# FISH DRYING: A REVIEW

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**Abstract -** Drying is a common fish preservation technique used in developing countries. Analysis of process factors involved in controlled fish drying permits process optimization and assists in design of suitable dryers. Various methodologies, with models of different complexities have been used to investigate fish drying kinetics. In this work, was done a review of the evolution of drying fish over the years.

Keywords: Fish, drying, Temperature, Air velocity, Relative humidity

## SECAGEM DE PEIXES: REVISÃO

**Resumo -** A secagem é uma técnica comum de preservação de peixes, utilizada nos países em desenvolvimento. A análise dos fatores envolvidos no processo de secagem artificial de peixes permite a otimização de processos e auxilia no projeto de secadores adequados. Diversas metodologias, com modelos de diferentes complexidades, têm sido usadas para investigar a cinética de secagem de peixes. Neste trabalho, foi feita uma revisão da evolução da secagem de peixes ao longo dos anos.

Palavras-Chave: Peixe, Secagem, Temperatura, Velocidade do ar, Umidade relativa

## INTRODUCTION

Fresh fish is susceptible to deterioration by fast destructive action of enzymes, oxidation of lipids, high pH, high water activity and accentuated contents of non-protein nitrogen substances. Accordingly, it is of critical importance to adopt measures ensuring perfect conservation immediately after capture and during distribution and commercialization.

There are several techniques for processing fish (drying, salting, smoking, etc.) which can be used to meet the above requirements. In this work, the emphasis will be allocated to the drying conservation process.

The relevance of drying operations within a vast range of industrial processes is unquestionable: drying is present in the chemical, agricultural, wood processing, food, ceramics, and pulp and paper industries, among others. It is estimated that drying operations are responsible for 10–25%of the national energy consumption in developed countries. The correct definition of drying procedures of a vast range of products is crucial in what concerns energy minimization and minimal time of kiln residence without compromising the final product quality. Drying can change the sensory characteristics and nutritional value of foods, and the intensity of these changes depends upon the conditions used in the drying process and the specific characteristics of each product.

Several parameters influence the time required to reduce the moisture content of the product. The principal external factors to consider are air temperature, relative humidity and velocity. Mathematical modelling of food drying processes represents an adequate and straightforward manner to predict drying behaviour of a given material in response to given drying conditions or to a change in these conditions. When a drying model is integrated with a proper control algorithm aiming at energy reduction and increased drying speeds, manual control can be replaced by automatic operation which may result in significant reductions in drying costs without compromises in product quality.

In this work, was done a review of the evolution of drying fish over the years.

## RESEARCHES ON FISH DRYING

According Bastos (1977), fish artificial drying started in 1940 by Torry Research Station - England, with the use of equipment with controlled thermodynamic conditions. To achieve the goal, several models were tried dryers, citing among them those of steam jacket, rolls and hot air dryers provided.



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The process of shrinkage in cod fillets during drying was analyzed by Jason (1958). He presented the shrinking process in three dimensions with graphics where this shrinkage is not presented as a linear function of moisture content. Jason (1965) considers the fish muscle as gel, possessing an isotropic medium at any moisture content. Commenting on the evaporation surface cites the influence of the thickness of the boundary layer of air which controls the diffusion of water on the surface and is easily checked at the beginning of the drying process. The author presents empirical equations in order to predict the evaporation of water due to the difference in air temperature and wet bulb temperature. To Chupakhin and Dormenko (1965), the drying of fish should not be performed with temperatures above 40°C. Also performed calculations for sizing dryers with drying air velocity equal to 1 m/s.

Peters (1966), states that the relative humidity has a greater effect when the air velocity is below 3 m/s. The drying time with relative humidities above 60% decreases considerably, even making use of the air speed above 6 m / s. Concluded that relative humidity and air velocity have a considerable effect on the drying of salted fish with light and a smaller effect on the fish with salt strong. He also asserts that, for drying, air velocity at the top must be at least 3 m/s, to avoid deterioration.

Wirth et al. (1975) discussed the importance of the critical temperature as the first term to be studied among the drying parameters. In their experiments, there can be subjected to salted shark (*Mustelus Shimitti, Galeorhinus Vitaminicus and Cynoscion Striatus*) at temperature of 35°C, obtaining in all experiments the final products, dried, uncooked and complete reconstruction, with an air speed between 1 and 3 m/s and relative humidity around 50-55%. The authors state that the drying is slower at lower speeds, but not much faster at higher speeds, which means a greater expenditure of energy.

Bastos (1977) studied the effects of drying temperature on white shark muscle previously salty, *Carcharhynus porous Ranzani*. The muscle in the form of fillets were salted by brining process mixed at a ratio of 30% sodium chloride in the weight of raw material. The salting time was 12 days, after which the fillets were subjected to salt drying in an oven with air circulation. The units of fillets were divided into two groups each consisting of five samples. One sample of each group remained without drying, as a control, the other four were dried at temperatures of 35, 45, 55 and 60°C, respectively. In the first experiment, the products covered by the temperatures above were dried to 50% moisture, while for the second drying was made up to 34% humidity. During the process, in both cases, the weight loss product, relative humidity and air speed in the greenhouse were measured every hour. In the control and salted and dried products were made the following determinations: moisture, total protein, chloride, protein solubility, rehydration capacity of the tissue, water retention capacity of the tissue and speed of desalting the muscle of shark. In both experiments, the chloride concentration was not increased, remaining around 19.1 to 23.0%, a value that falls within the limits recommended by the literature, for salted fish industrially. Soluble protein decreased for the samples of both experiments, the loss of solubility being proportional to the temperature rise. The samples were dried to 34% moisture, there was a greater loss of soluble protein when compared with the dry products to 50% humidity. In tests of rehydration (g água / l00g product), it was observed that dried at 35°C, rehydrated in a manner similar to the control (when the calculations were conducted to relate the water absorbed in grams per 100g of product ). However, when the water absorbed was expressed regarding the percentage of protein, it was observed that drying in any of the temperatures tested, leading to rehydration products quantitatively smaller, reducing its speed in comparison to controls, with this figure falling the temperature rise. The water holding capacity, was highest for the control, reducing the extent that the drying temperature increased. The dried at 35°C, retained a higher percentage of water compared to dry the fillets in the remaining temperatures. The desalting of the muscle occurred faster in samples dried at higher temperatures.

The drying of salted pressed shark was studied by Torrano and Okada (1977) with temperatures ranging from 40 to 60°C and 70% relative humidity. The authors present the variation of moisture as a function of drying time, explaining that without drying skin occurs more slowly pressed against the skin, through hardening. The presence of salt crystals on the membrane surface prevents the skin without leaving the water, while skin, it acts as attenuator of these types.

According Waterman (1978), in temperate zones, the air velocity should be between 1 and 2 m/s. He claims that a higher speed improves the level of initial drying, but reduces the period of constant velocity with no effect on total drying time. For this, the air temperature is between 25 and 30°C, ideally around 27°C with relative humidity between 45-55%. For this author, a lower relative humidity could result in a hardening of the fish and its increase reduces the degree of drying. Madrid and Copriva (1984) encourage the natural drying, with the use of sunlight, if environmental conditions are favorable, or the use of industrial dryers for drying fish. They said the temperature should not exceed 28°C, however, for tropical fish, it can reach 40°C, with relative humidity between 35 and 60%.

Shrinkage of rectangular slabs of ocean perch (*Sebastes marinus*) in all three dimensions during air drying at 24.5°C, relative humidity 35% and velocity 35.6 m/min was determined by Balaban and Pigott (1986). Percent change in dimensions with volume fraction of water was measured. It was observed that the dimension along the major axis of muscle fibers (length in this case) shrinks far less than the other two dimensions. Maximum shrinkage in length was 20%, while for width it was 50.5% and for thickness, 50.6%. At 95% confidence level, there was no significant difference between thickness and width shrinkage.

Cornejo (1987) studied the drying parameters and construction of a low cost dryer for salted fillets of shark. He obtained the characteristics of the drying air temperature as being between 35 and 40°C, relative humidity ranging from 40 to 50% and air velocity between 0.5 and 1m/s. Found that the drying of shark salted fillet shows no constant rate period of drying, where drying kinetics was perfectly predictable from equation (Fourier series) proposed by Lewis-Sherwood using the first five terms in the series. He noted also that the sizing of the dryer, no need to consider the effect of shrinkage.

Park (1987) studied the internal diffusion during the drying of salted fillet of shark (Carcharhinus limbatus) using the second Fick's law for the drying process with and without volume change. The diffusion coefficients were estimated using the Gauss-Newton, where the numerical value of the diffusion coefficients for drying without change of volume is greater than the numerical value for drying with volume change. He calculated the activation energy assuming the Arrhenius equation for the diffusivity as a function of inverse absolute temperature.

Improving the process of salting and drying the Zanzibar tilapia (Sarotherodon Hornorum) was studied by Sales (1988). The experiments were conducted to evaluate the effects of the following factors on the quality of the final product: ideal salt concentration on the mass of the cleaned fish, curing time after salting, drying time under natural conditions and salt-stable product stored dry at room temperature. Drying was performed by direct sunlight on wood and canvas tents, raised about 90cm above the ground. The time of sun exposure ranged from 4 to 6 hours, until a moisture content of the final product 40-45%. According to the author, the results demonstrated that can be obtained a good salted-dry with the use of a concentration of salt used according to the species to be processed on the mass of the cleaned fish for 20-24 hours of curing and 4-6 hours of sun drying.

Drying of tambacu fillets, previously salted and smoked with hickory liquid plant extract was studied by Roberts (1996). The work, experimental and mathematician, investigated the drying process, based on Fick's diffusion model, considering the effective diffusivity and constant air velocity of 1.5 m/s. The diffusive model of drying was used to fit experimental data with a correlation coefficient of 0.97, showing good fit to the case study. Park (1998) determined a diffusive model with and without shrinkage of the sample, for drying salted shark. He worked with three combinations of temperature and relative humidity (20°C - 40%; 30°C - 30%; 40°C - 45%) for two air velocities (0.5 and 3 m/s). The shrinkage of the material was considered as a linear function between the sample size and moisture content. The value of the effective diffusivity varied from 1.50x$10^{-10}$$m^2$/s and 2.85 x$10^{-10}$$m^2$/s for the drying process without considering the shrinkage between 0,87x$10^{-10}$$m^2$/s e 1,61x$10^{-10}$$m^2$/s considering the shrinkage sample.

Blasco e Alvarez (1999) considers the application of the flash drying to the moisture removal of fishmeal using superheated steam as trampon medium. Heat, momentum and mass transfer equations were applied and an algorithm based on these equatiom was developed and solved. The model was validated using experimental data obtained in a pilot pneumatic dryer (total length 60 m), provided with a steam jacket to maintain the superheated steam at a constant temperature. The drying time was less than 10 s to decrease the fish meals moisture content from 53.5% to 28% d.b. and in a second pass by the dryer the moisture down to 16.9%, using superheated steam at 111°C and 130°C in the jacket. The computational results are in agreement with the experimental data.

Bala e Mondol (2001) studied field level performance of the solar tunnel dryer for drying of fish. The dryer consists of a transparent plastic covered flat plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using four d.c. fans, operated by two 40 watt solar modules. This dryer can be used to dry up to 150 kg of fish and three sets of full scale field level drying runs for drying silver jew (*Johnius argentatus*) fish were conducted in February-March, 1999. The temperature of the drying air at the collector outlet varied from 35.1 8C to52.2 8C during drying. The fish was initially treated with dry salt and stacked for about 16 hours before drying. The salt treated fish was dried to a moisture content of 16.78% (w.b.) from 67% (w.b.) in 5 days of drying in solar tunnel dryer as compared to 5 days of drying in the traditional method for comparable samples to a final moisture content of 32.84%. In addition, the fish dried in the solar tunnel dryer was completely protected from rain, insects and dust, and the dried fish was a high quality product.

Bellagha et al. (2002) analyzed the kinetics of drying of lightly salted sardine (*Sardinella aurita*), using three air temperatures (35, 40 and 45°C) and three air velocities (0.5 m/s, 1.5 m/s 2 m/s). According to the authors, for biological materials, the temperature is the main factor influencing the drying kinetics. They observed two periods of decreasing drying rate from the drying curves obtained experimentally and obtained an empirical equation to predict the data of drying kinetics.

Prachayawarakorn et al. (2002) determined the sorption isotherms and drying characteristics of shrimp in superheated steam and hot air. The isotherms were studied at temperatures of 50, 60, 70 and 80°C and the drying characteristics were observed for temperature range between 120 and 180°C for superheated steam and between 70 and 140°C for hot air. The drying rate and the effective diffusivity were used to quantify the difference between drying by superheated steam and hot air drying. Temperature is the most important parameter for the rate of effective diffusivity in drying and drying by superheated steam than hot air. When compared with drying by hot air, held by superheated steam showed a lower degree of shrinkage of shrimp. The simulated drying curves were obtained by the Fick diffusion model for spherical geometry.

The drying of tilapia fillets (*Oreochromis niloticus*) was analyzed by Medina-Vivanco (2003). The samples were previously osmotically dehydrated in solutions of binary and ternary sodium chloride (NaCl-water-sucrose) at two different times (5h and10h) and noted that the drying rates were influenced by the presence of sucrose, showing an exponential increase with the increase of solute in solution and a decrease in NaCl content in the fillet. The best fit model to the experimental data was found that the apparent diffusivity as a linear function of moisture.

Freire et al. (2003) created an experimental device for drying foods, the removal of the drying curves and drying rates of samples of fish fillet carp (*Cyprinus carp*), tambaqui (*Colossoma macropomum*) and Nile tilapia (*Oreochromis niloticus*). The drying was accomplished by forced convection of heated air over the samples. Were performed precision measurements of the variables: sample weight, flow velocity, dry bulb temperature and relative humidity. The bench consisted of a metallic tunnel equipped with: a fan, a set of adjustable electrical resistance heating of the air, a flow regulator; sensors dry bulb temperature and relative humidity, a semi-analytical digital scale, and an anemometer three data collectors. The measured data were read and stored in time intervals determined by the characteristics of each case and used in tracing the curves. In drying conditions of 62°C, 10% RH to 57.6 $cm^2$ area of trade, the carp meat sample reached the equilibrium moisture content at 350 minutes and 400 minutes in tambaqui. The drying of the flesh of tilapia and carp allowed to approach their drying rate curves of logarithmic form, indicating that dehydration occurred by diffusion inside the sample.

In order to analyze the influence of the salting process income and characteristics of cod during processing, Andrés et. al (2005) also conducted drying experiments. They used the following operating conditions: air temperature at 15°C, air velocity of 1.2 m/s and relative humidity between 50 and 65%, drying the cod until it reached a moisture content of 47%. According to tests conducted by them, temperatures above 15°C favored the hardening of the sample surface, which limited the output of water. Duan et. al (2005) analyzed the drying



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characteristics of carp (Aristichthys nobilis) in the microwave. The results showed that the moisture content decreases with increasing drying time in the microwave, when energy is fixed. The drying rate is initially rapid and then falls slowly.

Ribeiro (2005) studied the influence of osmotic dehydration using binary (water + NaCl) and ternary (water + NaCl + sucrose and NaCl + water + corn syrup) in the convective drying of mapará (Hypophthalmus edentatus). For pre-treatments was evaluated the influence of temperature, salt concentration, sugar concentration and immersion time, the answers weight loss, water loss, solids gain, number of thiobarbituric acid (TBA), solid gain / water loss (GS / PA) and water activity by Response Surface Methodology. For each solution, a condition was to make the convective drying and this condition was determined by the lower values of GS / PA and TBA. The chosen conditions were: temperature of 46°C, 22% concentration and immersion time of 7 hours for dehydration with NaCl, and 42°C temperature, 11.5% concentration of salt, 30% concentration of sugar time and 8 hours for dehydration with NaCl + sucrose and 46°C temperature, 13% concentration of salt, 32.5% of sugar concentration and time of 6 hours for dehydration with NaCl + syrup corn. Convective drying curves were obtained at 40, 50 and 60°C temperature and drying air velocity of 1.5 m/s. To fit the experimental data were used diffusion models, without considering the shrinkage, and Page. The effective diffusivity values obtained were the order of $10^{-10}$ $m^2/s$. Page model showed better fit compared to the diffusional model. In the sensory analysis of all specimens obtained great acceptability, except for sample mapará osmotic treated with NaCl + corn syrup.

The influence of cod freshness on the processes of salting, drying and desalting was investigated by Barat et. al (2006). The drying process was conducted in an industrial oven drying, following industry standards. Each experiment lasted 96 hours, changing the operating conditions when the time reached 24 hours of drying. Thus, the conditions for temperature, relative humidity and air velocity were, respectively: 20°C - 50% - 1.9 m/s; 20°C - 50% - 2.13 m/s; 22°C - 45% - 2.13 m/s ; 24°C - 40% - 2.4 m/s; 26°C - 35% - 2.4 m/s.

Solar drying (natural convection) of Indian minor fish species, such as prawn (Macrobrachium *lamarrei*) and carp (chelwa) (*Oxygaster bacaila*), has been studied by Jain (2006). The hourly data for the rate of moisture evaporation, fish temperature and relative humidity of surrounding air have been recorded for complete drying of fish. These data were used for determination of the coefficients of convective heat and mass transfer. Convective heat and mass transfer coefficients are mainly dependent on the rate of moisture transfer under the drying process, which have been determined as the function of drying time and moisture content of fish. The empirical rational models have been developed to predict the convective heat and mass transfer coefficients with moisture contents.

Pezantes (2006) analyzed the drying process of fillets of bonito (Sarda sarda). The stage of pre-drying was determined for a time of 40 minutes at a temperature of 30ºC using an air speed in this period of 0.5 m/s. The kinetics of drying was performed according to the setting conditions of this process. The experimental data were fitted to the models of Fick and Page, and this presented the best fit, and may be used to predict the drying kinetics of Bonito salted and smoked. The effective diffusivity values found for the drying process are comparable to those reported in the literature.

Pinto and Tobinaga (2006) used as raw material for their work, samples of hake (Merluccius merluccius) and sardine (Sardinella brasiliensis). Tempeture the drying air were 30, 35 and 40ºC for air velocity of 1.2 m/s. It was observed that the air temperature had a greater effect during the first phase of decreasing rate of drying, where the temperature the material begins to rise to near the temperature air drying. The existence of a constant rate period was observed for all samples investigated, due to the high initial moisture content of fish fillets, and the duration of this period ranged from 3 to 6 hours, depending sample of air conditions used. They proposed the use of a dimensionless diffusion model, which considered the shrinkage of the sample and variable effective diffusivity. They obtained good agreement between experimental data and simulated, verifying a large influence on air temperature in the process.

Analysis of tissue composition in fish often requires dry samples. Time needed to dry fish decreases as temperature is increased, but additional volatile material may be lost. Effects of 10°C temperature increases on percentage dry mass (%DM) were tested against 60°C controls for groups of lake trout *Salvelinus namaycush*, rainbow smelt *Osmerus mordax*, slimy sculpin *Cottus cognatus* and alewife *Alosa pseudoharengus* by Lantry and O'Gorman (2007). Lake trout %DMs were lower at greater temperatures, but not significantly different from 60°C controls. Rainbow smelt and slimy sculpin %DMs were lower at greater temperatures and differences were significant when test temperatures reached 90°C. Significant differences were not found in tests using alewives because variability in %DM was high between fish. To avoid inter-fish variability, 30 alewives were each dried successively at 60, 70, 80, and then 90°C and for all fish %DM declined at each higher temperature. In general, %DMs were lower at greater temperatures and after reaching a stable dry weight, fish did not lose additional mass if temperature remained constant. Results indicate that caution should be used when comparing dry mass related indices from fish dried at different temperatures because %DM was negatively related to temperature. The differences in %DM observed with rising temperature could account for substantial portions of the variability in reported energy values for the species tested. Differences in %DM means for the 60 vs. 80°C and 60 vs. 90°C tests for rainbow smelt and alewife could represent of from 8 to 38% of observed annual energy cycles for Lakes Ontario and Michigan.

The drying behavior of prawn and chelwa fish (*Indian minor carp*) has been studied under open sun drying (OSD) by Jain and Pathare (2007). The drying rate curves contained no constant rate period and showed a linear falling rate throughout the drying process. An asymptotic regression precisely represents the open sun drying behavior with the coefficient of determination and mean square of deviation as 0.9996 and $0.33 \times 10^{-4}$ for prawn and 0.9993 and $0.58 \times 10^{-4}$ for chelwa fish, respectively. Effective moisture diffusivity values were estimated from Fick's equation. The hourly effective moisture diffusivity has an exponential relation with the hourly mean moisture content of fish. The average effective moisture diffusivities were $11.11 \times 10^{-11}$ and $8.708 \times 10^{-11}$ $m^2$ $s^{-1}$ for prawn and chelwa fish drying, respectively. The open sun drying of fish falls under falling rate of drying period. An asymptotic (logarithmic) regression model could adequately describe the drying of prawn and chelwa fish on the basis of statistical parameters such as coefficient of determination, standard error and mean square of the deviation value.

Simões (2007) analyzed the Nile tilapia drying (*Oreochromis niloticus*) of the Thai variety. The author studied the influence of two treatments in the convective drying of the fillets of Nile Tilapia (*Oreochromis niloticus*), Thai strain. The first procedure was performed to study the osmotic dehydration process using a binary solution (water + NaCl) and ternary (water + NaCl + sucrose). We studied the influences of factors: temperature, osmotic solution concentration and immersion time in the answers, solid gain, water loss, GS / PA and water activity by Response Surface Methodology. For each solution, a condition was optimized, which was determined by the smallest value of the SG / PA and water activity. The chosen conditions were: 34°C, NaCl concentration of 24.6% w/w immersion time of 230min for dehydration with NaCl. For dehydration with NaCl + sucrose conditions selected were 34°C, NaCl concentration 13% w/w, time of 185min and sucrose concentration of 37% w/w. To the best conditions of osmotic dehydration obtained for each solution were performed osmotic dehydration kinetics. The second treatment was evaluated the influence of drying temperature and concentration of liquid smoke in the smoking process fillet of tilapia (Oreochromis niloticus). The condition chosen was 40°C temperature and smoke concentration of 15% w/w. Convective drying curves for the two tratametnos were obtained at 40°C, 50°C and 60ºC and 1.5 m/s air velocity. To fit the experimental



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data were used diffusion models and Page. The values obtained were around $10^{-10}m^2/s$. Page model showed better fit compared to the diffusional model. In the sensory analysis all samples had good acceptability. The sample was dehydrated in NaCl and drought, higher hardness and gumminess. In the analysis of microstructure of the treated sample with NaCl + sucrose better preserved the structure of fish and the smoking process has saved the muscular structure of smoked and dried fish.

The effects of salting and drying meat shark (Carcharhinus Sorrah) were studied by Guizani et. al (2008). According to the authors, the loss of water during salting step was faster with dry salting than brine salting, however, both methods led to the same final water content at the end of the drying process. Veja-Gálvez et. al (2008) studied the drying kinetics of lobster (Cervimunida johni) in the temperature range between 50 and 90°C. They used five semi-empirical models (Newton, Henderson-Pabisa, Modified Page, Wang-Singh) and a new model proposed by them to simulate the drying data and compare the experimental results. The analysis showed that the Modified Page model is what best describes the drying behavior of the lobster.

Experimental drying curves of sardine muscles (*Sardinella aurita*) in parallelepiped form were performed under different drying air conditions (three air temperatures: 35, 40 and 50°C ± 1°C, two air velocities: 1 and 2.5 m/s and at atmosphere humidity) by Hadrich, Boudhrioua and Kechaou (2008). A diffusive three-dimensional model was established to describe drying of sardine sample in parallelepiped form. The calculated drying curves was compared to the experimental ones in order to determine apparent moisture diffusivity. An empirical equation describing the apparent moisture diffusivity within the sardine muscles was suggested versus temperature and local moisture content of the product. A good agreement was found between experimental and calculated drying kinetics. The law of variation of apparent moisture diffusivity versus local moisture content and temperature of the product was calculated by comparing experimental and predicted drying curves. Drying kinetics of sardine muscles showed the nonexistence of constant rate period. Therefore, the drying of sardine muscles took place during the falling rate period. A diffusive three-dimensional model was developed to identify the apparent moisture diffusivity within sardine muscles during air drying by the confrontation of experimental and theoretical kinetics. The model allowed a good description of drying kinetics with an apparent moisture diffusivity presenting a linear variation versus local moisture content and an exponential dependence versus temperature. A typical internal moisture content predicted by the computer model was obtained at various positions in the dried sample and for various drying times. Therefore, the suggested model could be applied to describe moisture distribution within similar products during.

Djendoubi et. al (2009) performed experiments and mathematical research on the drying of sardines (*Sardina pilchardus*). The drying kinetics was analyzed for five air temperatures (40, 50, 60, 70 and 80°C), two relative humidities (40% at temperatures of 40°C and 50°C and the other, ambient humidity) and air velocity constant 1.5 m/s. The drying kinetics of sardine was accelerated by the increase of air temperature and was small when increasing the air humidity. Drying curves were compared with simulated results obtained by semi-empirical models. Page model was what allowed us to obtain better results than the Newton, Henderson and Pabis. Page model was thus used to simulate the drying kinetics of sardine between 40 and 80°C.

Kilic (2009) investigated the cold air drying characteristics and their effects on fish quality. For this purpose, a single layer drying with low temperature and high velocity (LTHV) is applied, and 200 g each of the salted rainbow trout (*Oncorhynchus mykiss*) is used under the following experimental conditions: drying temperature (4,10,15 and 20°C), velocity (7 m/s) and relative humidity (40 - 50%). Based on the experimental data for the salted fish samples dried, some key characteristics of such a drying process, namely moisture content, dimensionless mass loss, drying rate, drying time and the best drying temperature are determined and discussed in detail. In addition, some food quality indicators such as mass shrinkage, total volatile nitrogen, thiobarbituric acid, free fatty acids, and microbiological properties are investigated for the salted fish samples. Consequently, an optimum drying temperature is found as 4°C since the fish samples have the best quality. Therefore, it is suggested that LTHV method be applied to prevent or minimize the microbiological and biochemical decompositions of the fish. Under these important explanations, the main objective of the present study is to experimentally investigate the cold air drying characteristics and their effects on the general quality indicators of fish samples. This lack of information is the motivation for this work. Moreover, its originality comes from the application of LTHV single layer drying technique for fish quality. As a result of this work, it can be concluded that, comparing to the microbiological and chemical properties of fresh and dried fishes in the literature, the LTHV single layer drying technique contribute to improve the quality indicators of dried fish in this work. This important result indicates that LTHV single layer drying technique would be an alternative to drying methods for the perishable food industry or semi-dried foods. Accordingly, in practice, it is expected that this paper will contribute to increase the motivation on the application of LTHV thin layer drying process in perishable food industry. In terms of low temperature and high velocity application (LTHV) in drying, the experiments of the rainbow trout (O. mykiss) were conducted to determine the cold air drying characteristics and fish quality properties by taking into consideration the general food quality indicators. These conditions were confirmed in the 2nd shelf. According to the results of the observations and quality analyses, it was deduced that the decreasing drying air temperature show a correlation with quality values.

Mathematical models for predicting the plenum chamber temperatures developed by a solar tunnel dryer and the drying of tilapia (*Oreochromis niloticus*) in the solar tunnel dryer was developed, and simulated in Visual Basic 6 (Microsoft Visual Basic 6.0™) by Kituu et al. (2010). Based on Student's t-test, the simulated and actual data for both plenum chamber temperature and moisture ratio did not differ significant at 5% level of significance. In addition, the simulated and actual moisture ratios showed similar trends, and reduced exponentially with drying time. Further, the performances of models at 10% residual error interval were 83%and 81% for plenum chamber temperature and moisture ratio, respectively. Finally, strong linear correlations existed between simulated and actual data for plenum chamber temperature (R2 = 0.961), and for moisture ratio (R2 = 0.995). Therefore, the model can be used to predict the drying of Tilapia fish in a solar tunnel dryer.

Boeri et al. (2011) compared the accuracy of several drying modelling techniques namely semi-empirical, diffusive and neural network (ANN) models as applied to salted cod (*Gadus morhua*). To this end, sets of experimental data were collected to adjust parameters for the models. Modelling of codfish drying was performed by resorting to Page and Thompson semi-empirical models and to a Fick diffusion law. The ANN employed a neural network multi-layer "feed-forward", consisting of 1 input layer, with four neurons, 1 hidden layer, formed by five neurons and 1 output layer with a convergence criterion for training purposes. The simulations showed good results for the ANN (correlation coefficient between 0.987 and 0.999) and semi-empirical models (correlation coefficient ranging from 0.992 to 0.997 for Page's model, and from 0.993 to 0.996 for Thompson's model), while improvements were required to obtain better predictions by the diffusion model (correlation coefficients ranged from 0.864 to 0.959).

Pacheco et al. (2011), study the drying curves and equilibrium isotherms of extruded fish feed. The drying curves were determined at air temperatures of 50, 60, 70 and 80°C and airflow velocities of 1.5, 2.5 and 3.5 m/s). The equilibrium isotherms of relative humidity of air were obtained between 10 and 80% at 30, 40, 50, and 70°C. The experimental data were fitted for non-linear regression by using Statistica® to the models reported in the literature. The results showed that the drying curves and the equilibrium isotherms were significantly influenced by variations of the air temperature in a similar way to solid materials as described in the literature. The statistical results for models of Page and Peleg showed that the fitting of the experimental drying curve and isotherm data were satisfactory.

Effects of pre-treatments and drying temperatures on the drying rate and the quality of African Catfish Clarias gariepinus was examined by drying samples of catfish under four different temperatures (40 0C, 45 0C, 50 0C and 55 0C) and four different pre-treatment methods (Salting, Sugaring, Blanching, and Control) using an experimental dryer were studied by Omodara and Olaniyan (2012). Drying of the fish samples for all the pre-treatments at 40 0C to 55 0C occurred in the falling rate period only showing that the predominant mechanism of mass transfer in drying process of catfish is that of internal mass transfer. The drying rate increases with increase in temperature for all the pre-treatment methods and decreases with time. The statistical analysis using a factorial design shows that drying rate was significant at (F; 0.05) but there is no significant difference in the pre-treatment methods as well as the interaction between drying temperature and the pre-treatment. The quality parameters (Protein, crude fat and Ash) measured decreases with increase in the drying temperature for all the samples with the blanched samples having the highest value of % protein of 55.94 at 45 0C. The sugared samples have the least value of 43.82% at 55 0C. The control has the highest amount of Ash 5.36% at 40 0C and 4.04% for blanched samples at 55 0C. Generally the values are higher for blanched samples and low for the sugar treated samples.

The effect of microwave drying on drying rate, effective diffusivity, and energy consumption of sardine fish was examined at four different microwave powers (200, 300, 400 and 500 W) by Darvishi et al. (2013). It was found that the moisture content was reduced from 2.76 to 0.01 (dry basis) and drying time of the samples was significantly reduced from 9.5 to 4.25 min as the power input increased. Five thin layer drying models were fitted to drying data. The Midilli model was selected as the best according to $R^2$, $\chi^2$ and RMSE. The drying of fish samples took place in the falling rate period and was governed by moisture diffusion. The effective diffusivity varied from $7.158 \times 10^{-8}$ to $3.408 \times 10^{-7}$ $m^2/s$ over the microwave power range. No significant differences were observed between the specific energy consumption of microwave-dried sardine fish ($\alpha = 0.05$). However, minimum specific energy consumption (3.78 MJ/kg water) was obtained at 500 W microwave levels.

Toujani et al. (2013), study the effect of air-drying process on the convective drying kinetics of silverside fish and to determine the suitable thin-layer drying model. This product is chosen for its high-protein content and nutritional value, and its use as a very important foodstuff in developing countries. A nonlinear regression procedure was used to fit experimental drying curves with most used empirical mathematical models available in literature. The comparison criteria between experimental and calculated data were the coefficient of determination and the reduced $\chi^2$. It was found that the Midilli *et al.* and two-term models give the best fit. The effective diffusivity was determined to be $8.7630 \times 10^{-10}$–$3.2131 \times 10^{-09}$ $m^2/s$ in the temperature range of 45–70C and in the relative humidity range of 20–40%. The activation energies for moisture diffusion were calculated to be varied from 35.6471 to 37.2625 kJ/mol.

According Aberoumand and Karimi reza abad (2015), the process selection for fish drying by fish processer depend on the fish species and consumer demand. Three fish species such as Govazym stranded tail, Hamoor and Zeminkan were purchased from market fish Behbahan. Govazim stranded tail, Hamoor and Zeminkan hold in 70°C oven for 24 h until completely dried. Fish drying carried out in the sun by placing it on a tray with a traditional outdoor sunlight at temperatures up to 37°C for 3 days. International standard AOAC methods were used for nutrients analysis of dried fish samples, Protein content of Hamoor in the oven method (%85.66 ±0.26) was higher than in others. The highest fat content (%5.56+0.04) in the sun method found for Hamoor and the lowest content (%3.22+0.12) is also in solar dry found for Govazym. The results showed that sun method creates a relative stability of the compounds. The oven drying method had a good effect on decreasing drying time. It is recommended that the fish drying with electric oven method is more suitable for feeding health nutrition and good shelf life.

A study was conducted to assess the effect of drying methods and pre-treatments on shelf-life and microbial quality of dried fish, by Tarle et al. (2015). The experiment was conducted in factorial arrangement of 2×3×2 with two drying methods (sun and oven drying,) three fish species (tilapia, cat fish and carp) and two preservatives treatment (garlic and ginger juice) laid out in Completely Randomized Design (CRD). Fresh fillets were analyzed for their microbiological quality. Drying reduced the moisture contents making it safe for long term storage. The dried fillets were stored at ambient condition and the samples were analyzed for microbial status every twenty days starting from the end of drying operation. Fresh fillet and untreated dry fillet were used as control. In the fresh fillets, a high load of aerobic bacteria of 5.11 log10 cfu/g was observed on carp, and E.coli was detected in all three species whereas no Salmonella spp.

Nuwanthi et al. (2016), study the effect of low levels of salt and combined effect of low salt and spices on quality of dried fish. The study was carried out using eviscerated and cleaned up GoldstripeSardinella with 0% (T1), 5% (T2), 10% (T3) salt levels and two different combinations of salt and spices (1%salt with 0.2%turmeric, 0.5%chlli, 0.5%pepper (T4) and 2%salt with 0.2%turmeric, 0.2%chlli, 0.2%pepper (T5)). Hot air dehydrator (65-70 °C) was used for fish drying. Chemical (moisture, water activity ($a_w$), Total volatile nitrogen (TVN), and sodium chloride), physical (texture and rehydration), microbiological (APC, mould and yeast count and coliform count) properties and sensory attributes of experimentally prepared dried fish were investigated. The chemical parameters for all treatments were significantly different ($p<0.05$) while physical parameters were not ($p>0.05$). T2 indicated the best chemical quality. The values for moisture, $a_w$, sodium chloride, TVN, texture and rehydration for T2, were 11.6584±0.03, 0.591±0.002, 12.43±0.15, 59.43 mg/100g±12.86, 1.54kg±0.14 and 12.70±3.54 respectively. T2 and T3 had least microbial counts while T1 and T5 had highest microbial count. But T5 had highest scores for all sensory attributes indicating consumer preference for low salt and spicy taste regardless of high TVN content and poor microbial quality. Therefore, it is essential to improve the methodology to enhance the quality of low salt and spices added dried fish

## FINAL CONSIDERATIONS

Fish drying has many significance: generally huge amount of fish caught from the internal water reservoir like pond, bill, stream etc.; if it become not possible to consume or sell all fish then drying is a suitable way for preserving; fish collected from sea needs to preserve by drying; preservation is also needed in such place where there is poor or no transportation system; fish is very fast rotting being. So, drying is must to keep them free from rotting; drying fish has a great demand in the market. It also help to meet up the fish or protein demand; nowadays drying fish is also being used as nutritious protein food for poultry; dried fish stays for long time and as the drying weights less so, it costs less while transporting (ROYSFARM, 2016).

Therefore, drying of fish has great importance in several regions of the world. The correct definition of drying procedures of this product is crucial in what concerns energy minimization and minimal time of kiln residence, without compromising the final product quality.

The results analyzed showed that the drying curves of fish were significantly influenced by variations of the air temperature and air relative humidity.

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