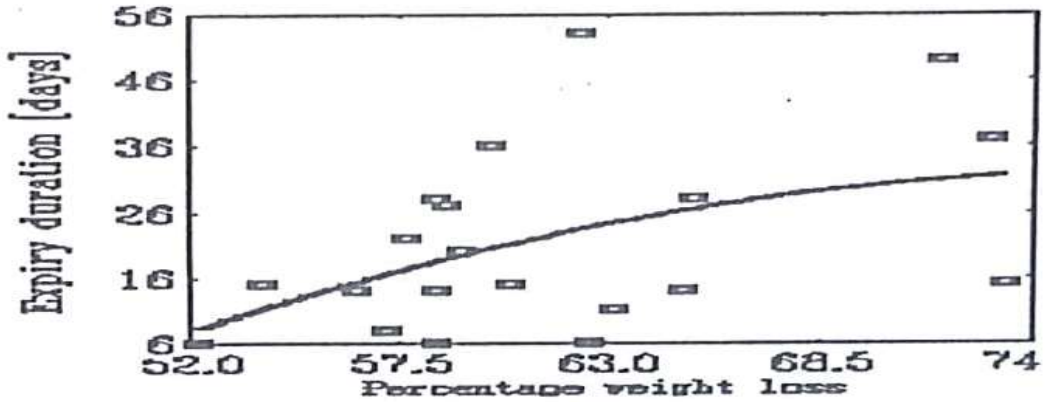


Fig. 5: Shelf life

The influence of brining on the fuel wood consumption was investigated by varying the concentration of the brine solution from 0% to 20% in steps of ten. No significant change in the fuel wood consumption was observed.

An attempt was made to assign a value to the shelf life of the smoked fish. An accurate assessment of the extent of spoilage of the fish proved to be too expensive and could not be effected by the project. As an alternative samples from each smoked batch were shelved and the time taken for visible fungal growth to be noticed was recorded as a measure of the shelf life of the sample. Percentage weight loss through the smoking process was used as a measure of the dryness of the final product. The shelf life of the fish increased with decrease in moisture content of the product, (figure 5). The squares represent the measurements while the solid curve is a third order polynomial fit. It is evident that the shelf life increases with increase in weight loss which indirectly is a measure of the moisture content of the product. An almost linear increase is observed between 52 and 65 % moisture content. Beyond 65 % the rate of increase decreases with weight

loss. This signals diminishing returns when the weight loss is above 65%.

In addition to shelf life being improved through drying, brining was also observed to have a significant influence. Samples with no brining recorded an average shelf life of fourteen days while those treated with 10% brine recorded an average of twenty days. Brining with 20% brine increased the shelf life to 53 days. This highlights the importance of brining in increasing the shelf life of smoked fish. Unfortunately the 20% brining was not favoured by smoked fish consumers because it was considered too salty. But a number of consumers suggested soaking the fish before cooking to reduce the salt content.

CONCLUSIONS

The ratio of the loaded weight of fish to the kiln capacity has considerable influence on kiln performance. Below 0.75 the wood consumption increases rapidly with decrease in the ratio.

Drip-drying duration beyond 30 minutes does increase slightly the fuel wood consumption. This limit may vary from site to site because the drying is affected by ambient temperature, relative humidity and wind speed.

Small fishes do dry quickly compared to large ones. Where possible fish splitting must be encouraged in order to reduce wood fuel consumption. Smoking fatty fish is not recommended because of the resulting high fuel consumption.

The duration of the smoking process, not including cooling phase, can be reduced to 3 hours by combining the partial cooking and the cooking phases with a kiln temperature corresponding to the cooking temperature. This will provide a reduction of 1 hour. An extra 30 minutes reduction is achieved by reducing the drying time by the same. The resulting time distribution is one hour for each of the three phases exclusive of the cooling phase.

Drying increases the shelf life of smoked fish and this is augmented by brining.

REFERENCES

1. Storey, R. M. Food processing and preservation lecture notes University of Leeds, 1983.
2. Storey, R. M. The technology of traditional smoking Proceedings of IFST South Eastern Branch mini symposium on smoked foods, 1986.
3. J. Kirenga, J., Matipa, R. and Bandula, D. D. Hot smoke-drying of fish using drum type oven FAO/DANIDA workshop on fish technology and quality control Mwanza, Tanzania 1983.

The manuscript was received on 4th October 1996 and accepted for publication after correction on 16th December 1996.