Effects of Processing on the Quality of Salted-Dried Fish of Different Species

NORYATI ISMAIL

School of Industrial Technology
Universiti Sains Malaysia, Penang, Malaysia

Abstract

The quality of salted dried fish processed under certain processing conditions were compared. Similar parameters used in the production gave different quality products. Salt uptake was very rapid and highest in shark (Notogaleus rhinophanes) followed by morwong (Nemadectylus macropterus) and sardine (Sardinops neopilchardus). Lightly salted products were preferred in all species ($p<0.01$). However, drying conditions affected different drying rates and product quality. Squid attained the highest drying rates amongst all species and at 50°C its rate was the highest followed by shark, morwong and sardine. A drying temperature of 50°C gave a compromise between product quality and drying rates. The effects of processing were demonstrated by the decrease in protein solubility, disappearance and decreased intensity of some bands in the IF pattern of water soluble proteins. Thermal studies by Differential Scanning Calorimeter on the muscle showed that shark, threadfin bream and sardine had two endothermic peaks in their thermogram while squid had three peaks at 37, 43 and 80°C. The effects of salting and drying on the myosin (146-150°C) and actin peaks (72-80°C) were manifested either by the disappearance or decreased peak areas (DHD) and T_{max} of the peaks. But changes in in vitro protein digestibility and amino acid contents were not significant. Changes in pH and total volatile bases were also studied. Scanning Electron Microscopic examination of the fish tissues showed the effects of disruption due to salting and the reduction in compactness due to drying.

Introduction

Salted fish processing started in antiquity (Cutting, 1955, 1962; Kruezer, 1974). However it persists till today for reasons of preservation, in parts of the world where infrastructures of transport and handling are poor, as well as a speciality product where the lightly cured product, such as Gaspe cure is a big business. This is in contrast to its earlier image which is exemplified by a quote from Cutting (1955) that "they are left in a condition that demands the greatest efforts by the stomach to extract the food value from the fibrous masses". In Asia where consumption is the highest, dried salted fish is also an important source of low-cost dietary protein (Poernomo *et al.*, 1992). However, much is left to be desired in terms of quality. The properties and stability of any salted dried fish depends very much on the final moisture and salt content. Many processors disregarded these criteria, aiming instead for greater yield at the expense of high moisture content in the product.

Each country has its own standard as to the amount of salt and moisture desirable in their products (Tapiador & Carroz, 1963). Levels of salt in the products vary enormously. For example, salted herring may range in salt content from 16-35% depending on the method of salting, the ratio of salt to fish, the condition of the fish at the time of harvest and the chemical composition of the salt used (Voskressensky, 1965). In Asian countries where most of the processing and trade in salted dried fish takes place the problem of incorrect moisture and salt content is widespread and accounts for heavy losses of the products (Zain & Yusuf, 1983). Despite established standards, Sripathy (1983) reported that the majority of market samples do not conform to any of the specifications; this was also observed by Gopakumar and Devadesan (1983).

This paper will compare the quality of different species of salted dried fish which were prepared under specified conditions. The effects of the processing conditions on the chemical properties of the product will also be discussed.

Materials and Methods

1. Processing conditions

Four types of fish were bought fresh from the market; threadfin bream or morwong (*Nemadectylus macropterus*), shark (*Notogaleus rhinophanes*), sardine (*Sardinops neopilchardus*) and squid (*Nototodarus gouldi*). Filleted threadfin bream, shark and whole sardines were immersed in saturated brine with a fish/brine ratio of 1:2 (w/v) at controlled temperature (26±2°C) over a period of time. Fish were removed at intervals.

One lot was taken for drying and another for analyses. For the drying studies, the fish were dried at a range of temperatures from 30°-70°C in a custom-made tray dryer at ambient relative humidity. No attempt was made to control the relative humidity. Squid, without salting, was also dried at these temperatures. The wet bulb temperatures were recorded. Weight losses were monitored by weighing at suitable intervals.

2. Analyses

Fish were analysed at regular intervals during salting for salt uptake and moisture loss. Total volatile bases in the fish were examined at all intervals. Effects of salting and drying on the properties of protein such as solubility, digestibility and its total amino acid content were examined. These were followed by isoelectric focusing technique as well as thermal studies. The structural changes in the product was examined by a scanning electron microscope. The products were subjected to reconstitution and quality evaluation by a panel of taste testers.

3. Analytical Procedures

a. Moisture content was carried out by the vacuum oven method.

b. Sodium chloride was determined by titration with silver nitrate (FAO, 1981).

c. A_w was determined on the Novasina AG Hygrosensor (Model en ZFBA - 3(4) EPP) with an A_w range of 0.1-1.00.

d. Total volatile bases (TVB) and trimethylamine (TMA) were determined by steam distillation of a trichloroacetic acid extract of the sample under alkaline conditions followed by titration with 0.005M sulphuric acid.

e. Solubility studies were conducted according to Obanu *et al.* (1975a).

f. Isoelectric focusing (IEF) in the pH range 3-10 on agarose gels was used to examine the effects of processing conditions on protein extracted from the fish tissue. The procedures for gel preparation, running conditions, fixing, stain and destaining were as described in 'Isoelectric focusing, Principles and Methods' by Pharmacy Fine Chemicals. A Pharmacy flat bed electrophoresis it BE-3000 and a constant power supply PCPs 2000/300 were employed throughout.

Samples were prepared for IEF by mixing 2g of the previously ground sample with 18 ml distilled water for 10 min. on a magnetic stirrer. The unfettered solution was dialysed against distilled water at 5°C for 24 h with five changes of water to remove salt. The dialysed solution was centrifuged at 0°C, 9000xg for 1h on a Damon/IEC refrigerated centrifuge model b-20A. The supernatant was kept refrigerated for no longer than 2 days prior to IEF.

g. Scanning Electron Microscopy (SEM)

Samples were freeze-dried and kept in a dissector prior to examination by scanning electron microscopy (SEEM). Representative surface areas and deep tissues were placed onto double-sided adhesive tape on aluminium stubs. The samples were coated with gold using a vacuum evaporator type Gee-4B (Electron Optics, Japan). The coated samples were viewed under a scanning electron microscope model ISI-100 International Scientific Instruments), fitted with an environmental cell modification, at various magnifications. Representative areas were photographed.

h. Differential Scanning Calorimetry (DSC)

Analysis was performed on Du Pot Series 190 Differential Scanning Calorimeter. This instrument was calibrated using biphenyl, AR grade. Approximately 10 mg of accurately weighed samples were sealed in a volatile sample pan. A sealed empty pan was used as a reference pan. The samples were scanned at a heating rate of 10K/min over the range 274-374 K at an instrument sensitivity of 0.05 mcal/sec. Peak transition temperatures were taken as peak maxima (T_{max}).

Results and Discussion

1. Processing factors

a. Salt Uptake and Moisture Loss

During brining salt penetrates the fish flesh with accompanying loss of moisture. Under ideal conditions salt uptake will continue until salt concentration in the aqueous phase of the tissue becomes equal to that in the brine. Factors such as brine concentration, time in the brine, temperature and size of fish will influence salt penetration (Graham *et al.*, 1986). Figs. 1 & 2 demonstrate the inverse relationship between salt uptake and water content during brining. Rapid rate of salt uptake is observed in the first 12h. This was similarly observed by Poernomo *et al.* (1992). Shark attained the highest salt content amongst the three species, possibly because of its coarser fibres (Ronsivalli, 1978) and large surface area. This is followed by morwong fillets (length 19.7 ± 3.6 cm,

max. thickness 1.4 ± 0.4 cm) which also presented a large surface area although salt uptake was restricted by skin on one side of the fillet. It's thickness would also slow down salt uptake (Crean, 1961) reaching equilibrium only after 8h when it contained 12% (wb) salt and 69% moisture. Both rate and total salt uptake for sardine (Fig. 1) were lower than for morwong and shark. The two observations could perhaps be explained by the following reasons: (a) because sardine was salted whole, therefore its skin would act as a barrier between the muscle and the brine thus slowing down the salt front, (b) being a fatty fish the fat content can act as a barrier to both the entry of salt and the withdrawal of moisture, (c) sardine protein is characterised by its low pH after death; when very fresh, 20-30% of its myofibrillar protein is already denatured, losing some of its water (Suzuki, 1981). Thus being in this state, it may not be able to absorb as much salt. These factors acted in combination to result in a slower rate and lower uptake of salt.

Fig. 3 shows that moisture loss is rapid in the first 12h. It is least in morwong followed by shark and then sardine. Although sardine started out with the lowest initial moisture content (Fig. 2; 74.5%) amongst all the three species, it showed a higher loss of moisture than the other two species (Fig. 3). Its salt uptake was also the least among all the three species (Fig. 1). This could perhaps reflect a specie-specific characteristic, which is related to its water holding capacity, which in turn is dependent on its post rigor conditioning.

b. Drying Rates

Each species of fish, except for squid, were salted to its equilibrium value under the given conditions and were subjected to drying studies at temperatures between 30°-70°C. In each study (Figs. 4-7) the rate of drying was obviously faster ($p<0.01$) at 70°C than at other temperatures. This was followed by 60°, 50°C and lastly by 40°C and 30∞C which in most cases were very similar with each other. When comparing the drying rate profile, temperature by temperature, for each species, sardine dried slowest. The presence of skin and its fat content could contribute to the slow drying rates. On the other hand the drying rates for squid were high at all temperatures, with that at 50°C significantly higher ($p<0.01$) than at other temperatures. Although rates are generally highest when drying at 60° and 70°C, the products obtained were often of burnt appearance, with brittle texture and the appearance of salt crystals visible on the surface.

When comparing the rates of drying at 50°C (Fig. 8) squid was seen to dry significantly faster at 50°C ($p<0.01$) compared to all the other fish. This is presumably because the squid were cut open and laid flat exposing a large surface area for a small volume (the mantle thickness ranged from 0.4-0.8 cm); high rates of drying resulted at all temperatures. Shark had the second fastest rate, drying significantly faster ($p<0.01$) than sardine and morwong. The large surface area and the fibrous nature of shark meat encouraged fast drying. Even though morwong presented a large surface area for evaporation, its drying rate at 50°C is the second slowest, although still significantly faster than sardine. This is presumably because of the presence of skin on one side of the fillet, restricting drying from occurring from this side. Furthermore salt content in morwong is high (40%, db) and as reported by Waterman (1976), this would slow down drying rate.

Although a drying temperature of 43°C was reported to be suitable with an inlet RH of about 45-50% giving a good product (Waterman, 1976) in tropical countries, 50°C is considered the optimum temperature for all the four species in this study after considering both product quality and rates of drying.

2. Chemical Analyses

a. Effect of salting on pH

During salting, pH was observed to decrease steadily from its initial value in the first 4h after which its value seemed to rise ever so slightly till the 8th hour and then remained more or less constant till the end of the salting period (Fig. 9). In shark, the leaching of urea into the curing brine, as much as 71% at the end of brining in some cases (Yang *et al.*, 1981), may contribute to the drop in pH. Kida and Tamoto (1969); and Regenstein *et al.*, (1984) have also demonstrated that when fish are in a medium containing sodium chloride or potassium chloride, reduction in pH will also be accompanied by the loss of water holding capacity.

A slight rise in pH during the course of salting may indicate development of bases possibly due to microbial degradation, which would be limited by the salt concentration higher than 12%. This concentration was only attained after 8h salting. Malle, Eb and Taillez (1986) found that the high pH in a culture medium used to study the level of contamination in fish muscle with 10% salt in the aqueous phase of the fish was sufficient to start the denaturation (Beatty and Fougere, 1957).

b. Effect of salting on TVB and TMA

In sardine and morwong, both TMA (Fig. 10) and TVB (Fig. 11) were observed to increase in the first 4h of salting. The rise observed in sardine, for both TVB and TMA, were higher than in morwong. The initial rise may be due to microbial degradation before the fish could acquire the necessary salt concentration to retard spoilage. At least more than 5% salt was required to retard the formation of TMA in mackerel homogenates (Ishida *et al.*, 1976). Besides, dark-fleshed fish is noted for higher contents of TMA than white-fleshed fish (Suzuki, 1981) and it also contains enzyme to reduce TMAO to TMA. After the initial rise the TVB and TMA contents decreased gradually till the end of salting.

In shark, the TVB content decreased rather sharply in the first 8h from 73 mgN/100g to 42 mgN/ 100g and it continued decreasing and levelling off till the end of salting. These decreases are attributed to the leaching of amines into the brine (Gordievskaya, 1973), including urea, which is broken down by urease to ammonia and is also leached into the brine on salting (Zaitsev *et al.* 1969). Similar observation was made by Yang *et al.* (1981). A similar trend was observed for TMA.

c. Effect of drying on TVB and TMA

TMA and TVB content in all the fish (Figs. 12, 13, 14) were found to increase on drying, more so at higher temperatures. These results concur with previous observations on development of amines in dried products (Spinelli and Koury, 1979; Hebard *et al.*, 1982). This increase was attributed to the instability of TMAO to heat (Sigurdson, 1947; Nakamura *et al.*, 1985), whose rate of decomposition varied with species (Tokunaga, 1975) and whose development is greatly affected by the rate of drying and the processing conditions (Spinelli and Koury, 1979) apart from being much greater in dark-fleshed fish than in white-fleshed fish.

3. Effect of Processing

a. Protein Solubility

Effect of Salting on Protein Solubility

Protein solubility decreased during brining. Solubility is very poor in KCl at 25°C but it improved slightly at 77°C (Figs. 15 & 16). Meinke *et al.*, (1972) observed similarly. Although as much as 50% extractable protein in shark has been reported by Waller (1980), the solubility observed in this study is much lower (Fig. 17); the extractability of sardine protein is the lowest (Fig. 16). Poor solubility was expected as Duerr and Dyer (1952) observed that when fish muscle was immersed in concentrated brine, the total myofibrillar protein rapidly became inextractable. When the average salt content reached 10%, i.e. when the concentration of the electrolytes reaches 2M, there is a decrease in bound water and a change in hydration which may result in precipitation (Kinsella, 1982). However this will not happen throughout the fish tissue until salt penetration is complete, i.e. at about 10% (wb) salt content (Crean, 1961). Complete inhibition of the fish muscle proteolysis occurs at 12% NaCl (Bilinski and Fougere, 1959). When the proteins have denatured, extraction by solubilising agents such as the ionic detergent, SDS, is necessary to dissolve the proteins. Solubility in SDS+b mercaptoethanol was found to be high: 72% for morwong, 67% for shark and 61.5% for sardine at the start of brining and declined gradually till the end of salting. Generally the solubility in SDS+B mercaptoethanol is higher than in the two other extracting media used. This observation concurs with that of Rehbein and Karl (1985). The salt soluble fraction consists mostly of myofibrillar protein and some sarcoplasmic protein (Poulter *et al.*, 1985). The myofibrillar fraction is highly sensitive to changing conditions (Aitken and Connell, 1979). In sardine, about 20-30% of the myofibrillar proteins in unsalted sardine is inextractable due to physiological changes (Suzuki, 1981). Thus, further changes, such as salting out would cause reduction in water holding capacity of the proteins, which in turn become increasingly insoluble (Kinsella, 1982).

Effect of Drying on Protein Solubility

Howgate and Ahmed (1972) observed that the effects of heating and drying on the extractability of fish proteins differed between species. Generally, the solubilities in KCl at 25°C and in KCl at 77°C of fish dried at different temperatures were quite poor (Figs. 17, 18, 19, 20). The solubilities decreased when dried at higher temperatures. The solubilities of fish protein improved tremendously in SDS, but the solubilities also decreased with higher drying temperatures.

Decrease in solubility was observed by Migita *et al.*, (1960) in fish dried at 5-10°C. These workers reported that solubility of myofibrillar protein was lowered while the denaturation of sarcoplasmic protein took place slowly and its solubility was lowered slightly. Suzuki (1981) reported that the heat coagulative sarcoplasmic protein adhered to myofibrillar protein when fish is heated. This leads to insolubilisation of the latter. Actin is also soluble in KCl solution and is most probably not changed by low heating. However actin cannot be extracted

out if myosin becomes inextractable (Howgate and Ahmed, 1972). Parsons and Patterson (1986) and Poulter *et al.*, (1985) also observed decreases in protein solubility in heated fish samples. The denaturing effects of both salting and drying processes reduced solubility of the products perhaps by changes in the number and distribution of SH groups, formation of cross-linking S-S bands, aggregations, or even partial loss of hydration and interaction with other components (Sikorski *et al.*, 1976). All these could contribute to the loss of protein solubility deserved in this study.

b. IEF

After brining

Figs. 21, 22 and 23 shows the IEF patterns of water-soluble proteins extracted from morwong, shark and sardine respectively. Six major bands each were observed in morwong and shark and about seven were observed in sardine. As brining time increased the intensity of most bands decreased, even more so in sardine. Only the very anodic and some cathodic bands persist. In shark and sardine some secondary bands were observed to appear in more cathodic positions. However, some bands appeared unaffected by the brining process such as band E and F in morwong and also E and F in shark.

After drying

Figs. 24, 25, 26 and 27 clearly demonstrates the effects of salting and drying on the IEF of water-soluble proteins of morwong, shark, sardine and squid. It can be seen that most bands start disappearing even at a drying temperature of 30°C. At higher drying temperatures almost all the bands have disappeared, except for a few which remain faintly visible even at higher temperatures.

c. Thermal studies

Thermogram of the fresh fish

Fresh shark meat has two distinct endothermic peaks in its thermogram (Fig. 28), the first and the smaller of the two displays a peak maximum (T_{max}) at 50° ± 2°C and the second and larger peak has a T_{max} at 72° ± 2°C. These represent thermal denaturation of the proteins. The thermogram lacks the basic three peak profile previously observed for fresh fish (Poulter *et al.*, 1985) and mammalian meat (Wright *et al.*, 1977) which were due primarily to transitions involving myosin (T_{max} 60°C), the second possibly due to sarcoplasmic protein transition at T_{max} 67°C and the third due to actin at T_{max} 80°C (Wright *et al.*, 1977). However there are fish species such as tilapia which display only two distinct peaks (Poulter *et al.*, 1985) whilst Davies *et al.*, (1988) working on intact muscle of cod and snapper noted that Peak II on the typical thermogram was not always present. Thus the first peak (T_{max} 50°C) in the shark thermogram could be that of both myosin and sarcoplasmic proteins, and the second peak (T_{max} 72°C) could possibly be actin.

Morwong also exhibited a two-peak thermogram (Fig. 29); the first has a transition temperature T_{max} at 46° ± 2°C and the second, larger peak has a T_{max} at 73° ± 1°C. Sardine on the other hand shows two very distinct peaks at 50° ± 1°C and 80° ± 1°C and a slight inflection at 32°C (Fig. 30) which may represent the transition of collaganeous material as the sardine sample was macerated whole.

Effect of salting on the thermogram of fish

The effects of salting on thermogram of fish proteins are shown in Figs. 28, 29, 30. In shark (Fig. 28) the transition temperature of the second largest peak (actin) decreased with increasing salting time from 72°C in the unsalted sample to 64°C ± 4°C in the 8h salted sample and 45°C ± 2°C in the 36h salted samples. Secondly, at longer salting times peak broadening was noted. The peak temperature of the first transition (myosin) also decreased to 46°C, and in the longer salted samples it disappeared altogether. The salt content in the unsalted, 8h and 36h samples were 3.1, 48.3 and 56.1% (db), and this, no doubt played a major role in changing the peaks. Ionic strength effects were proposed to be the causes of the changes observed (Quinn *et al.*, 1980), whilst Weinber *et al.* (1984) also showed that Cl destabilised the actin molecules.

Fig. 29 illustrates the effects of salting time on morwong protein. Transition temperature in both peaks decreased (from 73°-70°C for the first peak and 46° to 42°C) and peak broadening was also noted in the 4 and 12h samples. However, thermograms of the longer salted samples of morwong were poorly reproducible in terms of peak areas and temperatures. This is attributed in inhomogeneity of samples in terms of both moisture and salt contents.

Similar problems were encountered with longer brined sardines. After brining sardines were macerated whole, the T_{max} of the major peak were 80° and 64°C in the unsalted and the 12h salted sampled (Fig. 30) respectively, and these decreased substantially ranging from 41-55°C in the 24-48h samples.

Effect of drying on the thermogram of fish

Figs. 31-34 show the thermograms of morwong, sardines, shark and squid after drying. The general observation was that the first peaks that were seen in the thermogram of all the fresh unsalted fish were only observable in morwong and sardine samples which were dried at 30°C. They were absent in samples dried at higher temperatures and also in any of the other species examined. The second peak which was the major one (actin) was still observable in samples dried at 30-70°C. However as the drying temperature increased the peaks broaden and the peak area decreased in size. Changes in myofibrillar proteins start at approximately 50°C whereas denaturation of the sarcoplasmic proteins start at much lower temperatures (Hamm, 1966). Judging by the shape of the thermograms at the same drying temperature for all the species examined in this study, shark and squid seem to have experienced more severe effects of heat denaturation than either morwong or sardine. This is confirmed by the enthalpy (DHD) data in Table 1. Even though the samples contained different moisture contents decreasing DHD reflects the energy changed associated with protein denaturation during drying. Although squid dried faster at 50°C than the other fish species, the effect of heat treatment on squid was more severe than in the other species. Squid textural qualities change rapidly with increasing cooking temperatures up to 60°C (Otwell and Hamann, 1979b). This was associated with sarcoplasmic protein coagulation, destruction of myofibrils (Otwell and Hamann, 1979a) and thermal gelatinisation of the large amount of connective tissue in squid (Stanley and Smith, 1984). Parson and Patterson (1986) noticed a correlation between maximum heating temperature and the onset of denaturation, and that the length of heat treatment is reflected in peak areas of the thermogram. However, in this study it seems that heating temperatures gave smaller peak areas even though drying rate is faster at higher temperature and was conducted for shorter times. Duration of heating must affect the thermograms although this aspect was not investigated.

4. Nutritional implication

a. *In vitro* digestibility

Digestibility remained high throughout the salting period (Table 2) and changes in the digestibility over the salting period are negligible. Digestibility therefore was not negatively affected by salting. Table 3 illustrates the effect of drying temperature on *in vitro* digestibility of morwong, shark, sardine and squid. The digestibility ranged high between the fresh sample to the 70°C dried product. The digestibility of squid meat improved on drying. One possible reason for the improved digestibility is that the prepared squid meat was held at 3-5°C while awaiting drying. Self proteolysis may have occurred (Sikorski and Kolodziejska, 1976), leading to protein solubilities. Squid muscle contain proteinases, active at slightly alkaline pH and have maximum activity at 60°C (Rodger *et al.*, 1984a).

b. Amino Acids

Effect of salting on total amino acids

In all the three species of fish salted, variations in the amounts of individual amino acids was observed, however no trends were discernible. Most changes were not significant except for histamine in morwong ($p<0.01$) (Table 4). Histamine has been observed to form during curing of pickled sardine (Wada and Koizumi, 1986). In shark, a decrease in cystine was significant at ($p<0.05$). Decreases were also observed in glycine and histidine occuring in sardine although these were not significant. Lysine did not seem to have been affected at all and it appears that salting does not affect amino acid content. Salting up to 48h therefore does not incur significant nutritional damage to the proteins of salted fish. This observation concurs with that of Takama *et al.* (1985) who also found no effect on the amino acids during salting and pickling of *masu* salmon.

Effect of drying on amino acids

Drying did not adversely affect the total amino acid content in all the species. This concur with most previous reports (Tarr, 1962; Anon 1973; Aitken and Connel 1979). Yang *et al.* (1981) found no effect of drying at 105°C but at 170°C available lysine fell by 20%. Specific trends are not discernible in this study, however decreased are seen in cystine and lysine, both of which are known to be heat sensitive. Table 5 illustrate the effects of drying on amino acids in morwong.

5. Scanning Electron Microscopic Examination (SEM)

SEM was used to examine the appearance of the product during brining and drying. Plates la,b,c and d demonstrates the effects of brining on the structure of morwong flesh. As brining time increases, the surface is disrupted increasingly and more salt is evident. This trend continues with longer brining (Plates 2 a,b,). Corresponding SEM

micrograph of the deep tissue are shown in Plate 3. The fibres became more disrupted and greater quantities of salt are visible as brining time was increased (Plate 4). The disruption of the fibres could possibly be caused by withdrawal of water to the outside of the fibres, thus increasing salt concentration. This is turn could decrease water holding capacity and allow shrinkage of neighbouring fibres away from each other.

The micrographs of the surface and deeper tissues of fillets dried at 30°, 40°, 50° and 60°C are presented in Plates 5 & 6 respectively. Both series of micrographs indicate a decrease in compactness of the tissue structure as drying temperature in increased. This is reflected ultimately by the fragmentation of products dried at 60°-70°C during reconstitution. Decreased protein solubilities indicate some damage to the proteins in the dried products, and this is further echoed in the rehydration behaviour of the dried fish. Similar observations were made with shark, salted and dried at different temperatures and sardine. The SEM of squid showed that fresh squid have 'loosely' bound fibres which became bound or fused together at higher temperatures (Plate 7).

6. Quality Evaluation

a. Moisture and salt content

The stability of any dehydrated foodstuff is closely related to A_w rather than the total moisture content. A dry foodstuff will absorb moisture depending on ambient RH and also its intrinsic properties (Muslemuddin *et al.* 1984). Drying at 30° and often 40°C produced products with rather high moisture content and A_w of approximately 0.80. Morwong products dried at temperatures 50°C and above had reasonable moisture contents and their A_w are below 0.80. Growth of mould is inhibited at 0.80 and below whilst halophilic bacteria do not grow at 0.75 and below (FAO, 1981).

In Table 6, the predicted shelf life of morwong dried at 30° was only 1 week. The predicted shelf lives of products dried at 40°, 50° and 60° were 1 Ω - 2 months while that dried at 70°C was one year. Although microbial attack will be retarded at such low A_w browning reaction and lipid oxidation may be accelerated (Labuza *et al.*, 1970).

The moisture contents in dried salted shark (Table 7) varied between 26.8% (dried at 60°C) and 44.5% (dried at 30°C). A_w ranged from 0.65-0.72. The product was creamy white which was most attractive in products dried at 30°-40°C. However at 30°C the moisture content was high (44.5%). Drying at 50°C gave slightly yellowish products which were still quite attractive. Products dried at 60°C had a slight browning tinge while at 70°C, the products became brown. Similar colour changes were observed by Bose *et al.* (1958). The predicted shelf life for the shark products ranged from 1 week for the 30°C sample to longer than 2 months for the 60°C sample.

Commercial products of moisture content 30-35% and salt content of 16-17% were reported by Jinadatharaya and Vernekar (1979) to last less than 6 months.

Sardines dried at 30° and 40°C has an attractive appearance and did not suffer from severe shrinkage although some browning was apparent around the belly region. Products dried at 50°C were slightly more brown than those at 30° and 40°C. The browning was apparent along the belly and tail region on the central side. Browning was more severe in the 60° and 70°C dried samples (under the skin the meat also appeared brown), shrinkage was apparent and products had jarred texture. Table 8 shows the moisture content and A_w of sardines dried at different temperatures. The moisture ranged from 22.2% for samples dried at 70°C to 47.9% for those dried at 30°C. The A_w in the 30° and 40°C samples were >0.75. This means that the products required longer drying time to achieve microbial stability. Being a fatty fish the products are also liable to fat oxidation leading to rancidity and browning from lipid-protein reactions. Products dried at 50°, 60° and 70°C had A_w of 0.67-0.70 which were indicative of better microbial stability although still subject to rancidity problems. The products dried at 50°, 60° and 70°C were predicted to have shelf life of between 2-4 months and those dried at 30° and 40°C, because of high moisture and low, salt content, are expected to last only for a week.

The moisture content and A_w in squid products obtained were <15% and between 0.51-0.65 respectively. The products will therefore not have microbial problems unless they subsequently access moisture. It will also be prone to lipid oxidation although lipid is low in squid. With such figures for moisture content and A_w, the shelf life is predicted to be longer than a year.

b. Sensory evaluation

Irrespective of chemical or physical properties and storage life, organoleptic properties of a product determine its acceptability to the consumer. The production of dried marine products in this study involved a period of time in saturated brine (except for squid) and drying at various temperatures. Thus brining time and drying temperatures were individually examined for their effects on acceptability of the dried products. Lightly salted products, those salted for

2 and 4 hours were significantly preferred ($p<0.01$) over sample brined for longer times because of lower saltiness (Table 10).

Table 11 shows that aroma did not vary significantly with drying temperature for morwong. However, colour varied significantly with drying temperatures. The lightest coloured products were obtained by drying at 30° and 40°C and these were preferred over the other products. Texture scores did not vary significantly between drying temperatures. Based on colour preferences, drying rate and overall product quality appraisal, 50°C was chosen as a suitable drying temperature for morwong.

For shark the saltiness for the 2, 4 and 8h products did not differ significantly, although the mean scores were highest for the 4h product (Table 12). Samples dried at 70° and 60°C were significantly different in aroma to those dried at 50°, 40° and 30°C which were not significantly different from each other (Table 12). For colour, samples dried at 30° and 40°C had the highest scores and were significantly preferred ($p<0.01$) over the other samples. The 40°C sample scored the highest for texture, was not significantly different to the 50° and 60°C samples, but differed significantly from the 70°C sample. For overall acceptability, the 30°, 40° and 50°C samples scored the highest but did not differ significantly. They were however preferred ($p<0.01$) over the 60° and 70°C samples which were significantly different ($p<0.01$) from each other. Therefore based on acceptability, shark could be dried at 30°, 40° or 50°C but 50°C is chosen because of its faster drying rate.

Like the other two products, lightly salted sardines (salting time 2 and 4h) were preferred over the rest of the products on the basis of saltiness. The 8h product was ranked third and was significantly less preferred ($p<0.01$) to the 2 and 4h products. The 8 and 12h products were not significantly differentiated. Sardines brined for 8h were dried at 30°, 40°, 50°, 60° and 70°C to a moisture content of approximately 30%. Aroma did not vary significantly for these products (Table 13). The colour of the 30°, 40°, 50° and 60°C products did not differ significantly but 40°C differed significantly ($p<0.01$) from the 60° and 70°C products. Textures did not vary significantly amongst the products but for overall acceptability the 30°, 40° and 50°C products were significantly preferred ($p<0.01$).

Squid was fried in oil at 200°C for 2 min. and served to a panel of untrained assessors. Table 14 shows the mean scores for each attribute evaluated. There was no significant difference among the treatments for aroma, texture and overall acceptability. However the 30°C scored significantly less ($p<0.01$) for colour. Eventhough the 50°C sample scored the highest for colour, it was not significantly different from the others except for the 30°C and 40°C samples. The products dried at 50°C is recommended based on the high drying rate.

Conclusion

Different species demonstrated different rates and maxima of salt uptake during brining. However, no benefits were observed in lengthening the salting time beyond that required for maximum uptake, namely 8h for morwong and sardine and 4h for shark. The disadvantages of longer brining were demonstrated clearly in the poor appearance of salt encrusted products, evidenced visually as well as by SEM studies and by poor acceptance.

Drying temperature between 30°-70°C were applied to products salted for their optimum time. Squid was also dried without salting. A drying temperature of 50°C was found to be the best compromise between rate and product quality.

Overall effects of salting included a decrease in soluble proteins, a decrease in intensity and number of IEF bands and pronounced changes to the flesh structure as shown by SEM. Salting did not adversely affect either *in vitro* protein digestibility or amino acid levels. Drying had similar effects on the above parameters. Protein denaturation during both salting and drying was also exemplified in DSC studies of thermograms of the fish samples.

During salting there were also changes in pH and volatile bases, while during drying increase in volatile bases was also observed.

The products obtained from the above salting and drying procedures had sufficiently low A_w to ensure microbial stability; however, deterioration via browning reaction and oxidation rancidity could limit storage life.

The acceptability of freshly prepared products was limited by higher salt level, brittle texture and browning reaction products. In the product obtained using minimum brining times to reach maximum salt level and a drying temperature of 50°C, none of these factors were found to be a problem. Thus, on the basis of acceptability and nutritional considerations the above salting and drying conditions are recommended for production of salted dried fish products.

References

Aitken, A.D., and Connel, J.J. 1979. Fish. In: Effects of heating on foodstuffs. R.J. Priestley (ed.). London, Applied Science Publishers Ltd. pp. 219-254.

Anon. 1973. Expanding the utilisation of marine

fishery resources for human consumption. FAO Fisheries Report, No. 175.

Beatty, S.A., and Fougere, H. 1957. The processing of dried salted fish. Bulletin no. 112. Fisheries Research Board of Canada, Halifax, N.S.

Bilinski, E., and Fougere, H. 1959. The effect of sodium chloride on proteolysis and on the fate of amino acids present in muscle of codfish (*Gadus callarias*). J. Fish. Res. Bd. Can. 16(5) : 747-754.

Bose, A.N., Das Gupta, S.K., and Srimani, B.N. 1958. Studies on fish of the Bay of Bangladesh J. Sci. Ind. REs. XXVIII (part III) : 163-169.

Crean, P.B. 1961. The Light Salting of Cod. J. Fish Res. Bd. Canada. 18 (5): 833-844.

Cutting, C.L. 1955. Fish Saving: A History of Fish Processing from Ancient to Modern Times. Leonard Hill, London.

Cutting. C.L. 1962. Historical aspects of fish. In: Fish as Food. Borgstrom, G. (ed.). Vol. 2. Nutrition, Sanitation and Utilisation. Academic Press, New York, London.

Davies, J.R., Bradsley, R.G., Ledward, D.A., and Poulter, R.G. 1988. Myosin thermal stability in fish muscle. J. Sci. Food Agric. 45 : 61-68.

Duerr, J.D., and Dyer, W.J. 1952. Proteins in fish muscle. 4. Denaturation by salt. J. Fish Res. Bd. Can. 8 : 325-331.

FAO. 1981. The Prevention of Losses in Cured Fish. FAO Fish. Tech. Paper 219: 87 pp.

Gordievskaya, V.S. 1973. Shark flesh in the food industry translated from Russian by H.M. Mills, National Marine Fisheries Services, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce and the National Science Foundation, Washington, D.C.

Gopakumar, K., and Devadesan, K. 1983. The fish curing industry in India. The production and Storage of Dried Fish. Proc. of the Workshop on the Production and storage of dried fish. University Pertanian Malaysia, Serdang, Malaysia, 2 - 5 November 1982. FAO Fish Rep., 279 Suppl. by James, D. (ed.) : 63-69.

Graham, P.P.; Hamilton, R.S., and Pierson, M. 1986. Influence of brining procedures on salt content and distribution in smoked whitefish chubs. J. Food Processing and Preservation 19(4) : 295-309.

Hamm, R. 1966. Heating system. In: Physiology and Biochemistry of muscle as food. Briskley, E.J., Casens, R.G., and Trautman, J.C. (eds.) Univ. of Wisconsin Press, Maddison, WI.

Hebard. C.E., Flick, G.J., Martin, R.E. 1982. In: Martin, R.E. Flick, G.J. Hebard, C.E. Ward, D.R. (eds.) Chemistry and biochemistry of marine foods products. AVI Publishing Co. Westport. p 149.

Howgate. P.F. and Ahmed. S.F. 1972. Chemical and bacteriological changes in fish muscle during heating and drying at 30°C. Journal of the Science of Food and Agriculture, 23.: 615-627.

Ishida, Y., Fujii, T., and Kadota, H. 1976. Microbiological studies on salted fish stored at low temperature. I. Chemical changes of salted fish during storage. Bull. Jpn. Soc. Sci. Fish. 42(3):351-368.

Jinadatharaya Sri, Y.A. and Vernekar Sri, V.S. 1979. Modern method for curing and drying shark fish. Seafood Export J. 11(1):48 - 50.

Kida, K. and Tamoto, K. 1969. Studies on the muscle of aquatic animals. IV. On the relation between various pH values and organic acids of Nagazuka muscles (*Stichaeus grigorjewi* Herzenstein). Scientific Report of the Hokkaido Fisheries Experimental Station. 11:41-57.

Kinsella, J.E. 1982. Relationships between structure and functional properties of food proteins. In: Food Proteins; Fox, P.F., and Condon, J.J. (eds.) App. Sci. Pub. London and New York : 51-104.

Kruezer, R. 1974. Fish and its Place in Culture. In: Fishery Products by Kruezer, R. (ed.) : 22-47. Fishing News Ltd., London.

Labuza, T.P., Tannenbaum, S.R. and Karel, M. 1970. Water content and stability of low-moisture and intermediate-moisture foods. Food Technology May. 24:542-550.

Malle, P., EB, P. and Tailliez, R. 1986. Determination of the quality of fish by measuring trimethylamine oxide reduction. International Journal of Food Microbiology. 3:225-235.

Meinke, W.M., Rahman, M.A., and Mattil. K.F. 1972. Some factors influencing the production of protein isolates from whole fish. J. Food Sci. 37:195 - 198.

Migita, M., Matsumoto, J.J., and Suzuki, T. 1960. Bull. Jap. Soc. Sci. Fish. 26:925-930.

Muslemuddin, M., Wahed, M.A., and Khaleque, M.A. 1984. Influence of relative humidity on the moisture sorption characteristics of some dehydrated fish products. Bangladesh J. Sci, Ind. Res. XIX 1-4:37-45.

Nakamura, K., Iida, H., Nakamura, K., and Ishikawa, S. 1985. Studies on utilisation of shark meat I. Changes in chemical composition of shark meat during storage and processing. Bull. Tokai. Reg. Fish.. Res. Lab. 115:17-22.

Otwell, W.S., and Hamann, D.D. 1979a. Textural characteristics of squid (*Loligo pealei* Lesuer) : Scanning electron microscopy of cooked mantle. J. Food microscopy of cooked mantle. J. Food Sci. 44:1629-1635, 1634.

Otwell, W.S., and Hamann, D.D. 1979b. Textural

characterisation of squid (*Loligo pealei* L.) : Instrumental and panel evaluations. J. Food Sci. 44:1635-1643.

Parsons, S.E., and Patterson, R.L.S. 1986. Assessment of the previous heat treatment given to meat products in the temperature range 40°-90°C. Pat 2 : Differential scanning calorimetry, a preliminary study. J. Food Technol. 21:123-131.

Poernomo, A., Giyatami, Fawzya, Y.N. and Ariyani, F. 1992. Salting and drying of mackerel (*Restrelliger kanagurta*). Asean Food Journal. 7(3):141-146.

Poulter, R.G., Ledward, D.A., Godber, S., Hall, G., and Rowlands, B. 1985. Heat stability of fish muscle proteins. J. Food Technol. 20:203 -217.

Quinn, J.R., Raymond, D.P., and Harwalker, V.R. 1980. Differential scanning calorimetry of meat proteins as affected by processing treatment. J. Food Sci. 45:1146-1149.

Regenstein, J.M., Jauregui, C.A., and Baker, R.C. 1984. The effect of pH polyphosphates and different salts on water retention properties of ground trout muscle. J. Food Biochem. 8(2):123-131.

Rehbein, H., and Karl, H. 1985. Solubilisation of fish muscle proteins with buffers containing sodium dodecly sulfate. Z. lebensm Unters Forsch. 180:373-378.

Rodger, G., Weddle, R.B., Criag, P., and Hastings, R. 1984. Effect of alkaline protease activity on some properties of comminuted squid. Journal of Food Science. 49:117119, 123.

Ronsivalli, L.J. 1987. Sharks and Their Utilisation. Marine Fish. Rev. 40(2):1-13.

Sikorski, Z.E., and Kolodziejska, I. 1986. The composition and properties of squid meat. Food. Chem. 20:213.

Sikorski, Z., Olley, J., and Kostuch, S. 1976. Protein changes in frozen fish. Crit. Rev. Food Sci. Nutr. 8:97-129.

Sigurdsson, G.J. 1947. The chemistry of wood smoke. In: Fish as Food dried fishery products. J. Agric. Food Chem. 27(5):1104-1108.

Sripathy, N.V. 1983. Some recent research on traditional fish products in the IPFC region. In: The production and storage of fried fish. Proc. of the Workshop on the Production and Storage of dried fish. University Pertanian Malaysia, Serdang (Malaysia), 2-5 November, 1982. James, D. (ed.). FAO Fish Rep., (279) Suppl.: 265p.

Stanley, D.W., and Smith, H.O. 1984. Proteolytic activity in North American squid and its relation to quality. Can. Inst. Food Sci. Technol. J. 17:163-167.

Suzuki, T. 1981. Fish and Krill Protein: processing technology. Applied Science Publisher Ltd., Essex, England. pp. 260.

Takama, K., Sugira, S., Iseya, Z., Wakayama, E., and Furiu, T. 1985. Effect of salting and subsequent pickling on the quality of Masu Salmon fillets. Bull Fac. Fish., Hokkaido Univ. 36(3):147-157.

Tapiador, D.D., and Carroz, J.E. 1963. Standards and requirements for fish handling, processing, distribution and quality control. FAO Fish Rep. 9, FIT/R9.

Tarr, H.L.A. 1962. In: Fish as Food. Bergstrom, G. (ed.) vol. 2, pp. 235. London & New York Academic Press.

Tokunaga, T. 1975. Thermal decomposition of trimethylamine oxide in muscle of some marine animals. Bull. Jap. Soc. Sci. Fish. 41(5):535-546.

Voskresensky, N.A. 1965. Salting of herring. In: Fish as Food. Borgstrom, G. (ed.). vol. 3. pp. 107 -132.

Wada, S. and Koizumi, C. 1986. Changes in Histamine Contents during the Processing of Rice-bran Pickles of Sardine. Bull. Jap. Soc. Sci. Fish. 52(6):1035-1038.

Waterman, J.J. 1976. The production of dried fish. FAO Fish. Tech. paper. 160:52p.

Weinber, Z., Regenstein, J.M., and Lilliford, P.J. 1984. The effects of salts on thermal transition curves of cod muscle. J. Food Biochem. 8:335-339.

Wright, D.J., Leach, I.B., and Wilding, P. 1977. Differential scanning calorimetry studies of muscle and its constituent proteins. J. Sci. Food Agri. 28:557-564.

Yang, C-T., Jhaveri, S.N., and Constantinides, S.M. 1981. Preservation of grayfish (*Squalus acanthias*) by salting. J. Food Sci. 46:1646-1649.

Zain, A.M., and Yusof, S. 1983. Salt and moisture contents of Malaysia dried fish. In: The production and storage of dried fish. Proc. of the Workshop on the Production and Storage of Dried Fish. Universiti Pertanian Malaysia, Serdang, Malaysia. 2 - 5 November. FAO Fish. Rep., (279) Suppl.:216-222.

Zaitsev, V., Kizevetter, I., Lagunov, L., Makarova, T., Minder, L., and Podsevalov, V. 1969. Salting and Marinating. Chpt. 5. In: Fish Curing and Processing translated from Russian by A. De Merindol, MIR publishers, Moscow.

Discussion

Dr Noriyati informed the Seminar that the study was conducted in Australia and shark was used in the study because of its abundance.

Table 1. Changes in enthalphy of denaturation (ΔHD) during drying.

Drying temperature (°C)	Morwong		Sardine		Shark		Squid	
	Moisture content (%)	ΔHD kJ/g	Moisture content (%)	ΔHD kJ/g	Moisture content (%)	ΔHD kJ/g	Moisture content (%)	ΔHD kJ/g
Fresh	80.7	13.17	74.4	19.19	79.4	18.85	80.8	16.00
30°	47.2	10.32	47.9	11.54	44.5	3.74	13.5	4.05
50°	29.6	9.74	22.7	8.74	34.1	1.09	10.7	2.17
70°	11.9	6.90	22.2	5.94	37.7	0.21	14.9	0.25

Table 2. *In vitro* digestibility of salted fish.

Salting time (h)	Digestible Protein (%)		
	Morwong	Shark	Sardine
0	98.4[a]	99.4[a]	99.5[a]
4	99.6[a]	99.6[a]	99.3[a]
8	99.6[a]	97.7[a]	99.2[a]
12	99.5[a]	97.4[a]	99.4[a]
18	99.4[a]	99.4[a]	98.6[a]
24	99.5[a]	99.3[a]	98.6[a]
36	99.5[a]	99.1[a]	98.5[a]
48	99.7[a]	98.2	98.1[a]

Table 3. *In vitro* digestibility of dried fish.

Drying temp. (°C)	Digestible Protein (%)			
	Morwong	Shark	Sardine	Squid
Fresh Sample	98.4[a]	99.3[a]	99.5[a]	88.1[a]
30°	99.6[a]	99.9[a]	98.5[a]	98.3[b]
40°	99.8[a]	99.7[a]	97.5[a]	96.7[b]
50°	99.7[a]	99.5[a]	97.0[a]	97.9[b]
60°	99.8[a]	99.6[a]	97.4[a]	97.1[b]
70°	99.8[a]	99.5[a]	94.0[b]	97.7[b]

Note : Different superscripts down the column indicate significance at 99% confidence level.

Table 4. Total amino acid content in salted morwong.

Amino acid (g/16 gN)	Salting time (h)			
	0	12	24	48
Aspartic acid	9.91	10.63	10.07	10.59
Threonine	4.80	4.88	3.37	3.58
Serine	4.11	5.98	5.41	4.21
Glutamic acid	12.76	18.01	14.34	16.48
Proline	4.18	4.84	4.47	4.05
Glycine	3.99	5.41	5.72	5.91
Alanine	5.96	7.05	6.68	6.17
Cystine	0.50	0.56	0.85	0.53
Valine	5.04	5.70	5.95	5.44
Methionine	3.33	2.86	3.14	2.68
Isoleucine	4.28	4.30	5.23	5.39
Leucine	6.77	3.18	8.48	6.59
Tyrosine	4.50	2.51	4.11	3.78
Phenylalanine	4.21	2.67	3.47	3.48
Lysine	9.47	9.89	8.86	9.19
Histidine*	6.79[a]	3.46[b]	2.43[c]	1.82[c]
Arginine	9.39	8.42	7.42	8.56

* Amino acid showing a decreasing trend, significant at 99% confidence level.

Table 5. Total amino acid composition in dried morwong.

Amino acid	Drying temperature °C			
	Fresh fish	30°C	50°C	70°C
Aspartic acid	9.91	10.65	10.36	9.12
Threonine	4.80	5.25	3.93	4.10
Serine	4.11	4.76	3.58	3.88
Glutamic acid	12.76	13.97	12.32	12.37
Proline	4.18	4.66	2.89	2.87
Glycine	3.99	7.11	4.78	6.40
Alanine	5.96	8.71	6.95	7.39
Cystine	0.50	0.78	0.57	0.58
Valine	5.04	5.95	5.295	4.75
Methionine	3.33	2.89	3.07	2.63
Isoleucine	4.28	3.94	4.73	4.13
Leucine	6.77	6.39	8.10	7.56
Tyrosine*	4.50^{a}	3.13^{a}	2.57^{c}	2.65^{c}
Phenylalanine*	4.21^{a}	2.61^{a}	2.28^{b}	2.49^{b}
Lysine*	9.53^{a}	9.47^{a}	9.48^{a}	9.14^{b}
Histidine*	6.79^{a}	2.22^{a}	2.58^{c}	2.89^{c}
Arginine*	9.39^{a}	7.43^{b}	6.54^{c}	5.05^{d}

* Amino acid showing decreasing trend. Different superscripts denote significance at 99% level.

Table 6. A_w and moisture contents in dried morwong.

Drying temp. (°C)	A_w	Moisture (%)	Salt (% wb)	Predicted shelf life
30	0.83	47.2	21.3	1 week
40	0.79	37.2	25.3	1H months
50	0.74	29.6	28.3	2 months
60	0.71	24.7	30.3	2 months
70	0.69	11.9	35.5	1 year

Table 7. A_w and moisture contents in dried shark.

Drying temp. (°C)	A_w	Moisture (%)	Salt (% wb)	Predicted shelf life
30°	0.72	44.5	24.6	1 week
40°	0.72	29.8	31.1	2 months
50°	0.71	34.1	29.2	1H months
60°	0.65	26.8	32.4	2 months
70°	0.70	37.7	27.6	1H months

Table 8. A_w and moisture contents in dried sardine.

Drying temp. (°C)	A_w	Moisture (%)	Salt (% wb)	Predicted shelf life
30	0.86	47.9	9.14	1 week
40	0.77	38.4	11.7	1 week
50	0.67	22.7	13.7	2 months+
60	0.70	29.2	12.3	2 months+
70	0.70	22.2	12.0	4 months

Table 9. A_w and moisture contents in dried squid.

Drying temp. (°C)	A_w	Moisture (%)	Salt (% wb)	Predicted shelf life
30	0.43	13.5	8.0	1 year +
40	0.38	12.1	8.2	1 year +
50	0.31	10.7	8.3	1 year +
60	0.41	14.9	7.9	1 year +
70	0.44	15.0	7.9	1 year +

Table 10. Mean scores for saltiness in dried products.

Products	Salting time (h)				
	2	4	8	12	18
Sardines	(15.6)	(20.8)	(26.4)	(29.1)	(30.2)
	7.97^{a}	7.67^{a}	5.57^{bc}	5.49^{c}	3.69^{d}
Morwong	(23.2)	(28.0)	(43.5)	(44.4)	(42.4)
	7.95^{a}	6.95^{ab}	6.76^{bc}	5.32^{c}	3.95^{d}
Shark	(43.6)	(43.2)	(45.6)	(48.3)	(46.6)
	7.21^{a}	6.82^{a}	6.41^{a}	4.50^{b}	3.42^{c}

Note : Figures in parentheses denote salt content (% db) in the samples. Different superscripts along horizontal column indicate significance at 99% confidence level.

Table 11. Mean sensory scores for salted dried morwong.

Attributes	Drying temperature (°C)	Mean Score
Aroma	70	7.31[a]
	60	7.23[a]
	40	6.76[a]
	30	6.26[a]
	20	5.98[a]
Colour	70	3.43[c]
	60	6.80[b]
	50	6.85[b]
	40	6.92[a]
	30	7.20[a]
Texture	70	7.33[a]
	50	6.87[a]
	60	6.85[a]
	40	6.13[a]
	30	5.60[a]
Overall acceptability	70	7.22[a]
	60	6.92[a]
	50	7.07[a]
	40	6.30[a]
	30	5.82[a]

Note : Different superscript along horizontal column indicate significant difference at 99% confidence level

Table 12. Mean sensory scores for dried salted shark.

Attributes	Drying temperature (°C)	Mean Score
Aroma	70	6.17[b]
	60	6.14[b]
	50	7.66[a]
	40	7.60[a]
	30	7.21[a]
Colour	70	5.21[a]
	60	5.55[b]
	50	6.65[b]
	40	7.80[ab]
	30	7.49[a]
Texture	70	5.09[a]
	60	6.09[a]
	50	6.45[a]
	40	6.56[a]
	30	6.41[a]
Overall acceptability	70	5.70[a]
	60	5.84[b]
	50	7.22[a]
	40	6.90[a]
	30	7.32[a]

Table 13. Mean sensory scores for salted dried sardines.

Attributes	Drying temperature (°C)	Mean Score
Aroma	70	6.91[a]
	60	7.21[a]
	50	7.13[a]
	40	-
	30	6.60[a]
Colour	70	5.63[b]
	60	6.27[b]
	50	6.67[ab]
	40	7.43[a]
	30	6.42[ab]
Texture	70	5.46[a]
	60	7.13[a]
	50	6.93[a]
	40	6.90[a]
	30	5.85[a]
Overall acceptability	70	4.65[c]
	60	6.12[ab]
	50	6.87[ab]
	40	7.33[a]
	30	6.81[ab]

Note : Different superscript indicate significance at 99% confidence level.

Table 14. Mean sensory scores for salted dried squid.

Attributes	Drying temperature (°C)	Mean Score
Aroma	70	6.83[a]
	60	6.69[a]
	50	5.65[a]
	40	6.69[a]
	30	5.56[a]
Colour	70	6.46[a]
	60	6.29[a]
	50	6.69[a]
	40	6.41[a]
	30	3.45[a]
Texture	70	5.99[a]
	60	6.62[a]
	50	6.38[a]
	40	5.57[a]
	30	4.95[a]
Overall acceptability	70	6.53[a]
	60	6.01[a]
	50	5.84[a]
	40	6.51[a]
	30	5.32[a]

Note : Different superscripts denote significance at 99% confidence level.

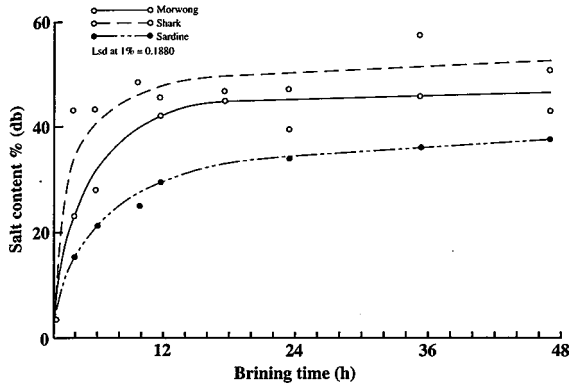


Fig. 1. Salt uptake by different species of fish during brining.

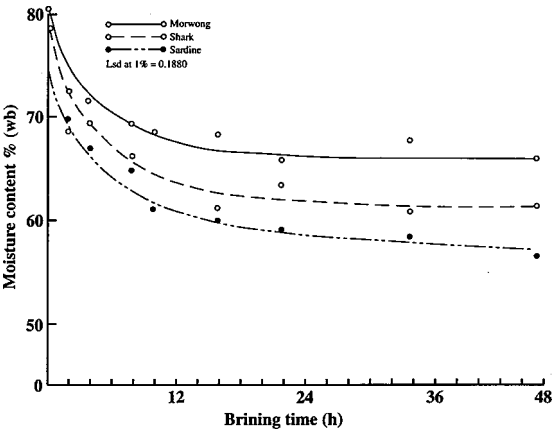


Fig. 2. Changes in moisture content during brining.

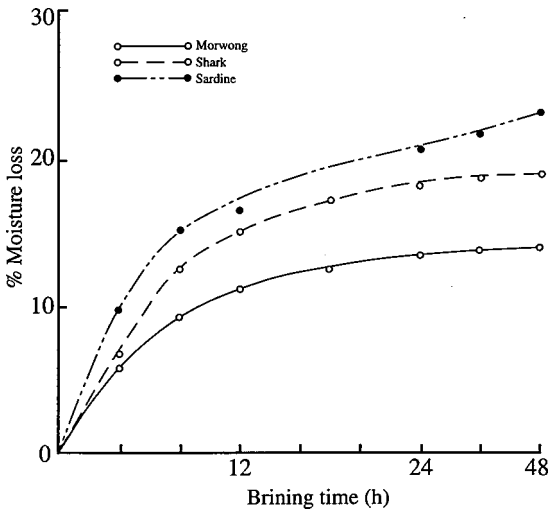


Fig. 3. Percentage moisture loss in fish during brining.

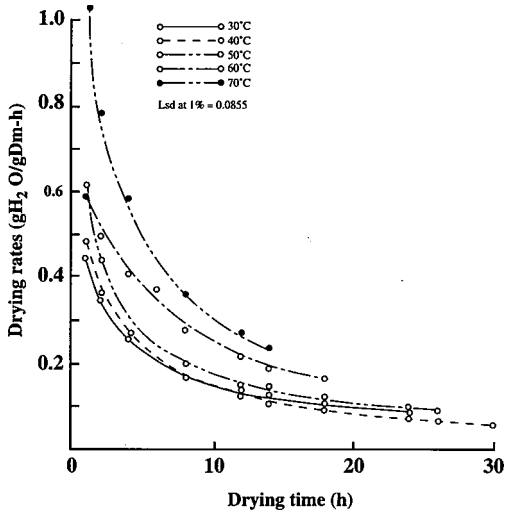


Fig. 4. Effect of temperature on the drying rates of salted morwong.

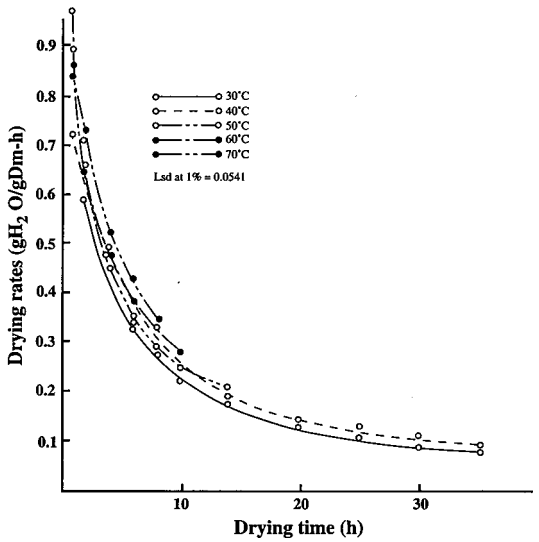


Fig. 5. Effect of temperature on the drying rates of shark.

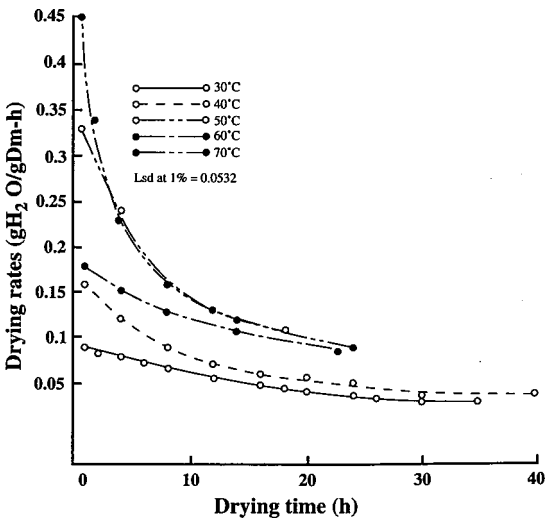


Fig. 6. Effect of temperature on the drying rates of salted sardines.

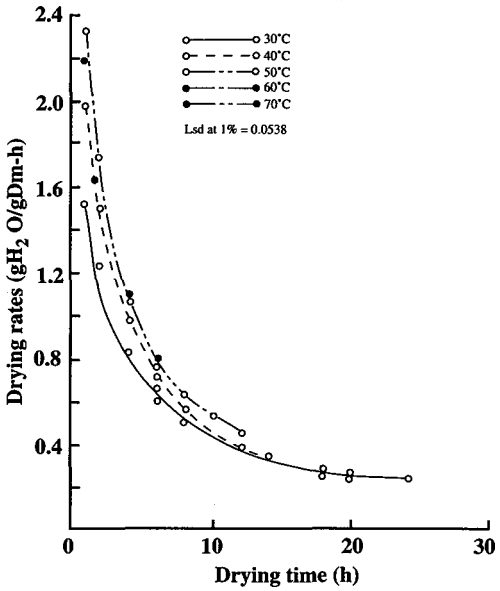


Fig. 7. Effect of temperature on the drying rates of squid.

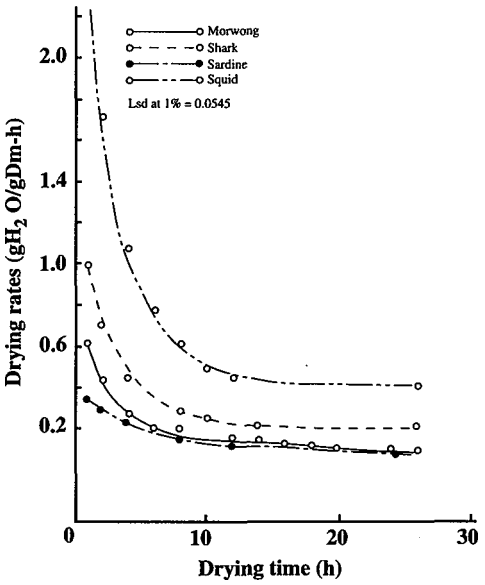


Fig. 8. Relationship between drying rates and drying time for different species at 50°C.

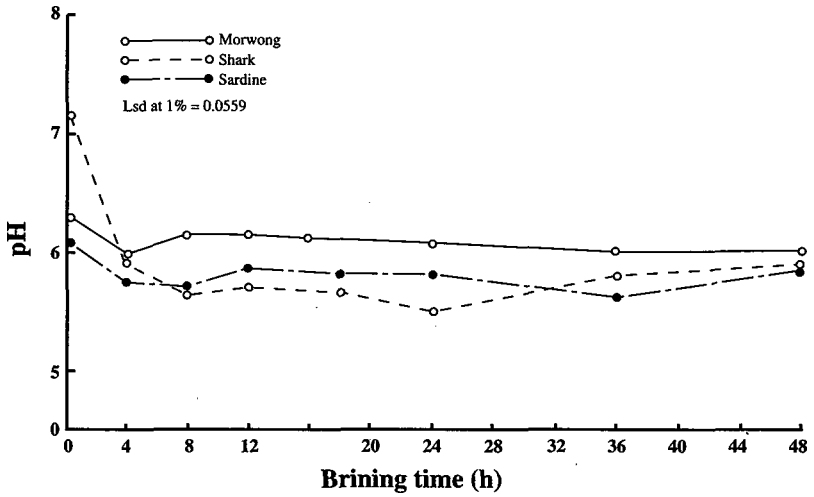


Fig. 9. Changes in pH of fish during brining.

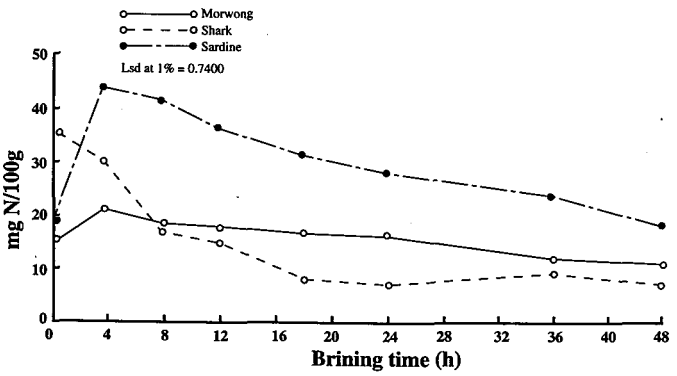


Fig. 10. Changes in TMA content of fish during brining.

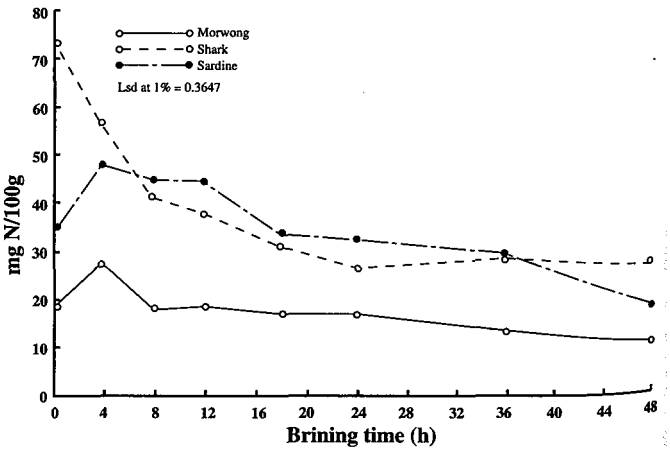


Fig. 11. Changes in TVB content of fish during brining.

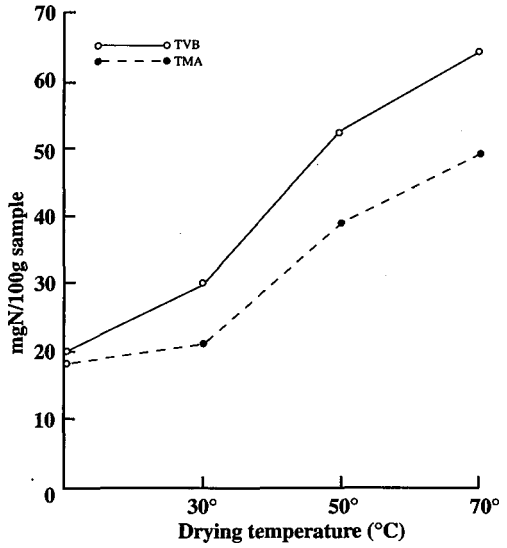


Fig. 12. TVB and TMA content in morwong dried at different temperatures.

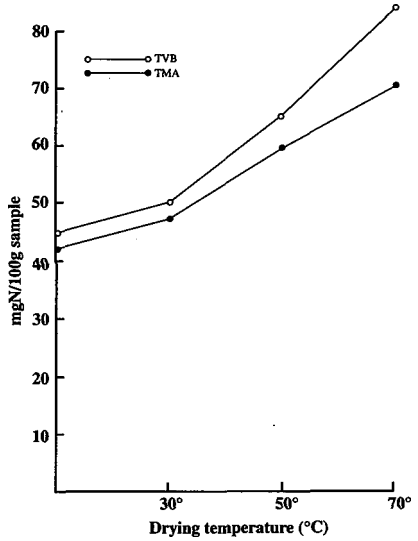


Fig. 13. TVB and TMA content in sardines dried at different temperatures.

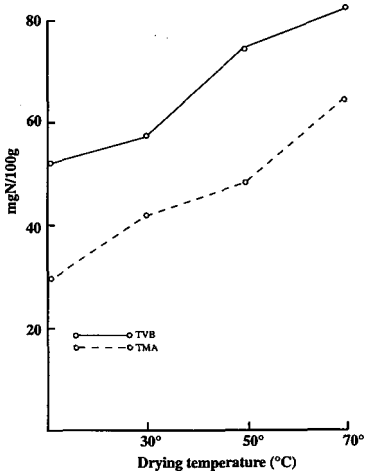


Fig. 14. TVB and TMA content in shark dried at different temperatures.

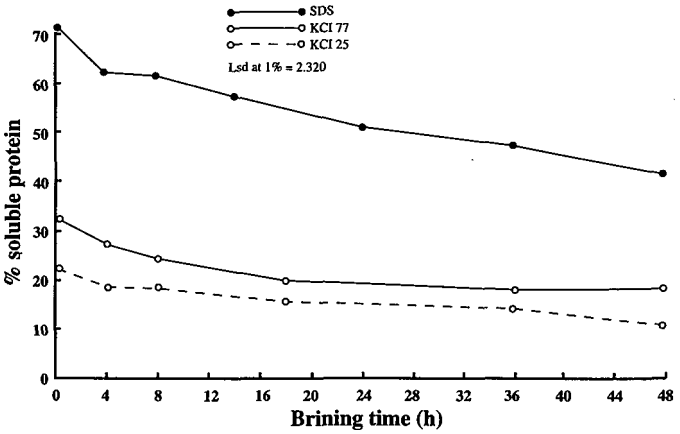


Fig. 15. Solubility of morwong proteins in different media on salting

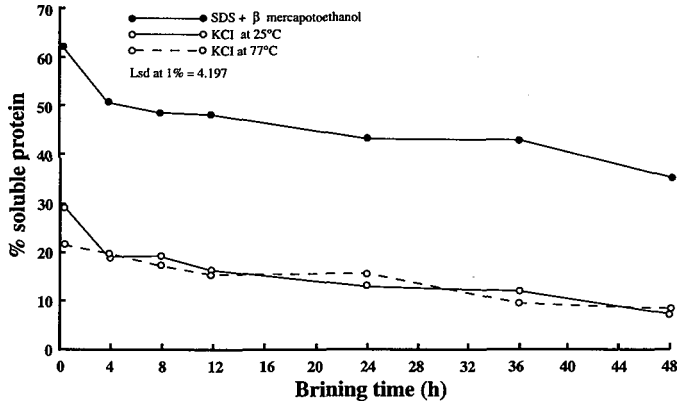


Fig. 16. Effect of salting time on protein solubility of sardine.

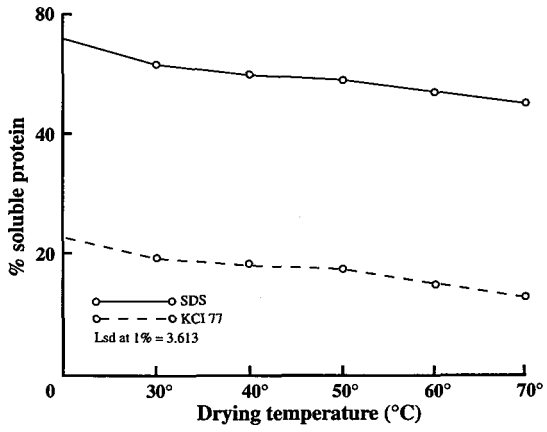


Fig. 17. Effect of drying temperature on the solubility of shark proteins.

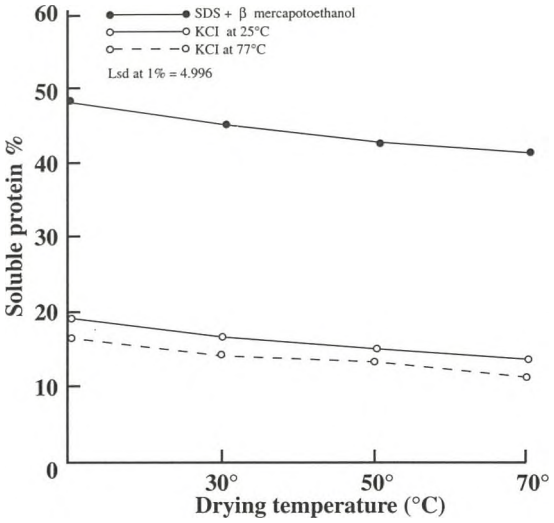


Fig. 18. Effect of drying temperature on the solubility of proteins of sardine.

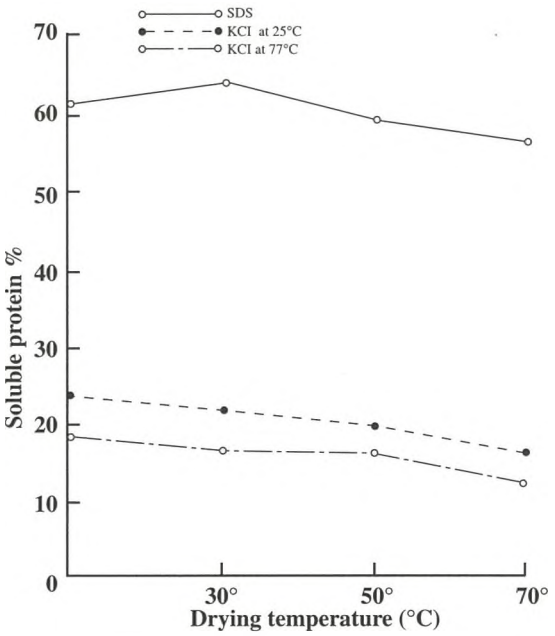


Fig. 20. Solubility of morwong proteins in different media on drying at different temperatures.

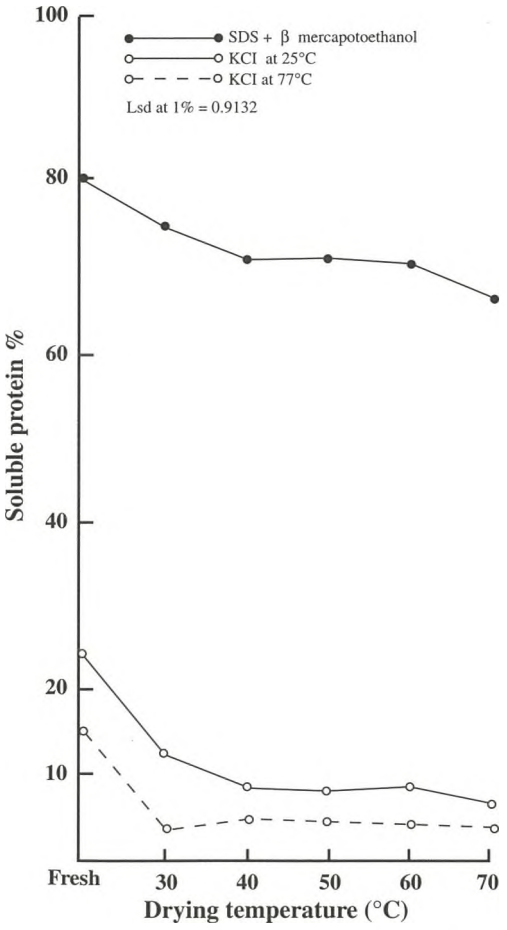


Fig. 19. Effect of drying temperature on the solubility of proteins of squid.

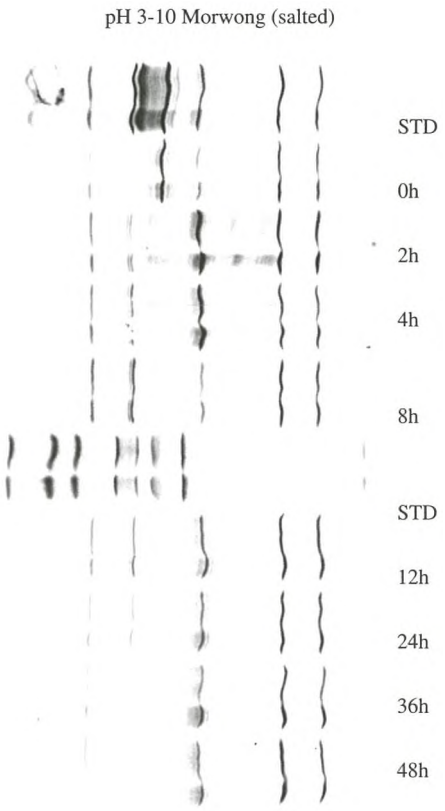


Fig. 21. IEF patterns of water soluble proteins of morwong fillets after brining for 0,2,4,8,24,36 and 72h.

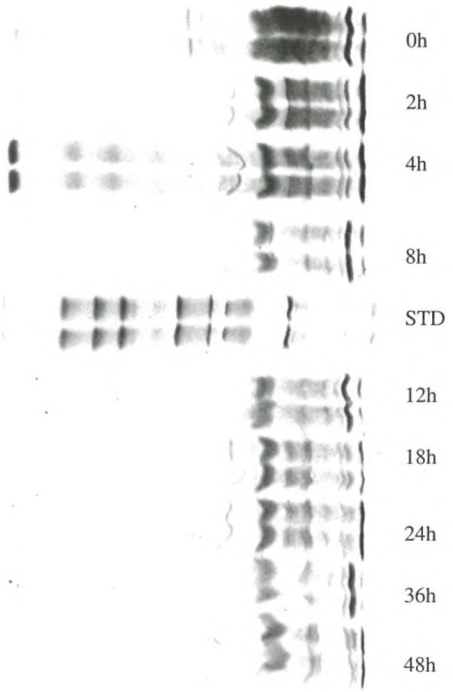


Fig. 22. IEF patterns of water soluble proteins of shark fillets after brining for 0,2,4,8,12,24,36 and 48h.

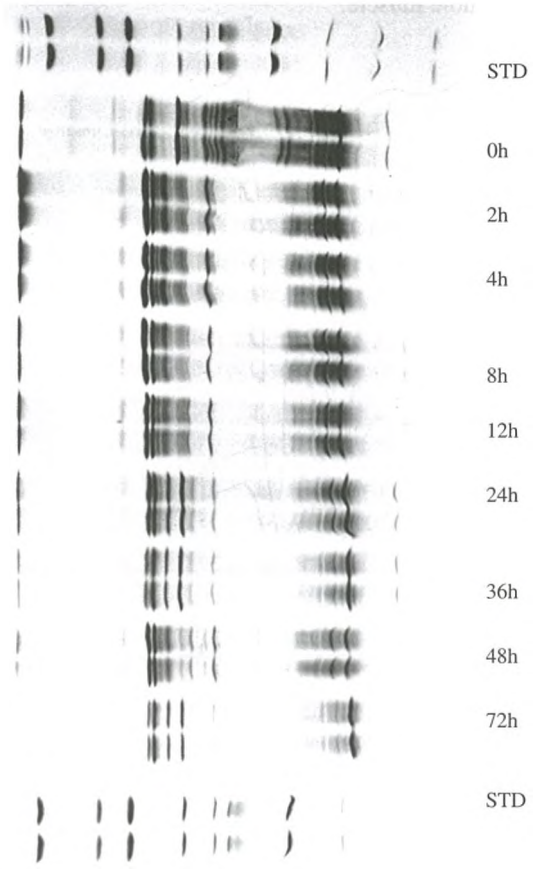


Fig. 23. IEF patterns of water soluble proteins of sardine after brining for 0,2,4,8,12,24,36,48 and 72h.

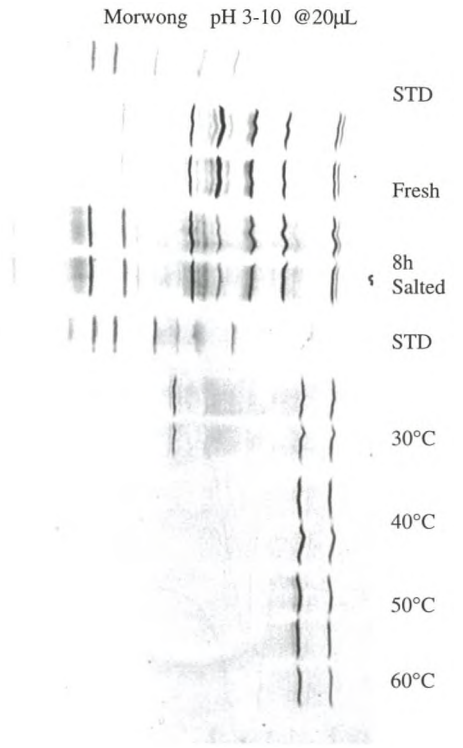


Fig. 24. IEF patterns of water soluble proteins of morwong fillets brined for 8h and dried at 30°, 40°, 50° and 60°C.

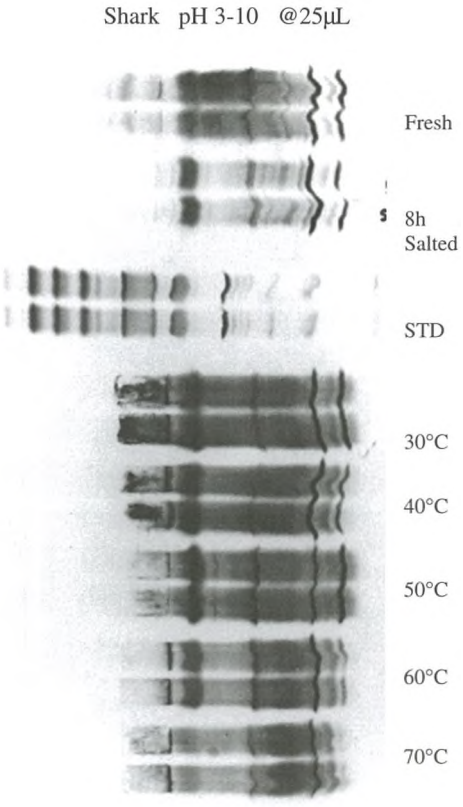


Fig. 25. IEF pattern of water soluble proteins of shark fillets brined for 4h and dried at 30°, 40°, 50°, 60° and 70°C.

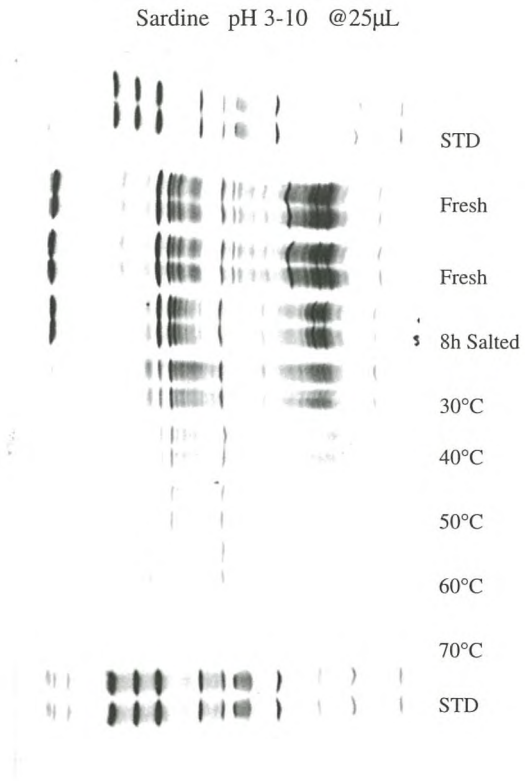


Fig. 26. IEF pattern of water soluble proteins of sardine brined for 8h and dried at 30°, 40°, 50°, 60° and 70°C.

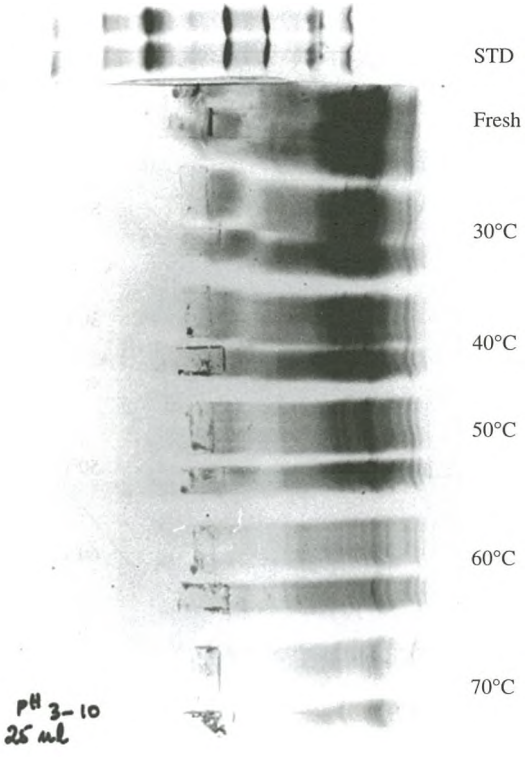


Fig. 27. IEF pattern of water soluble proteins of squid dried at 30°, 40°, 50°, 60° and 70°C.

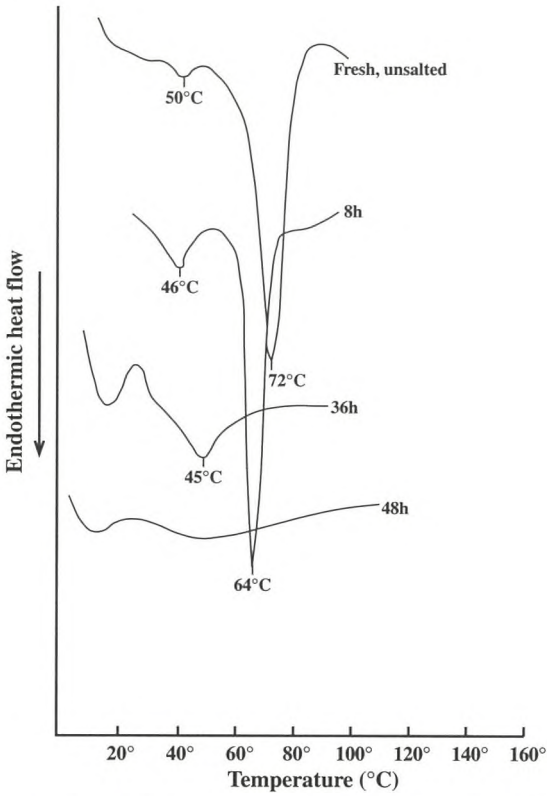


Fig. 28. DSC thermogram of salted and unsalted shark whole muscle.

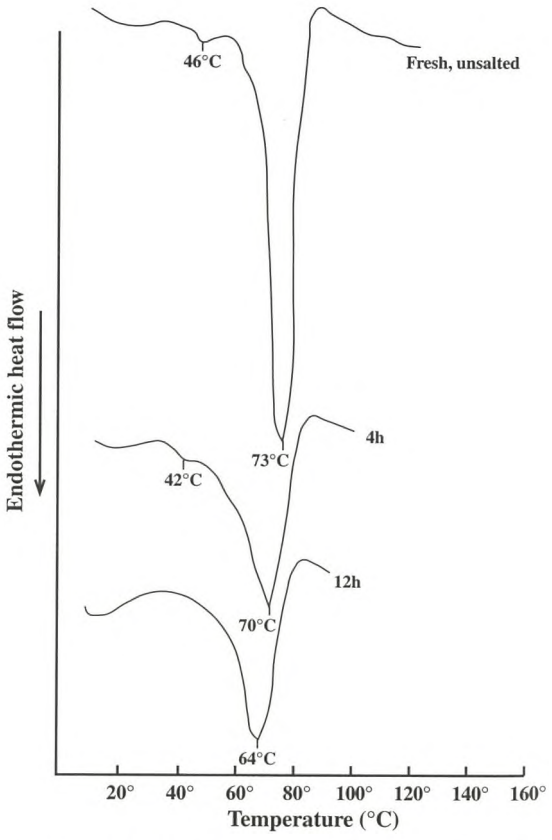


Fig. 29. DSC thermogram of salted and unsalted morwong whole muscle.

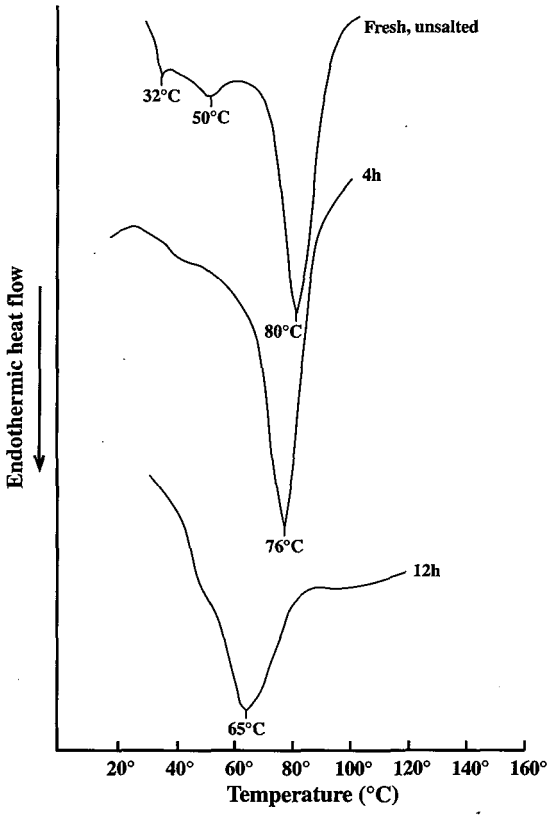


Fig. 30. DSC thermogram of salted and unsalted sardine whole muscle.

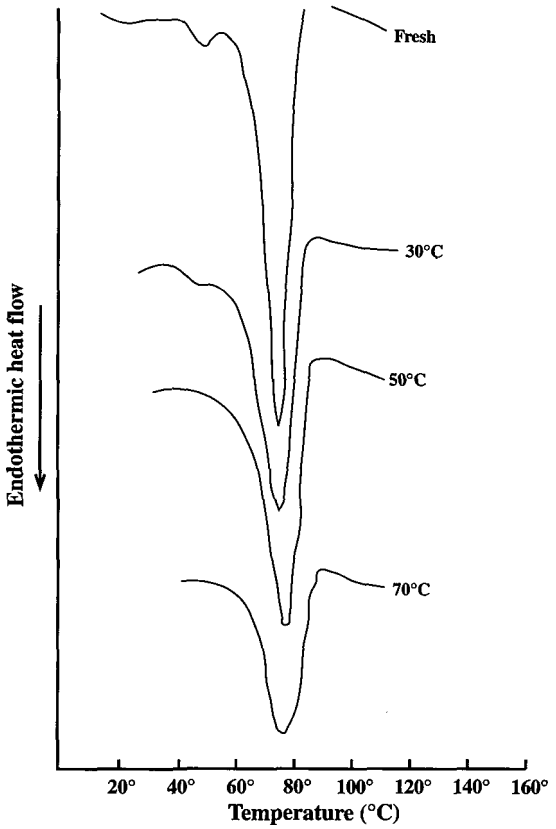


Fig. 32. DSC thermogram of dried, salted sardine previously dried at different temperatures.

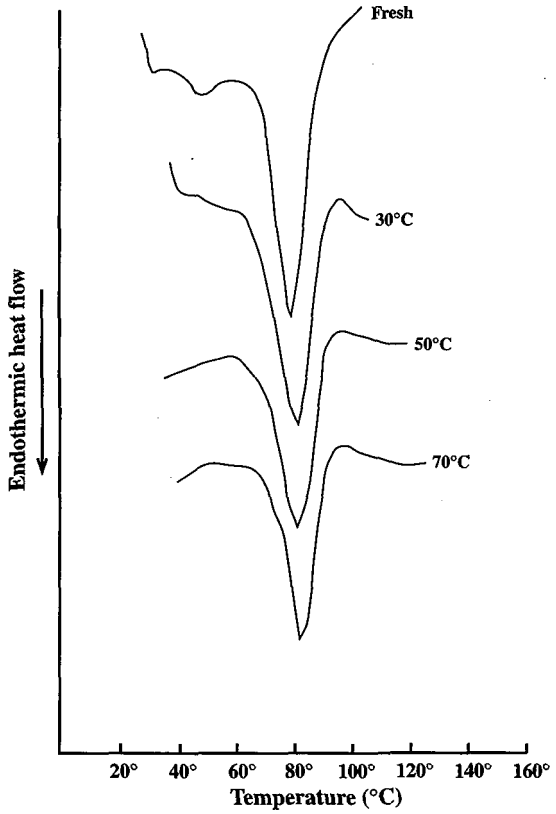


Fig. 31. DSC thermogram of dried, salted morwong previously dried at different temperatures.

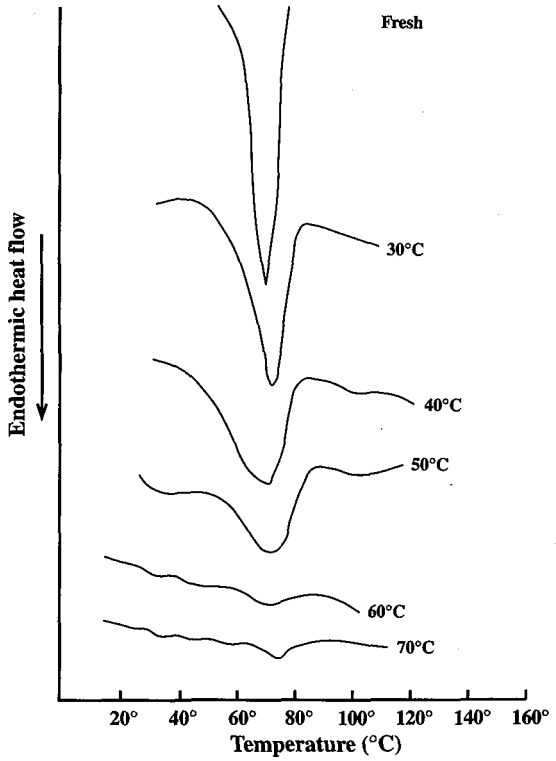


Fig. 33. DSC thermogram of dried shark previously dried at different temperatures.

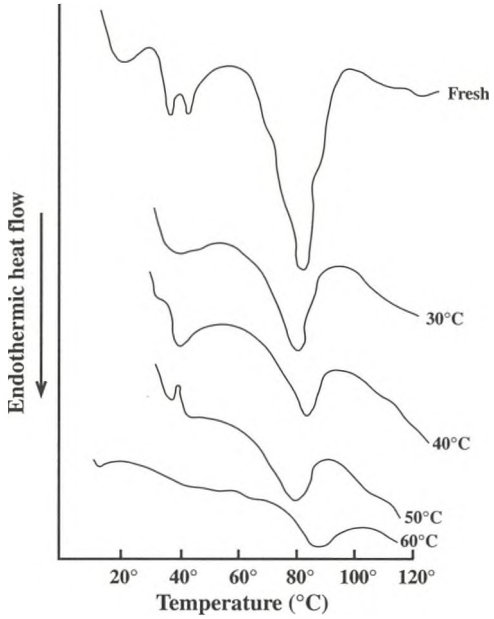
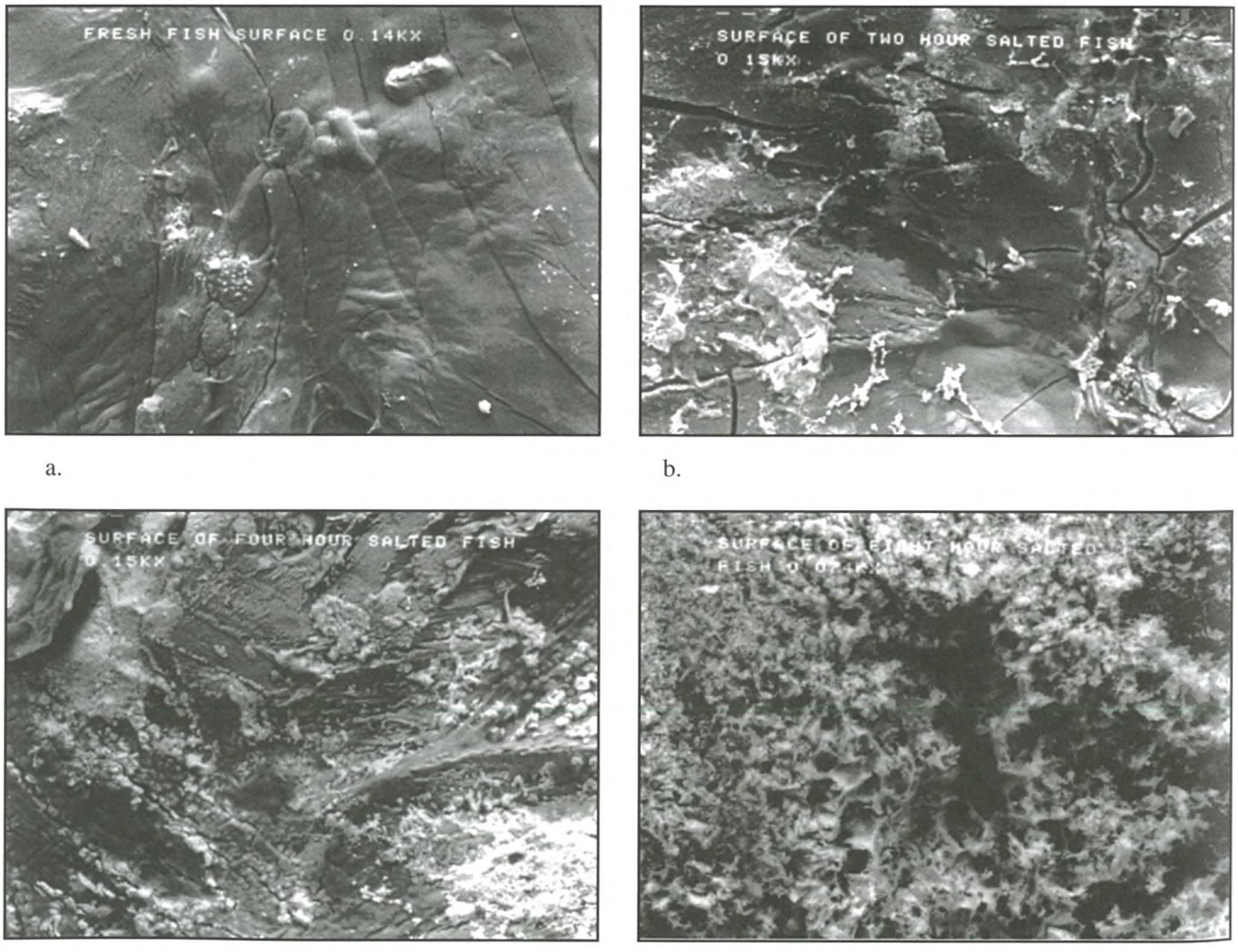


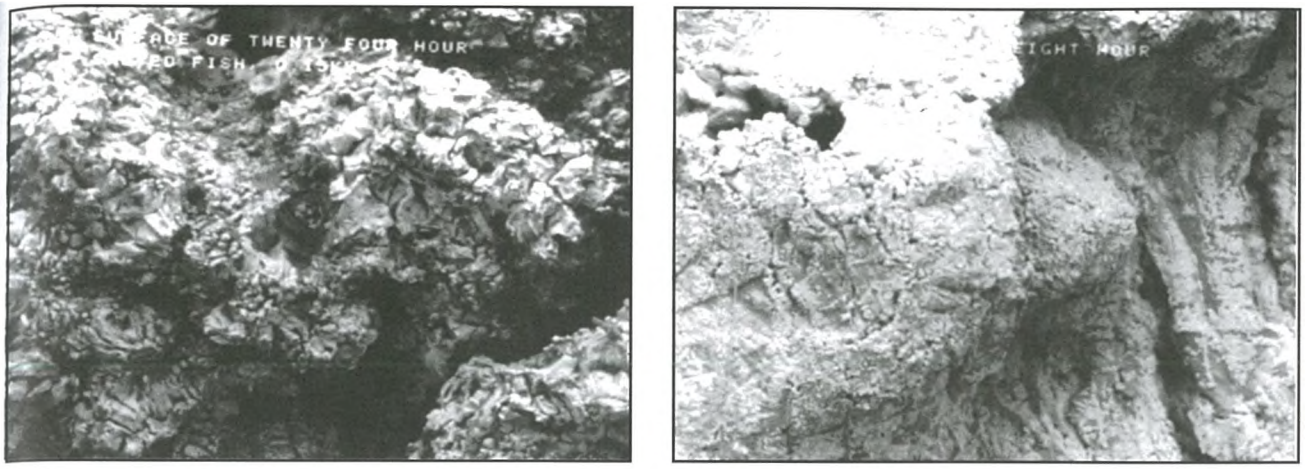
Fig. 34. DSC thermogram of dried squid previously dried at different temperatures.



a. b.

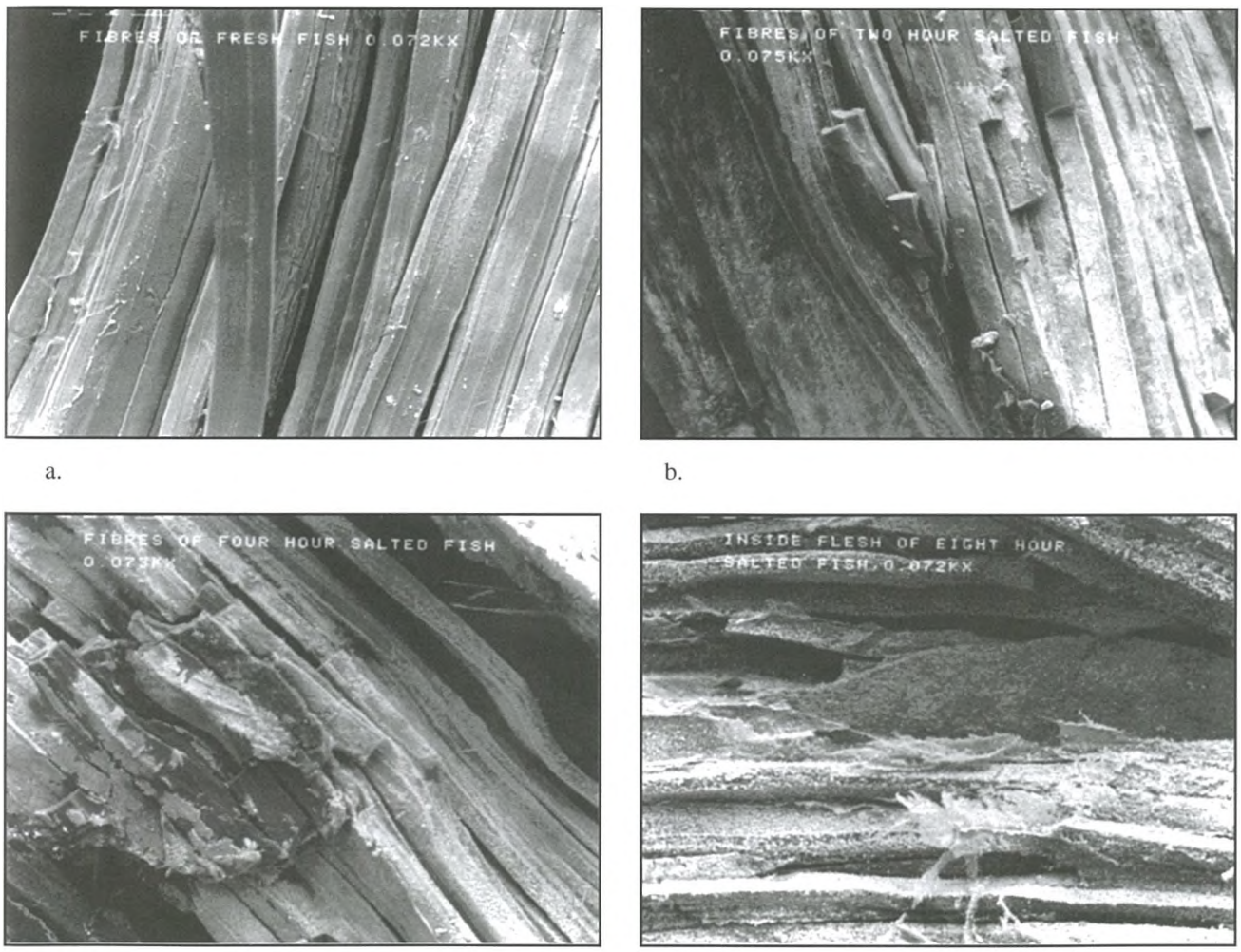
c. d.

Plate 1. SEM micrograph (150x) of the surface layers of morwong brined for 0, 2, 4, 8h (a,b,c,d respectively).



a. b.

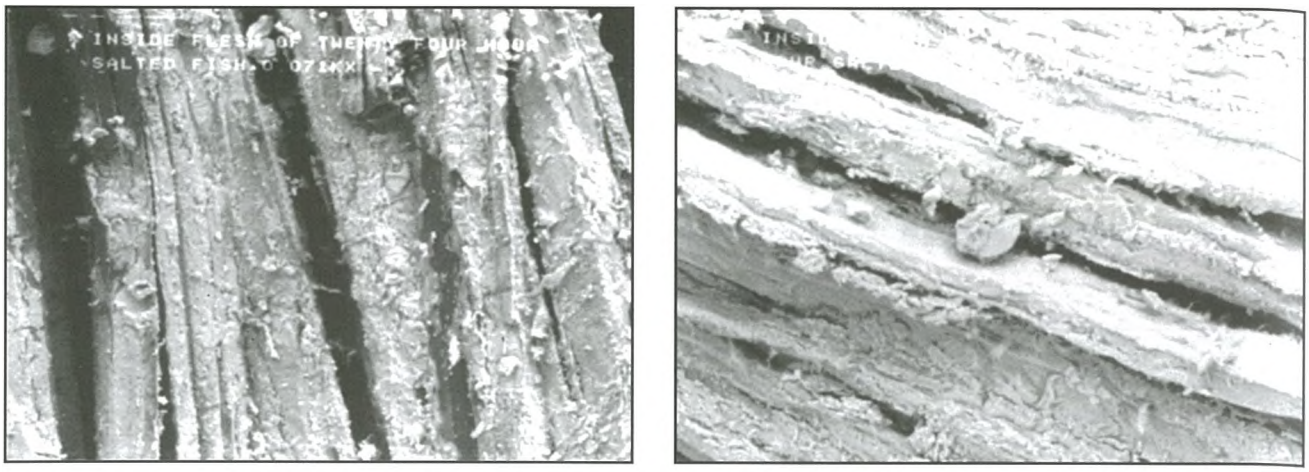
Plate 2. SEM micrographs (150x) of the surface layers of morwong brined for 24 and 48h (a,b respectively).



a. b.

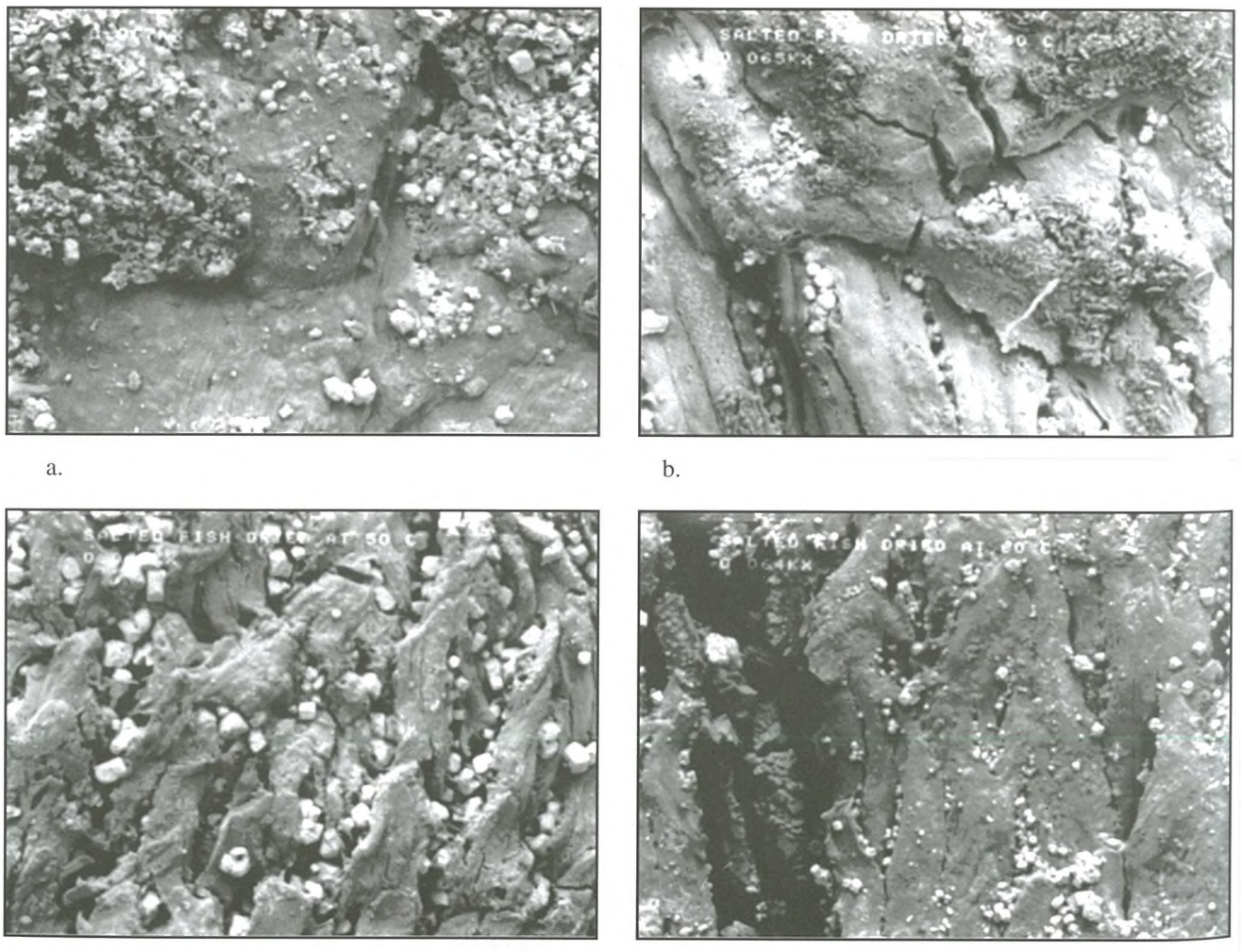
c. d.

Plate 3. SEM micrographs of deep tissue of morwong brined for 0, 2, 4 and 8h (a,b,c,d respectively).



a. b.

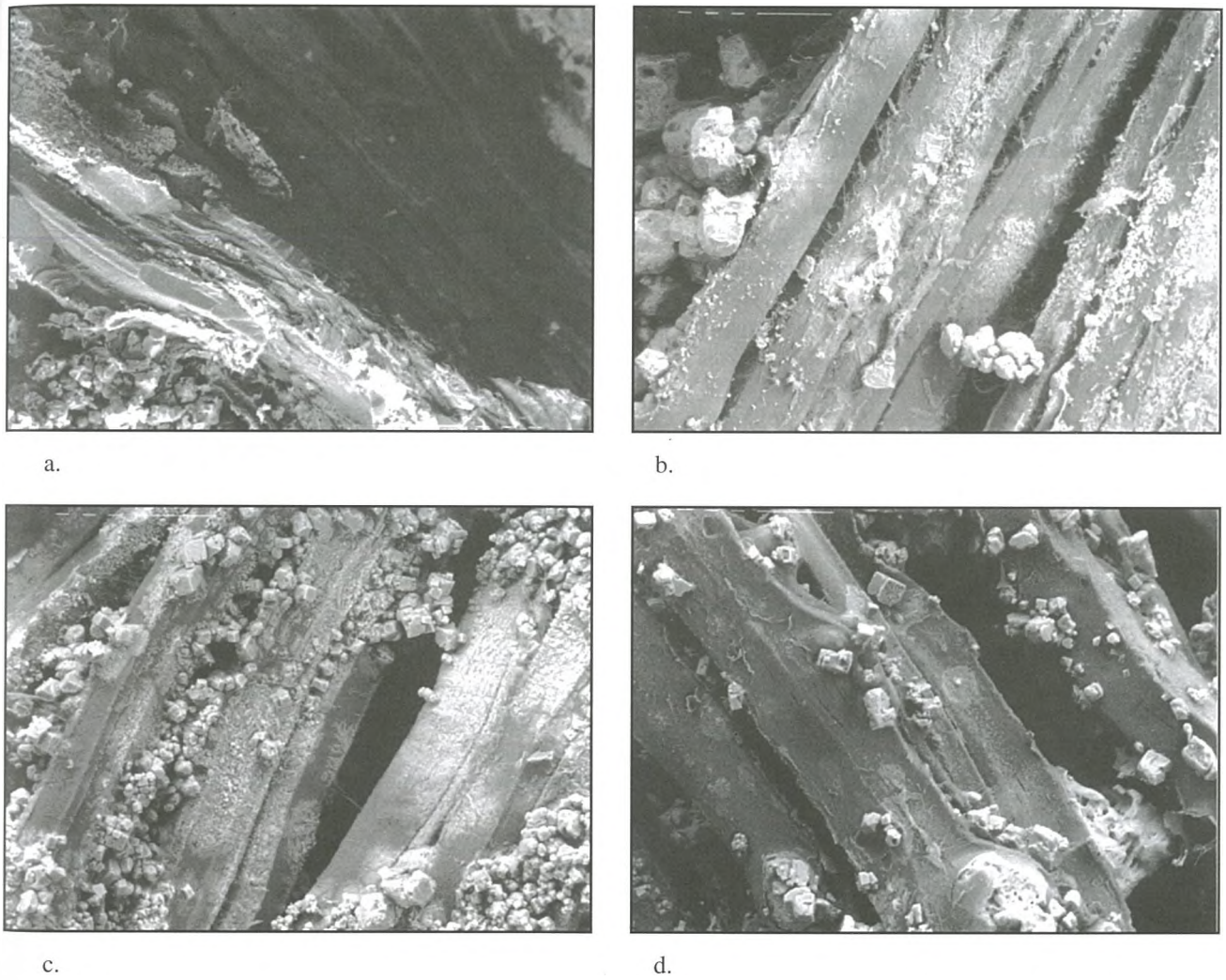
Plate 4. SEM micrographs of deep tissue of morwong brined for 24 and 48h (a and b respectively).



a. b.

c. d.

Plate 5. SEM micrographs (65x) of surface layers of morwong dried at 30°, 40°, 50° and 60°C (a,b,c,d respectively).



a. b.

c. d.

Plate 6. SEM micrographs (125x) of the deep tissue of morwong dried at 30°, 40°, 50° and 60°C (a,b,c,d respectively).

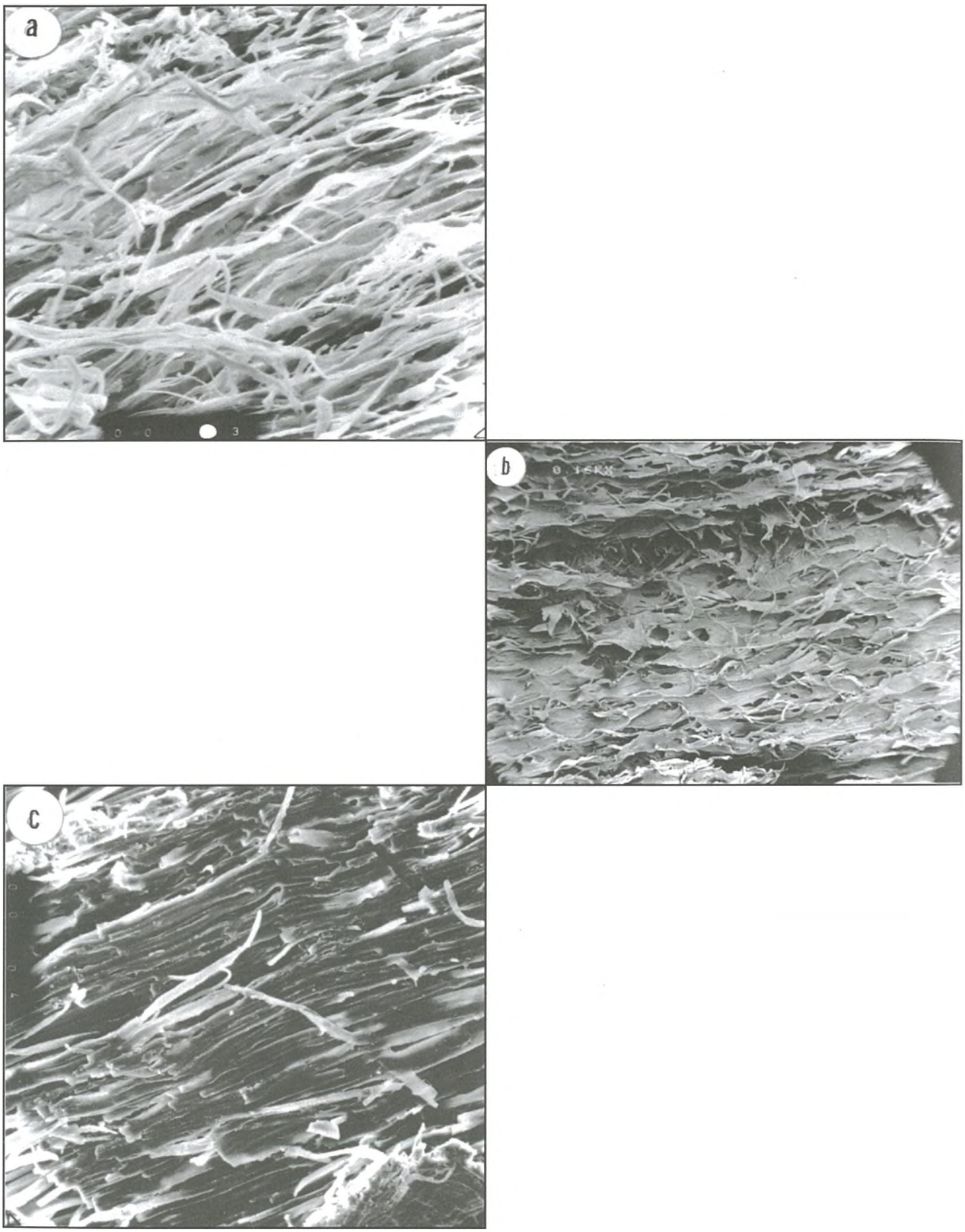


Plate 7. SEM micrographs of fresh squid tissue and those dried at 40° and 70°C (a,b,c respectively).