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Dissertation thesis

Influence of drying method on drying kinetics and organoleptic properties of selected Cambodian fresh water fish species

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DECLARATION

I, Anna Hubáčková, hereby declare that this thesis entitled "Influence of drying method on drying kinetics and organoleptic properties of selected Cambodian fresh water fish species" submitted in partial fulfillment of the requirements for the degree of Ph.D., at the Faculty of Tropical AgriSciences of the Czech University of Life Sciences Prague, and the work presented in it is entirely my own work. Information derived from the published or unpublished work was acknowledged in the text and in a list of references is given.

May 1st 2017

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Anna Hubáčková

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ABSTRACT

A great part of the population in Cambodia is strongly dependent on agriculture and one of the most important means of food production is freshwater aquaculture. Drying was investigated as one of the promising techniques for fish processing in this country.

The objective of this study is to investigate the influence of drying under different conditions on selected freshwater fish species, namely swamp eel *(Monopterus albus)*, Nile tilapia *(Oreochromis niloticus)*, walking catfish *(Clarias batrachus)* and giant snakehead *(Channa micropeltes)*, and to compare their properties influenced by drying pre-treatments by salting for 2 hours, 4 hours and overnight.

Fish drying was tested in a solar dryer and an electric oven. The mean drying temperature in the solar dryer was 55.6 °C, the relative humidity of the drying air was 19.9 % and the average value of the velocity of the drying air was 0.37 $m \cdot s^{-1}$. Further, the overall average efficiency of the dryer was 12.37 % and the average evaporative capacity was equal to 0.049 $kg \cdot h^{-1}$.

The drying conditions in the electric oven were constant, the temperature was 50 °C and 60 °C at 26.2 to 30.8 % and 18.9 % of relative humidity.

The experimental data from drying of unsalted fish data were fitted in drying models. The acceptability of the drying models was performed by correlation analyses (R^2), standard error of estimate (*SEE*), and root-mean-square error (*RMSE*) values for solar dryer and electric oven thin-layer drying for unsalted samples. The cubic model shows the best results.

Drying curves of salted samples are mostly logarithmic and it was determined that curing fish in salt for 2 to 4 hours is sufficient. It was determined that the temperatures tested are sufficient enough to decrease the water activity of fish samples regardless of the duration of salting treatment. Based on sensory evaluation of the dried fish samples it was determined that most preferred fish from the species tested for drying in the solar dryer is swamp eel followed by walking catfish.

KEY WORDS

Cambodia, Fish, Drying, Drying kinetics, Mathematical modelling, Organoleptic properties

ABSTRAKT

Převážná většina obyvatel Kambodže je závislá na zemědělství a jedním z nejdůležitějších odvětví v produkci potravin je chov sladkovodních ryb, mezi jejichž nejrozšířenější způsob zpracování patří sušení.

Cílem této práce je vyzkoumat vliv sušení v rozdílných podmínkách u čtyř běžných druhů sladkovodních ryb: hrdložábříka bílého *(Monopterus albus)*, tlamouna nilského *(Oreochromis niloticus)*, keříčkovce žabího *(Clarias batrachus)* a hadohlavec červeného *(Channa micropeltes),* a porovnat jejich vlastnosti, které byly u části zkoumaných ryb ovlivněny nasolováním před sušícím procesem po dobu 2 hodin, 4 hodin a přes noc.

Sušení v solární sušárně probíhalo při průměrné vnitřní teplotě 55,6°C, relativní vlhkosti vzduchu 19,9 % a rychlosti proudění vzduchu 0,37 $m \cdot s^{-1}$. Následně byla u solární sušárny vypočtena účinnost 12,37 % a odpařovací kapacita 0,049 $kg \cdot h^{-1}$.

Sušení v elektrické sušárně bylo provedeno za konstantní teploty 50 °C a 60 °C s relativní vlhkostí vzduchu 26,2 až 30,8 % a 18,9 %. Na základě koeficientu determinace (R^2), standardní chybě odhadu (*SEE*) a střední čtvercové chyby (*RMSE*) byl vybrán kubický model pro sušení v solární a elektrické sušárně.

Sušící křivky solených vzorků jsou převážně logaritmické a z průběhu sušících křivek a ze stanovení obsahu soli ve vzorcích vychází, že doba nasolení mezi 2 – 4 hodinami je dostačující. Dále bylo stanoveno, že testované teploty sušení zajišťují dostatečné snížení vodní aktivity (a_w) bez ohledu na dobu nasolování. Senzorická zkouška uvedla, že z vybraných druhů ryb jsou pro konečného spotřebitele nejlépe přijímány vzorky z hrdložábříka bílého, následovány keříčkovcem žabím.

KLÍČOVÁ SLOVA

Kambodža, Ryby, Sušení, Kinetika sušení, Matematické modelování, Organoleptické vlastnosti

PREFACE

Despite continued technological development and ever increasing globalization, a great part of the population in developing countries suffers from lack of access to electricity. Cambodia is an example of a country where only 34 % of population had access to electricity (WBG, 2011). At the same time, more than 85 % of the population in Cambodia is strongly dependent on agriculture, and freshwater aquaculture is one of the most important means of food production (Hortle, et al., 2004). In 2009, over 420,000 of people were directly employed in the fisheries sector, accounting for almost 5 % of the Cambodian workforce. Furthermore, it is estimated that livelihood of more than 2 million people depends in some way on this sector (FAO, 2014).

Fresh fish meat contains up to 80 % of water by mass and it is considered to be a highly perishable material. The high water content results in an extremely short shelf-life when left unprocessed. Since preservation enables storage and transport and thus opens up the possibility of trade, proper preservation techniques are significant not only for ensuring the local food supply but may stimulate economic development in a wider region. The benefits to farmers themselves are in allowing them to maintain a constant and adequate price of their products, improving their bargaining position and widening their possible market. Many preservation techniques such as fermenting, smoking, frying, salting, and conversion into fish sauce or paste were developed. Solar drying is one of the most attractive and promising solar energy systems, as it is simple, does not require much initial investment, and can be very effective, especially in tropical regions (Fudholi, et al., 2013). Preservation techniques in general depend on processes that lower water activity of the preserved food (a_w) and thus inhibit or prevent the activity of undesirable microorganisms and enzymes that require aqueous environment, as well as the growth of mould and fungi. In drying, this is achieved by actively removing water itself from the food matrix.

Since there is only limited access to electricity and other energy resources in rural Cambodian communities, most of the local fish production is processed using only the most basic preservation method, which is open sun drying. While it is the most easily accessible means of preservation, open sun drying has major disadvantages.

First, it requires a large open space area exposed to direct sunlight. Second, it is generally inefficient. The fish are often dried to an unstable moisture content, which is conducive to microorganism proliferation, and consuming such food may lead to food poisoning. Third, open sun drying exposes the dried food to dust, bird excrements, or insect infestation and as such it is highly unhygienic and may actually pose a health risk to consumers (Suzuki, 1988). Apart from the simple open sun drying method, there are certain more advanced drying methods that make use of solar energy. The solar drying system is a significantly more hygienic and effective alternative to open air drying, although it is still affordable and simple. There are several classes of dryers: natural and forced convection solar dryers, direct solar dryers, and indirect solar dryers. Many studies from Asia are specifically focused on processing of plant products by drying (Fudholi, et al., 2013) but less data is available for meat and fish drying. Thus, the purpose of this study is the evaluation of solar drying of four common Cambodian fish species as an alternative to traditionally used open sun drying and conventional dryers powered by electricity. The evaluation of mathematical models for thin layer solar drying of fish as well as the influence of drying method on organoleptic properties of dried fish were investigated during this study.

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m_f	Mass flow rate [kg · s^{-1}]
C	Specific heat of air [J · kg^{-1} · °C^{-1}]
T_0	Outlet air temperature [°C]
T_i	Inlet air temperature [°C]
A_C	Collector area [m^2]
I	Global solar radiation on the plane of the collector [W · m^{-2}]
W	Mass of water removed from a wet material [kg]
L	Latent heat of vaporization of water [kg^{-1}]
g_0	Initial total mass [kg]
M_i	Initial moisture content on wet basis [%]
M_f	Final moisture content on wet basis [%]
M	Moisture content of the product at any time on wet basis [%]
m	Mass of the product at any time [kg]
d_m	Mass of dry matter [kg]
m_0	Mass of the fresh product [kg]
MC	Moisture content of the product at any time on dry basis
DR:	Drying rate [kg · kg^{-1} · h^{-1}]
E:	Evaporative capacity [kg · h^{-1}]
X_{2m}	Dryer outlet absolute humidity
Xa	Ambient absolute humidity
R_{reh}	Final rehydration ratio
m_r	Mass of the product after rehydration [kg]
m_t	Mass of the product before rehydration [kg]
R_{rec}:	Final recovery ratio
MR	Moisture ratio
MC_e	Equilibrium moisture content on dry basis
MC_i	Initial moisture content on dry basis
D_{eff}	Effective moisture diffusivity [m^2 · s^{-1}]
R^2	The coefficient of determination

R	Correlation coefficient
$MR_{exp,i}$	Experimental value of moisture ratio
$MR_{pre, i}$	Predicted value of moisture ratio
N	Number of observations
RMSE	Root mean square error
SEE	Standard error of estimate
R^2_{adj}	Adjusted R-Squared
A_w	Water activity
p_{H_2O}	Partial pressure of water vapour above the product [Pa]
$p^0{}_{H_2O}$	Partial pressure of water vapour [Pa]
t	Drying time [s]
z	Number of constants in drying model
L	Half-thickness of the samples [m]
a, b, c, y_0, x_0	Constants

Greek Symbols

ΔM	Weight loss in one hour interval
ΔT	Difference in time reading [h]
ηc	Thermal efficiency of a solar collector [%]
ηp	System drying efficiency

1 INTRODUCTION

1.1 OVERVIEW OF STUDY AREA

1.1.1 LOCATION AND CLIMATE, DEMOGRAPHY AND HEALTH CONDITION

Located at Peninsula of mainland Southeast Asia, Cambodia´s area is mostly landlocked and bordered by: Thailand (west and northwest), Laos (north) and Vietnam (east and southeast). Cambodia has got a coastline (about 300 km) along the Gulf of Siam. The country´s interior is usually flat or with low-lying central plains of the Mekong, which are surrounded by mountainous and highland regions (Ahmed, et al., 1998; WBG, 2011). The Darlac Plateau constitutes a part of the eastern border with Vietnam while the Cardamom and Damrei mountains are in the southwest. The Dangrek range, meaning "Carrying-Pole Mountains" in Khmer, makes up a large part of the north-western border with Thailand (Lamberts, 2001).

Cambodia´s population is 15.4 million. 52 % of the population live in the central plains, 30 % in the surroundings of Lake Tonle Sap, 11 % in the highlands and mountains, and only 7 % along the coast. The national average population density is low for the region at 75 people per km².

Total country area is 18,104,000 Ha and agricultural area is 5,655,000 Ha. Forests cover 56.5 % of the total area (9,966,600 Ha), arable land stretches on 22.7 % (4,000,000 Ha), the area of permanent meadows and pastures is 8.5 % (1,500,000 Ha), permanent crops cover an area of 0.9 % (155,000 Ha) and other land is 11.5 % (2,030,400 Ha) of an area (FAO. 2016). The climate in Cambodia is tropical, with characteristic seasons (Fig. 1.1): dry season (November-April), with cooler temperatures, particularly between November and January. Average temperatures are relatively uniform across the country. The highest temperatures (26 to 40 °C) are in the early summer months before the rainy season begins and throughout the rest of the year they remain at 25 to 27 °C. The wet season arrives with the summer monsoon, in May-November, bringing the heaviest rainfall to the northwest and southeast. The monsoon-driven rainy season (May-October) brings moisture that accounts for anywhere between 80 to 90 % of the country's annual precipitation (mean monthly rainfall at this time of year can be more than 5000 mm in some areas) and south-westerly winds ushering in clouds. The solar irradiation over the country is consistent and high, bringing approximately 6 to 9 hours of solar irradiation in average per day. Its Global Horizontal Irradiation (GHI) ranges between 1,450 and 1,950 kWh/m2 /yr; some 65% of the country is estimated to have GHI levels of 1,800 kWh/m2 /yr or more. Direct normal irradiation (DNI) is also high, with most of the country having DNI levels of 1,100– 1,300 kWh/m2 /yr, meaning there is a big potential for broad use of solar energy (WBG, 2011).

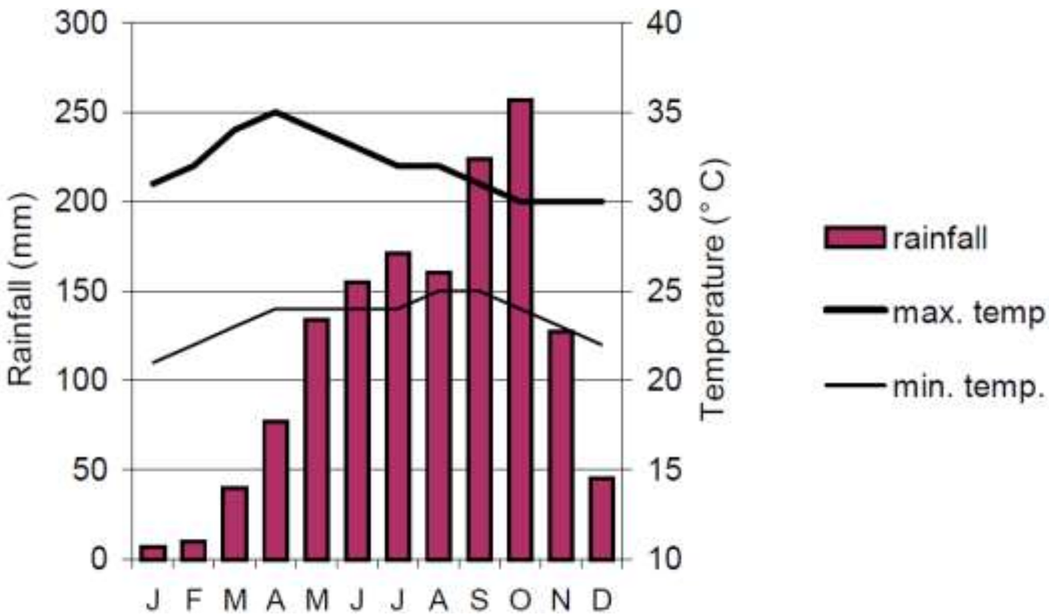


Figure 1.1 Average monthly rainfall and minimum / maximum temperatures for Phnom Penh (Lamberts, 2001)

Cambodia is one of the more disaster-prone countries in Southeast Asia, affected by floods and droughts on a seasonal basis and experiencing increased rainfall and prolonged drought. Changes in precipitation and temperature negatively affect current yields, especially in irrigated wheat and rice.

The aforementioned rainfall also plays a role in influencing the size of mosquito populations and mosquito habitats representing the risk of mosquito-borne diseases. Only 55 % of the population in Cambodia has access to public health facilities hence Cambodia has one of the highest rates of fatalities from malaria in Asia. Incidence of dengue fever, malaria and water-borne diseases are likely to become more prevalent, while food insecurity related to extreme events also threatens the lives and livelihoods of millions of Cambodians (WBG, 2011).

Cambodia's vulnerability to climate change is linked to its characteristics as a post-civil war country. During the 20-year period from 1987 to 2007, a succession of droughts and floods resulted in significant loss of life and considerable economic loss. Climate change may bring not only negative impacts but also new economic opportunities, but the lack of available information hampers the country's ability to respond to a changing climate environment (WBG, 2011).

Figure 1.2 Map of Cambodia (Ontheworldmap.com, 2012)

Asia has relatively few natural lakes, with only about 15.4 % of the global total area of 1.236 million km². Most of these Asian lakes are confined to the volcanic areas of the continent, primarily the Indonesian and Philippine archipelagos and northern India. There is one major exception, the Great Lake (Tonle Sap) in Cambodia (Fig. 1.2).

The lake is characterized by its unusual hydrology, it expands from 2,000 – 3,000 km² in the dry season to 10,000 - 12,000 km² in the flood season (it expands by 4 - 6 times). This expansion is caused mainly by the flow reversal of the Tonle Sap River (De Silva & Funge-Smith, 2005; FAO, 2011). During the monsoon season, the Great Lake covers around 6 % of Cambodia's total land area.

At the beginning of the dry season the Tonle Sap River level decreases and water begins to drain from the Great Lake (FAO, 2011). Groundwater supplies serve both domestic uses and irrigation and the Mekong River and its tributaries are the most abundant sources of water (only groundwater amounts are not sufficient to support large-scale irrigation) (WBG, 2011). A very important part of the national and global natural heritage is a rich diversity of aquatic species and definitely aquatic environment. Important wetlands, mangroves, sea grass areas, flooded forests and coral reefs are significant parts of aquatic habitats (Khim, 2010).

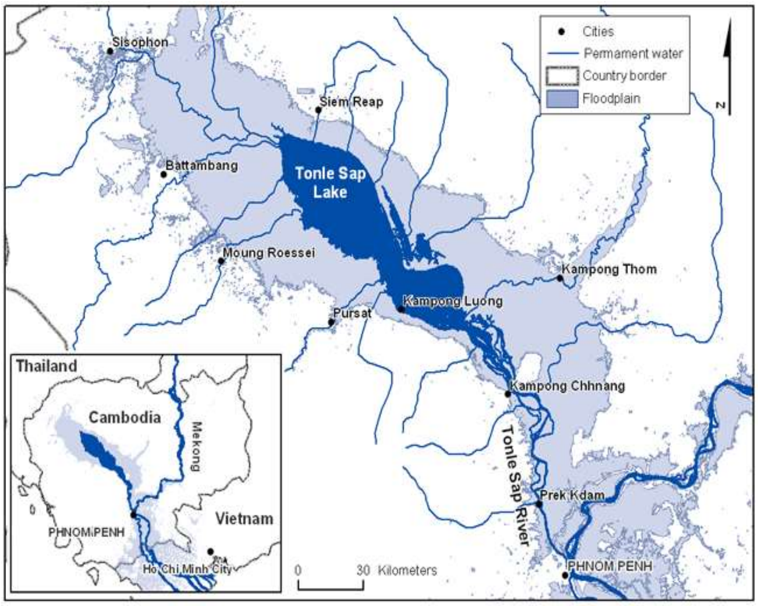


Figure 1.3 Tonle Sap lake and channel (Lamberts, 2001)

TONLE SAP ECOSYSTEM

In the Tonle Sap ecosystem grow predominantly diatoms and Green algae. It makes up almost two thirds of the plankton species. The rest is blue-green algae, some *Xantophyta*, *Chrysophyta*, *Pyrrophyta* and *Euglenophyta*. Zooplankton communities vary throughout the year and the number of zooplankton species and zooplankton density in the flooded areas is almost one hundred times higher than in the river.

The flooded forest is also a rich source of wide range of plants used as food and for medicinal purposes for man and husbanded animals. For example wood in particular is collected for domestic use as fuel wood or as charcoal and as construction material and lianas are collected for fishing gear production and for furniture. In many places, the original vegetation is entirely cleared. Cultured crops consist of maize, lotus, rice, vegetables and mung bean. Floodwater is used for irrigation and for cultivation of flood-recession rice. In some parts are places for growing of grasses that are used for grazing of herded animals (ducks, cattle, pigs) (Lamberts, 2001).

Aquatic snakes, frogs, toads, and other reptiles and amphibians are very common, even though larger species like crocodiles and turtles have disappeared altogether or become rare as the result of excessive hunting (Lamberts, 2001; Khim, 2010). Forest around the water sources hosts the largest breeding water bird colony anywhere in Southeast Asia and the ecosystem is home to some of the world's rarest and most endangered bird species that play an important role as fish predators and in nutrient recycling. Larger animals are captured for trade, as pets or as food, while forest animals and their products that are collected include honey and beeswax.

Extensive migration of fish between the Mekong and the Tonle Sap ecosystem determines the initial stock levels and the potential final production. Harvested fish are either consumed directly or processed for added value (smoking) or for preservation (smoking, fish sauce production, drying and fermented *prahoc*) (Lamberts, 2001). The most commonly caught fish is the small river carp (*Henicorhynchus lobatus* Smith, 1945) (Khim, 2010). Juvenile specimens of fish collected from the wild form the majority of seed for local aquaculture in the Tonle Sap (Lamberts, 2001).

Threats of aquatic biodiversity are represented by fisheries activities and by activities arising from outside the fisheries sector. Fisheries sector influences the biodiversity by exploitation of fish at time of fish migration, that are vulnerable stages (spawning times), fishing in sensitive areas (spawning grounds) and using destructive fishing methods (poisons, explosives and electrocution). Large numbers of highly migratory fish migrate at the same time, making them vulnerable to intensive fishing (fish licenses have a short duration that leads to encouraging of fishers) (Coates, et al., 2003).

In Cambodian freshwaters are found more than 500 fish species. Local fish species are categorised as ‘”Black” or “White”.

‘White fish’ is a group of species that are mainly associated with the main channels and streams, it means mainly riverine species, but which also migrate into the floodplains. Many species undertake both longitudinal (lake - channel - Mekong) and lateral (main water - floodplain) migrations. Most white fishes have rather high requirements for water quality (Lamberts, 2001; Khim, 2010; FAO, 2011).

This group include the family *Cyprinidae*, especially *Hampala macrolepidota* Kuhl & Van Hasselt, 1823, *Cirrhinus microlepis* Sauvage, 1878, *Henicorhynchus siamensis* (Sauvage, 1881), *Henicorhynchus lobatus* Smith, 1945, *Barbonymus altus* (Günther, 1868), *Barbonymus gonionotus* (Bleeker, 1849), *Osteochilus melanopleurus* (Bleeker, 1852), *Labeo chrysophekadion* (Bleeker, 1849), *Leptobarbus hoevenii* (Bleeker, 1851), *Cyclocheilichthys enoplos* (Bleeker, 1849), *Cyclocheilichthys apogon* (Valenciennes, 1842), *Thynnichthys thynnoides* (Bleeker, 1852).

Also included is family *Siluridae*, especially fish *Wallago attu* (Bloch & Schneider, 1801), *Phalacronotus apogon* (Bleeker, 1851).

Other fish in the group are from family *Pangasiidae,* especially *Pangasius larnaudii* Bocourt, 1866, *Pangasius pangasius* (Hamilton, 1822), *Pangasianodon hypophthalmus* (Sauvage, 1878).

This group also include the family *Channidae*, especially *Channa micropeltes* (Cuvier, 1831), *Channa striata* (Bloch, 1793),

Last but not least, fish are also included from family *Notopteridae*, especially *Notopterus notopterus* (Pallas, 1769), *Chitala ornata* (Gray, 1831), family *Eleotridae*, especially *Oxyeleotris marmorata* (Bleeker, 1852), family *Osphronemidae*, especially *Trichopodus pectoralis* Regan, 1910, *Trichopodus microlepis* (Günther, 1861), family *Clariidae,* especially *Clarias batrachus* (Linnaeus, 1758) and family *Anabantidae*, especially *Anabas testudineus* (Bloch, 1792) (Lamberts, 2001; FAO, 2011; Fishbase, 2016).

"Black fish" are mostly carnivorous or detritus feeders and are able to survive in wetlands areas and in swamps all year around, engage in only limited lateral migrations. This group of fish include species that are able to survive under less favourable water conditions. A quite high number of them is air breathers, in particular they can tolerate low dissolved oxygen levels for at least some time and they have specific adaptations for living under such conditions. This category includes family *Channidae*, especially species *Channa micropeltes* (Cuvier, 1831), *Channa striata* (Bloch, 1793). Also group consist from *Clariidae,* especially species *Clarias batrachus* (Linnaeus, 1758), family *Bagridae,* especially consist by *Mystus* species and family *Osphronemidae* consist by *Trichogaster* species and last but not least, family *Anabantidae*, especially *Anabas testudineus* (Bloch, 1792) (Lamberts, 2001; FAO, 2011; Fishbase, 2016).

1.1.2 ECONOMY AND AGRICULTURE FOCUSED TO FISHERY SECTOR IN CAMBODIA

Cambodia is a low income country located in the Southeast Asia region. Agricultural resources consist primarily of 4 million Ha of cultivated land (WBG, 2011); (FAO, 2014). Agriculture contributes by 37 % to the GDP and employs about 67 % of the workforce in 2012, thus remains the backbone of Cambodia's economy - 80 % of its population lives in rural areas (FAO, 2014). The country's economy relies secondary on industry and services (WBG, 2011).

The majority of the population relies on agriculture based on primary commodity and source of income for farmers - irrigated rice (75 %), industrial crops (primarily rubber) and others. The majority of the population relies on agriculture based on primary commodities, especially - irrigated rice (75 %) and industrial crops (primarily rubber). The population depends on agricultural production as a source of household income and food supply (FAO, 2014; FAO, 2015). The country has experienced rapid economic growth since 1993, with an annual GDP growth of 7.3 % in 2012 (FAO, 2014). The contribution of fisheries to GDP (gross domestic product) in 2004 was estimated by Mekong River Commission (MRC) to be

US$ 350 million/year representing over 12 % of GDP, but the true value for the fisheries harvest may be much higher than reported official data (Khim, 2010).

Globally, inland fisheries contribute only about 10 % to world’s fish production. Asia is the leading producer of inland fish, accounting for over the 80 % of total production. Cambodian fish production is the highest in Asia (De Silva & Funge-Smith, 2005). The inland fisheries in Cambodia produced 390,000 t of fish and overall Cambodia’s fisheries produced an estimated 515,000 t of fish in 2009 (FAO, 2011).

Fisheries provide significant opportunities for integration into rural farming livelihoods, offer alternative sources of income and help to buffer against shortfalls in agricultural production (De Silva & Funge-Smith, 2005). Overall, the fisheries sector plays an important role in food industries development, food security, and poverty alleviation in many parts of the world (Opara, et al., 2007). Cambodia’s fisheries (freshwater, marine fisheries and aquatic resources) provide seasonal, part-time and full-time employment for up to four million people. It means fishery provides employment for around 1,420,000 people directly through production and more than 2.5 million people are thought to derive some type of livelihood benefit from involvement in the fisheries sector, such as processing and trading of fishery products (De Silva & Funge-Smith, 2005; FAO, 2011; FAO, 2014). The fish trading consist of a complex of numerous intermediaries. Fish is collected at landing sites, transported to local retail markets or consolidated by wholesalers into larger quantities for export or shipment to urban centres. Processing and trading operations vary in size from family scale to large scale. Usually, families have a production for their own consumption or barter for other goods through small to medium and large commercial operations. The system includes grading, processing, preservation, storage, transportation and trade of fish and fishery products. These activities are conducted throughout the country. Fish which enter the capital must first pass through one of the municipality’s three fish distribution centres. In Phnom Penh itself, there are plenty of official retail markets, with over 2,000 traders, mainly women. It follows that fisheries sector is especially important in the rural areas where there are few job opportunities in this family system (Khim, 2010).

The fisheries sector makes a very significant contribution to domestic food security especially to rural communities. The Cambodian people have a strong preference for freshwater fish and the domestic demand for fish is expected to increase with population growth which will lead to pressure on the fisheries resources. Fish consumption on per capita basis was 33.0 kg in 2007 and other studies show consumption as high as 60 kg/person/year plus with over 5 kg of other aquatic animals/person/year (FAO, 2011). A household in Cambodia spends 18.2 % of its monthly expenditure on fish, meat (pork, beef, poultry) and eggs. Fish is half of this expenditure at 9.1 % of total expenditure, while meat (pork, beef), poultry and eggs are 5.1 %, 2.6 % and 1.3 % respectively. The richest households in Cambodia spend only around 5 % of their monthly expenditure on fish, but the stated percentage expenditure is fairly consistent across most wealth groups. Fisheries sector provides 81.5 % of the animal protein in the national diet and also provides a critical source of essential vitamins and micro-nutrients (Khim, 2010) however fish consumption tends to vary geographically (Lamberts, 2001).

1.1.3 FISHERY SECTOR IN CAMBODIA

The country's freshwater fisheries are among the most productive in the world due to the presence of large floodplains around the Mekong River that flows through eastern Cambodia and the mentioned Tonle Sap River in the west, which cuts across the country diagonally. The two rivers meet in Phnom Penh and continue to flow as the Bassac and Mekong Rivers into Vietnam (Ahmed, et al., 1998; FAO, 2011). Permanent fresh water area is 4,520 km² and during the rainy season, shallow flooded areas created provide extremely high fisheries productivity and diversity (FAO, 2011). Various other smaller rivers and streams run off this main drainage system, and are all important for fishing and transportation (Ahmed, et al., 1998). Agricultural production is dependent on the annual recession and flooding of the Tonle Sap Lake and the Mekong River, which bring fertile alluvium soils to other land. Water management and irrigation practices are supporting the rice production that is associated with fishery benefits.

In Cambodia, the majority of inland fisheries require very little entry capital and are often practiced as part-time job (environmentally non-destructive). Examples include the operation of a few traps in a channel or paddy field and children foraging for shellfish and other aquatic animals in wetland areas and paddy fields (De Silva & Funge-Smith, 2005). Women are engaged in a variety of fisheries-harvest activities, small-scale capture fisheries, gathering aquatic plants and animals, and aquaculture. In the Tonle Sap region, women fish on fishing grounds nearby their households, which allows them to take care of their household responsibilities. In coastal areas, women collect crabs and other coastal aquatic resources nearby (Lentisco & Lee, 2015).

A global fish harvest destined for marketing is still largely hunted traditionally, although the contribution of farmed fish (aquaculture) is increasing rapidly (Opara, et al., 2007). Aquaculture includes mainly cage culture (*Oreochromis niloticus, Pangasianodon hypophthalmus* and *Clarias batrachus)*, pond culture and fish culture in rice fields. Cage culture originated from the need to manage non-marketable sized fish and has been a common practice in Cambodia for centuries. In Cambodian "industrial" inland fisheries, called the *dai* fishery, most of the catch is for daily consumption, because in many rural areas there is an absence of refrigeration. The catch is processed into various traditional products, such as fish pastes, sauces, particularly fermented fish *prahoc*, or a dried fish. A portion is consumed locally as a fresh fish and a small proportion of high-valued species is exported to neighbouring countries (De Silva & Funge-Smith, 2005; FAO, 2011). Freshwater fish and fisheries products are highly marketed and distributed much more than the marine fisheries products in local markets (Khim, 2010). Domestic demand for marine fisheries products are limited and most marine fisheries products are exported (FAO, 2011).

INLAND FISHERIES

Catch of freshwater fisheries is segmented into different scales defined legally by the Minister of Agriculture, Forestry and Fisheries proclamation. Small-scale fishing ranges from 32 % to 41 % in Cambodia and refers to subsistence fishing. It shall be operated in the family-scale fishing areas at any time in the open access area by using small-scale fishing gears.

Middle-scale fishing is in the range between 23 to 30 % in Cambodia and shall be operated only in the open access area by using middle-scale fishing gear characterized according to the size, type and numbers of those gears. Gears used are large arrow shaped traps with bamboo fences, traps, gillnets, encircling seines and long lines. Migrating fish are guided up to bamboo fences to the arrow-shaped head of the gear. Subsequently fish are gathered in large submerged drum-shaped traps (Lamberts, 2001).

Large-scale fishing ranges from 12 % to 21 % and shall be operated only in fishing lots by using large-scale fishing gears (Khim, 2010). Used techniques in the large-scale fishing operations depend on the fishing location in the ecosystem. Surrounding floodplain and inside the Tonle Sap lake fishing is mainly done by seining. Barrage fisheries is used in the delta formed at the point where the Tonle Sap channel connects to the lake (it is focused on longitudinally migrating fish). The bag net is locally called dai. It is used in fishing lots on the Tonle Sap channel (Lamberts, 2001). Seining fisheries consist of the installation of an extended system of bamboo fences that are being erected when the floodwaters have considerably receded. Subsequently, the fish are systematically chased out of parts of the area and collected in a large fenced holding area. A barrage is constructed there made of wooden poles and bamboo fencing that blocks the entire width of a branch of the channel. Dai fisheries use large cone-shaped bag nets of about 100 m of length and with a mouth diameter of 25 m. Nets are suspended from floaters and anchored in the channel, where they are held open by the current.

For operating fishing is needed logistical coordination for ensuring all inputs like equipment, labour, guarding, actual fishing, marketing, transport and processing of the catch. These inputs are large and labour-intensive and require investment. Especially some fishing operations that use large amounts of wood and bamboo. These are inputs only for one or at most two fishing seasons (Lamberts, 2001).

TONLE SAP AQUACULTURE SYSTEM

Aquaculture has a long history in Cambodia. The production of higher-value fish relies on the provision of feed made from lower grade fish that are caught from the river and other wetlands. Fisheries and farming are combined when fish are raised in the waters that cover rice fields. This practice relies on recruiting wild stocks of fish and other animals. Aquaculture development can be very beneficial, but it should be based upon the same principles required for capture fisheries development and management (Coates, et al., 2003; Khim, 2010).

Most of the production comes from pens, cages, or a combination of these. Ponds only recently started producing a considerable amount of fish. Fish species used in these aquaculture systems are juveniles from the wild (carnivorous snakehead species) or caught as fingerlings. Firstly, fish will be cultured by nursery farmers until they reach 250 g and then they will be sold to grow-out farmers. Fluctuating water levels do not only affect the position of the cages and the depth of water in which they can be kept, but also determine the amount of seed and of trash fish available as feed. Siltation may hamper the movement of cages that are constructed from bamboo or wood with a wooden frame, often in the shape of a boat and in a wide variety of sizes. Direct impacts on the cultured fish are probably limited since most of the species naturally occur in habitats with poor water quality: high temperatures, low dissolved oxygen levels, etc (Khim, 2010).

1.1.4 FISH AND THEIR ROLE IN HUMAN DIET

Fish are after mammals and birds the third most important source of meat. In some countries, the fish consumption is as high as the consumption of other meat. The global consumption of fish and other sea food is recently increasing, which relates to the effort to consume less fat. The larger part of global fish consumption is formed by hunted sea fish, freshwater fist constitute the lesser part (Pipek & Pour, 1998).

It is commonly known that the food consumption of the typical Cambodian consists primarily of fish or fish products and rice. In poor households fish intake is 13 and 83 g raw whole fish per person per day. The frequency of intake of small fish made up to 50 to 80 % of all fishes eaten during the fish production (Bala & Hossain, 2012). The contribution of protein to the overall energy supply has not changed over the last 30 years (the main source of protein in rural areas is prahoc). Meanwhile the total energy from carbohydrates (rice) has declined from 83 % to 77 % (Lamberts, 2001).

Fisheries and aquatic animals (molluscs, crabs, tadpoles, shrimps, frogs, snails, snakes, water birds from wetland habitats and other reptiles) provide an affordable source of high quality animal protein (easily digestible and its contribution is the highest in the world - greater than 10 %), phosphorus, selenium, vitamins A and D, iodine, magnesium and essential fatty acids (Hortle, et al., 2004). Worldwide, fish contribute to 50 % of total animal proteins in some island developing states (Gambia, Indonesia, Japan, Bangladesh, Cambodia, Congo, Equatorial Guinea, Ghana, Sierra Leone and Sri Lanka) and more than 38 million people are directly engaged in fish farming and fishery products account for 15 % - 16 % of global animal protein intake. Overall, the fisheries sector contributes to the economic activities associated with harvest, handling, processing and distribution, providing a valuable foreign-exchange earnings and an agricultural export trade (Opara, et al., 2007).

Fish represent a food of excellent nutritional value and are a valuable source of micronutrients, minerals, essential fatty acids (that are often lacking in red meat) and proteins. They make a very significant contribution to the diet of many fish-consuming communities (De Silva & Funge-Smith, 2005; Rahman, 2007). Fish muscular tissue consists of muscle fibres or cells (86 – 88 %) of a diameter 0.1 to 0.2 mm, extracellular space (interstitial space 9 - 12 % and capillary space 2 – 3 %). Fibrils consist of working units of cell 65 %, sarcoplasm (regulatory and transport space filled with liquid and functional units 20 – 23 %), and 6 % of connective tissue. Meat of lean fish contains 80 % water, 8 % - 25 % proteins, less than 5 % lipids, with little carbohydrate, 0.6 % - 1.5 % mineral compounds, whereas fatty fish has 10 % - 30 % lipids. The flesh is highly buffered due to the presence of phosphates and creatine in the muscle, has a low oxidation–reduction potential and the pH of fish flesh is neutral (De Silva & Funge-Smith, 2005; Opara, et al., 2007; Rahman, 2006). Fish meat contains abundant amounts of water-soluble vitamins, and fish oil (particularly from the liver) is rich in vitamins A and D. The nutritional value of fish differs considerably depending on the species, health status, body part or type of the muscle, processing technique, and duration after harvest (Opara, et al., 2007). The human body is incapable of synthesizing already mentioned fatty acids and they must be supplied in the diet. Fatty acids provide the structural elements of cell membranes; contribute to osmoregulation; are important for brain development; act as precursors to eicosanoids, a heterogeneous group of highly active "local hormones"; influence reproduction and egg quality; and are important for development of vision. Fatty acids are crucial to life apart from being energy sources, and medical studies indicate the positive effect of fish in the diet on human health, growth and general well-being (De Silva & Funge-Smith, 2005). The particularly low incidence of heart disease in fish-eating populations has been attributed to high ingested levels of the so-called omega-3 called eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) polyunsaturated fatty acids (PUFAs) in fish oil (Opara, et al., 2007). Fish oils or fats in fish are more unsaturated than butterfat or beef, and they contain considerable proportions of highly unsaturated acids, while they are usually classified as drying oils (Rahman, 2007; Mujumdar, 2006).

Food distribution remains a problem for a large part of the population, resulting in structural food insecurity at the national level, and acute or chronic food insecurity particularly in rural areas. This problem of availability, together with problems of access to and utilization of food, as well as the lack of diversity in the diet of most people, results in high levels of child and adult malnutrition, even though national food supplies are adequate (Lamberts, 2001).

1.1.5 TRADITIONAL TECHNIQUES OF FISH PRESERVATION IN CAMBODIA

In Cambodia, fish and aquatic products are sold in both fresh and processed forms. Fresh products include live and frozen. Fish is also transported around the country, mostly after it has been processed (Khim, 2010). Processing of freshwater fish has a long tradition in Cambodia. Products include: dry salted fish, smoked fish, fish paste, fish sauce, fermented fish and dried fish for animal feed. Fish paste is of vital importance for many poor Cambodians during periods of low fresh fish availability (FAO, 2011). Fish stored in the form of processed products such as fish paste (*prahoc*) and fish sauce are vital components of the annual food security cycle. *Prahoc* is particularly important to hill tribes during the rainy season because at that time farmers are too busy cultivating rice to go fishing (Khim, 2010). *Prahoc* is a fermented food which is made by salting fish and other shellfish, then leaving them for a while to let the enzymes work on the process of fermentation and thus it is made into one of the most essential seasoning. Not only is it used as seasoning, it can be served as a side either as it is or mixed with herbs or used in main ingredients of main dishes (Kubota, et al., 2015).

Fermented fish, „*phaak*“, is made by lactic fermentation of salted freshwater fish and steamed sweet rice. Customarily, it is made by scaled whole or cut fish; fish is mixed with organs, or fish eggs (Ahmed, et al., 1998). Family *Cyprinidae* are often used as main ingredients and others, like family *Osphronemidae* or *Channidae*, are also used (Kubota, et al., 2015).

Homemade fish sauce is usually made from freshwater fish, and quite often the entire process of making the sauce (catching fish to final sauce) takes place at home. The broth, by-product of making the paste called tuk trey, and is also used as seasoning.

Marine processed fish commodities include: shrimp, lobster, crab, squid, octopus, cuttlefish, much of which is dried (FAO, 2011).

Freshness of harvested fresh produce such as fish and seafood is decreasing immediately after harvest. Pre-treatment of fish and seafood immediately after harvest and landing is essential for improving sanitation and removing the inedible portions that would contribute to aging and spoilage. Gutting and bleeding are the primary pre-processing treatments that are commonly carried out. Using of improved handling systems, maintenance of cold chain, and finally application of appropriate physical and biochemical treatments are necessary to reduce losses, maintain quality, extended storage and shelf life. Other pre-treatments such as washing and cleaning also reduce contamination by physical debris and microbial organisms, which pose health and safety hazards to the consumer.

As stated below, pre-treatments are common in most of the drying processes for improving storage stability, product quality and process efficiency (Rahman & Perera, 2007).

1.2 MEAT COMPOSITION AND ITS ORGANOLEPTIC AND TECHNOLOGICAL PROPERTIES

Meat structure depends on the way of life, function of individual body parts and a variety of intravital factors (species, race, nutrition, health, etc.), postmortem changes and processing.

Meat is mostly composed of skeletal muscle, other compounds are fatty (adipose) tissue and fibrous tissue. The basic unit of skeletal muscle is the muscle fibre which is composed mostly of myofibrils (contractive fibres). Lean muscle is composed of water, adequate proteins (Feder's number is the ratio of water to protein content), fats (lipids, unsaturated fatty acids), minerals constitute around 1 % (iron, zinc, magnesium, calcium, potassium), vitamins, especially group B, and extractive compounds, which can be extracted by water at temperature 80 °C (Pipek, 2002).

1.2.1 PROTEINS

From nutritional point of view, proteins are the most valuable compound of meat (Pipek, 2002). Pure lean muscle contains 18 – 22 % of proteins, which include all essential amino acids. According to their solubility in water and in salt solutions, proteins are divided to myofibrillar (soluble in salt solutions, myosin in thick filaments, actin is thin filaments), stromatic (proteins of the connective tissue, not soluble in water nor salt solutions), collagen (high content of glycine, hydroxyproline and proline, contains tryptophan and cysteine, content of collagen influences the tenderness of the meat) and sarcoplasmic proteins, that are soluble in water and weak salt solutions (Pipek, 1998).

Sarcoplasmic proteins become denatured with high temperatures and take part in making the muscle structure firm during cooking (Pipek, 1998). The molecules of myoglobin and hemoglobin are formed by protein chains of globin and a pigment group – heme. Myoglobin is a muscle pigment that serves as oxygen storage in the muscles. Hemoglobin is a blood pigment that mediates the transport of oxygen from the lungs into the muscles. Its share in content of all heme pigments in meat is depending on the content of blood and other heme pigments 10 – 30 %. The central iron atom in myoglobin datively binds various ligands and thus respective derivates are formed: oxymyoglobin (vermilion red, iron binds a molecule of oxygen), carboxymyoglobin (cherry red, bound molecule of carbon dioxide), nitromyoglobin (pinkish red, bound molecule of nitric oxide) (Pipek & Pour, 1998). The red colour and lightness of the meat is determined mostly by the content of heme pigments (myoglobin, hemoglobin), thy hydration state of the meat and its pH value (Pipek, 1998). The nearer the pH value is to the isoelectric point, the lower is the solubility of proteins, which then bind low amounts of water, light only reaches the superficial layers of the meat and reflects more thus creating an impression of lighter meat (Pipek & Pour, 1998).

1.2.2 LIPIDS

Lipids are mostly present in meat as fats (triglycerides), in lower extent as phospholipids, supporting matters, etc. Fats (lipids) undergo oxidation and hydrolysis. Lipases cleave from fats fatty acids that subsequently undergo oxidation. The products of breakdown of fats and fatty acid oxidation (especially carbonyl compounds) have a very intense aroma (Pipek & Pour, 1998), thus it can be said that fat in meat is very important from sensory point of view, as it carries many aromatic compounds. The oxidation of lipids is responsible for rancidity (an objectionable defect in food quality), development of off-flavours, the loss of fat-soluble vitamins A, D, E, K (Rahman, 2007) by interaction with the peroxides (Fellows, 2000), and appearance and texture may also be affected (pigments in many foods), especially in dehydrated foods (Rahman, 2007).

Several factors affect the oxidation rate: type of substrate (fatty acid), moisture content, oxygen content, extent of reaction, temperature, enzyme activity, protein content, UV light, free amino acid content, and other chemical reactions presence of natural antioxidants and metals (Rahman, 2006). Water is a solvent for heavy metal catalysts that promote oxidation of unsaturated nutrients. After the water is removed, the catalysts become reactive, and the rate of oxidation accelerates (Fellows, 2000).

Palatability is a complex perception of taste, aroma and tenderness and it is formed especially by extractive compounds (they develop during meat ripening) that are carried by fat (Pipek & Pour, 1998). The palatability of meat is significantly influenced by glutamic acid or by sodium glutamate. It is produced from glutamine which cleaves off ammonium when heated up. Intramuscular fat, which forms veinlets between cells, is essential for the taste and tenderness of meat. Meat with a higher content of intramuscular fat is more valued than meat without fat, because it is tenderer and has a more distinctive flavour (Pipek, 1998).

1.2.3 WATER ACTIVITY

When considering the stability of foods, it is not the total moisture content that is critical but rather the amount of moisture that is available to support microbial growth, enzymatic and chemical activity (Brennan, 2006). However knowledge of the moisture content alone is not sufficient to predict the stability of foods. Some foods are unstable at low moisture content, whereas other foods are stable at relatively high moisture contents. Water activity (a_w), a major factor in food preservation and final processing, is a parameter to predicting food spoilage (Mujumdar, 2006; Marinos-Kouris & Maroulis, 2006). It is defined as the ratio of the vapour pressure of water in a food to the saturated vapour pressure of water at the same temperature. In either case the water content is a very important factor controlling the rate of deterioration (Fellows, 2000). When a wet solid is in constant contact with a fresh gas, it continuously loses moisture until equilibrium is reached between the vapour pressure of the moisture in the solid and the partial pressure of the vapour in the gas. The solid and gas are then in equilibrium, and the moisture content of the solid is the equilibrium moisture content under the prevailing conditions (Visavale, 2012). The relationship between equilibrium moisture content and water activity, known as the sorption isotherm, is an important characteristic that influences many aspects of storage (Marinos-Kouris & Maroulis, 2006; Fellows, 2000; Rahman & Labuza, 2007). See in Fig. 1.4 by (Belessiotis & Delyannis, 2011) the graphical representations of the relationship between moisture content at the corresponding water activity, over a range of values at constant temperature. Moisture desorption from the product is in dynamic equilibrium with the absorption of the environmental air moisture content (Visavale, 2012). The effect of water activity and its relation to its stability (Fig. 1.5) was also studied on biochemical reactions in the food system (Marinos-Kouris & Maroulis, 2006).

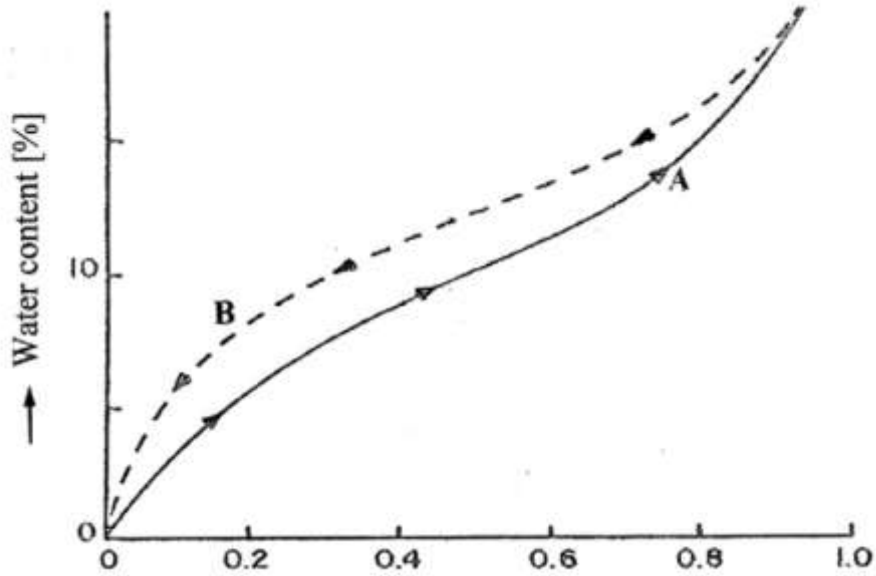


Figure 1.4 Sorption isotherms. (A) Absorption curve. (B) Desorption curve.

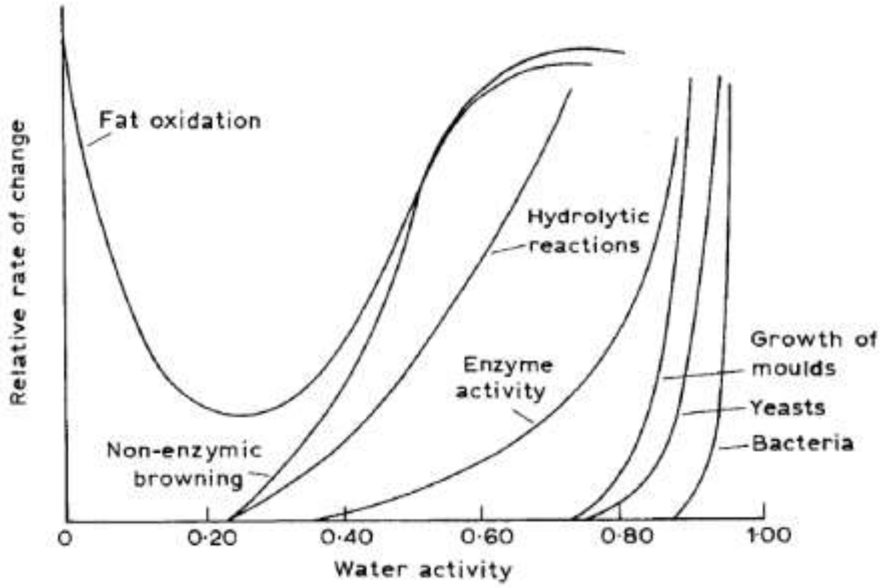


Figure 1.5 Influence of water activity on the stability of foods (Brennan, 2006)

As was mentioned, activity of water as a medium is clearly correlated with the deterioration and stability of food due to the growth of microorganisms and is more important than the total amount of water. The minimum water activity is the limit below which a microorganism or group of microorganisms can no longer reproduce (Rahman & Labuza, 2007; Pipek & Pour, 1998).

There is a minimum of water activity for specific microorganisms to grow for complete microbiological stability. For the majority of foods, this is in the water activity range of 0.6 - 0.7 (Jayaraman & Das Gupta, 2014; Rahman & Labuza, 2007). Pathogenic bacteria cannot grow below a water activity of 0.85 - 0.86, whereas yeast and moulds are more tolerant of a reduced water activity of 0.80, but usually no growth occurs below a water activity of about 0.62. Oxidation activity is only possible at water activities higher than 0.4. In many foods the rate of oxidation of fat is minimum in the a_w range of 0.20 - 0.40. Enzymatic activities may continue at low levels of water activities of 0.1 - 0.3 and the rate of nonenzymatic browning is highest in the a_w range 0.40 - 0.60. Hydrolytic reactions are also most rapid in the a_w range 0.40 - 0.70 (Brennan, 2006; Mujumdar, 2006; Rahman & Labuza, 2007).

The critical limits of water activity may also be shifted to higher or lower levels by other factors, such as salt content, pH, antimicrobial agents, heat treatment, and temperature (Brennan, 2006; Mujumdar, 2006; Rahman & Labuza, 2007). However, decrease in water activity by addition of salt is not the most important conservation factor as drying has more relevance in lowering water activity (Pipek & Pour, 1998).

1.2.4 WATER HOLDING CAPACITY

The ability of foods to bind water, water holding capacity, significantly influences the quality of food products. The economy of production also depends on water holding capacity, especially water loss in production, storage and heat processing (Pipek, 1998).

From technological point of view, we distinguish free water and bound water and according to the fact if it flows freely from the product under given conditions (if cell membranes are damaged) (Fellows, 2000). Hydrating water has the strongest bond (it is bound electrostatically and by hydrogen bonds), another part of water is immobilized between structural parts (in physico-chemical sense, it does not flow at cutting, increased pressure is necessary for its release) and the rest of water is freely mobile in intercellular space. Immobilization of water depends on the charge of the protein molecule. The share of immobilized water increases when the distance between peptide chains grows by electrostatic repulsion, while decrease of this distance by transverse bonds leads to decrease of immobilized water content. Actin and myosin (thick and thin filaments) play a major role in this immobilization.

Water holding capacity is usually expressed in % as ratio of bound water (i.e. hydrating and immobilized) to overall water content in the meat. From factors that influence water holding capacity it is important to mention pH, salt concentration, content of some ions (multiply charged ions decrease retention by creating transverse bonds between peptide chains which leads to a network-like structure), intravital factors, post-mortem changes or grinding of meat. Muscle tissue that is ground without damaging most of the fibres has a lower water holding capacity than a finely homogenized tissue, where the sarcolemma is torn and filaments are loosen up to myofibrils.

The influence of salts on water holding capacity is the result of influence of anions and cations. The water holding capacity of muscle tissue initially increases with growing salt concentration, reaches its maximum to finally decrease to its original value (unswelling). Swelling at higher ionic forces is caused by ions of neutral salts attracting polar water molecules, which dehydrates the protein molecule which can ultimately lead to denaturation of the protein. Maximum water holding capacity is reached at salt concentration of about 5 % (without addition of water), however, water and fat contents need to be taken into consideration (Pipek, 1998).

Water holding capacity changes significantly with port-mortem changes (initially it decreases due to acidification and tightening of structure – rigor mortis – and later increases again during ripening: muscle stiffness loosens, pH increases slightly and organoleptic properties improve significantly) (Opara, et al., 2007).

1.3 PRINCIPLES OF FOOD PRESERVATION

In most countries, innovation, sustainability, and safety have become the main foci of a modern industry and economy. Preservation methods start with the complete analysis and understanding of the whole food chain (growing, harvesting, processing, packaging, and finally distribution). In these days, demand for healthy, stable, safe and high quality food affects how food is preserved (Rahman, 2007). Food ingredients and foodstuffs are mostly perishable materials that gradually or faster undergo unwanted changes. Animal meat is a live tissue that directly after slaughter suffers major disorganization of enzyme systems. Meat, unless immediately processed, undergoes quickly autolytic changes and is easily attacked by microorganisms. Fish meat is even more perishable than that of homoeothermic animals. The aim of development of food processing technologies is to reach durability of food and ensure expected properties. Their loss should be minimized at any stage of food harvesting, processing, distribution, and storage. During the whole processing cycle, food materials undergo complex changes, including:

- Physiological changes (following physiological processes in living plant and animal tissues, e.g. incorrect progress of post-mortem changes in meat as a result of improper handling),
- Enzymatic changes (partial changes catalysed by natural enzymes or by extracellular enzymes produced by present microorganisms),
- Chemical changes (accelerated by access to air and temperature, non-enzymatic browning and oxidation, contamination of food or formation of toxic substances such as nitrosamines or polycyclic aromatic hydrocarbons during storage, which limit shelf life),
- Microbial changes (Voldřich, 2002).

1.3.1 MICROBIAL CHANGES IN FOOD

The four sources of microbial contaminants are water, air, soil and animals. It is necessary to mention that environmental factors can trigger several reactions that may lead to food degradation (temperature, pressure, oxygen, humidity, and light) (Rahman, 2007). Microbial changes can endanger the consumer's health, destroy the food or decrease its nutritional and sensory value. Conservation intervention for slowdown or killing of unwanted microbial growth is part of technological processing. After introduction of microorganisms into the product starts an adaptation phase, so called *lag phase.* The adaptation phase can be prolonged by manipulation conditions, technological processing and storage, e.g. storing in cool, vacuum packaging, marinating, salting, acidification, addition of conservation agents etc. After the lag phase follows so called *log phase* during which cells divide.

Factors influencing microbial growth include nutrient availability, water activity, food acidity (limiting value is pH 4.0, under this value the spores of sporulating bacteria do not germinate and these acidic foodstuffs can be pasteurized, on the contrary foods less acidic have to be sterilized), redox potential (the usual scale is +500 to + 300 mV for aerobic microorganisms, +300 to +100 mV for facultative aerobic microorganisms and +100 to -100 mV and less for anaerobic microorganisms), and temperature (Voldřich, 2002). With increasing temperature, the minimum temperature for the microorganism's growth is reached. With further increase of the temperature, the growth rate of the microorganisms also increases, reaching its maximum at optimum temperature. Further temperature increase leads to a slowdown in microbial growth rate until it completely stops at a certain temperature (Voldřich, 2002; Rahman, 2007). For thermophilic bacteria the optimum growth temperature is around 55 °C and the growth range is between 45 and 70 °C, for mesophilic bacteria the optimum is around 35 °C and the range between 10 and 45 °C and for psychrophilic bacteria the optimum is 15 °C and range between 5 and 20 °C. Psychrotrophic microorganisms are able to grow in cold storage temperatures and thermoduric bacteria can survive pasteurization temperatures. Thermoduric bacteria include especially genera *Micrococcus, Bacillus, Clostridium, Lactobacillus, Pediococcus* and *Enterococus.* The danger of these microorganisms is based on the fact that they can grow in conditions of cold storage as well as in temperatures usually more favourable to thermophilic bacteria (Voldřich, 2002).

1.3.2 FOOD CONSERVATION TECHNOLOGIES

Preservation involves the action taken to maintain foods with the desired properties for as long as possible. Reasons for food preservation are to overcome inappropriate planning in agriculture, provide variation in diet and produce value - added products, that can give quality foods with improved nutritional, functional, convenience, and sensory properties (Rahman, 2012).

The preparation steps in food production are common practices such as keeping hygiene and limiting contamination of the product during manipulation with the ingredients such as washing, dusting and others (Voldřich, 2002). Following conservation methods lead to killing off of a part (ideally the majority) of microorganisms present in the food. The conservation procedures are based on physical interventions, including:

a) Conservation by killing microorganisms by heat, which leads to denaturation of cells, that subsequently die off (blanching, pasteurization, sterilization, tyndallization, dielectric heating, infrared and resistance heating)
b) Conservation by radiation and the physical methods (ultrasound, high hydrostatic pressure and High intensity pulsed electric field)
c) Conservation by chemosterilization (Pipek, 2002)
a) Conservation by freezing and storage at -18 °C and cooling heat processed foods to storage temperature of -1 to -4 °C
b) Conservation by lowering water activity and increasing osmotic pressure by drying, concentration, sweeting or salting (Rahman, 2012)
c) Conservation by addition of substances that change the metabolism of microorganisms (sorbic acid, benzoic acid, organic acids, sulphur dioxide and sulphites, propionic acid and nitrites, addition of alcohol, antibiotics and smoking)
d) Conservation by biological methods when desirable microflora is developed in the food (Voldřich, 2002; Rahman, 2007).

1.4 APLICATION OF THE CONSERVATION TECHNOLOGIES

1.4.1 SALTING

Addition of salt, salting mixtures and other ingredients enhances the product's aroma, taste and other organoleptic and technological properties (the durability of meat is increased by lowering water activity). The salt content with addition of nitrites or nitrates needed to dissolve the muscle (myofibrils) proteins and reach needed water holding capacity and structure is about 2 % of the meat mass. Pieces of meat are either mixed with salt or the salt is rubbed into the meat surface. Higher concentration gradient causes diffusion of salt into the meat and water diffuses out of the meat into the salt layer. This leads to partial dehydration of the meat and at the same time creates concentrated salt solution – brine. When salting meat on a bone, the salt "flows around" the bone which creates an "unsalted shadow" behind the bone and can lead to spoilage of the meat (Pipek & Pour, 1998).

Salting is one of the most common pre-treatments used for fish products (natural type of osmotic dehydration characterized by equilibrium and dynamic periods, in the dynamic period, the mass transfer rates are increased or decreased until equilibrium is reached) and in combination with drying contributes to the development of sensory qualities in the products. Fish is converted into shelf-stable products by reducing the moisture content (like smoking) and acting as a preservative, the tissue cells are shrunk, the fish flesh loses most of its translucent appearance and does not feel sticky. Fish could be placed in salt solution (absorption of salt is faster from higher salt brine concentration) or covered with dry salt - water is removed from the flesh, salt enters the tissues (body juices become a concentrated salt solution), and due to the interaction with all the proteins causes coagulation. It could be advantageous in some products, that brine solution with concentration greater than 15.8 % tend to remove moisture from the fish, but these strong brines and short salting time decreased distribution of salt into the centre of the fish (Brennan, 2006; Mujumdar, 2006).

Soft-textured fish or low fat fish tend to absorb salt faster than tough-textured or highly fatty fish. It must be noted, that different species and their different parts have variable fat content (salmon has less fat at the tail), due to this fact fish may absorb salt at different rates – time of salting should be specific for each species. Geometrical shapes of fish having different thickness and width along the length also contribute to the difficulty in controlling the salting process and cause no uniform salt distribution (Rahman, 2006). Moreover, the concentration of salt also influences the rate of surface evaporation and moisture binding of fish muscle (Rahman, 2007). Overall, salt absorption is affected by brine concentration and brining time, temperature, geometry and thickness, species, texture and fat content, and finally fish quality (Mujumdar, 2006).

Unsmoked and unsalted fish may be hot air dried using relatively low air temperatures. Dried fish products are used as ingredients in ready meals and soup mixes and many fishery by-products are produced in dried form (Brennan, 2006).

1.4.2 SMOKING

The use of wood smoke to preserve foods is one of the most ancient food preservation processes, as old as open-air drying, and in some communities one of the most important ones. Smoke is not primarily used to reduce the moisture content of food, but generated heat also causes a drying effect - smoking is considered as a pre-treatment rather than a drying process. Smoking is mainly used for meat and fish (Brennan, 2006). The main purposes for using smoking process are it imparts desirable colour and flavour to the foods, and mainly some of the compounds formed during smoking have bactericidal and antioxidant effect (Rahman, 2007).

The gaseous phase of smoke contains suspended liquid and solid particles. The liquid particles depend on the temperature and density (concentration) of the smoke. Solid particles such as ash, soot, resin and tar represent undesirable admixtures of the smoke and sediment on the surface of the product as well as the smoking facility. Very often they include carcinogenic components, especially polycyclic aromatic hydrocarbons.

The composition of chemically active compounds of smoke is very variable depending on the conditions (especially temperature) and the sort and composition of the wood. Common smoking media can contain alcohol (especially methanol and propanol), carbonyls (aldehydes, especially formaldehyde, which has bactericidal effect and contributes to aroma and colour forming, browning of the meat surface is caused by reaction of carbonyls with proteins creating dark melanoides), carboxylic acid (bactericidal, their esters contribute to aroma forming), phenols (antimicrobial and antioxidant effects, create a typical aroma), aromatic hydrocarbons etc.

During pyrolysis, wood components (cellulose, lignin and hemicellulose) decompose to charcoal and smoke. Soft wood gives more carbonyls and less carboxylic acids than hard wood, smoke from soft wood also contains more solid particles (Pipek & Pour, 1998). Several types of smoke can be distinguished according to temperature:

- Cold smoke typically has temperatures of 18 to 23 °C. This is a way of producing fermented meats, the time of smoking reaches several days (in various intervals).
- Warm smoke has temperatures around 60 °C and is used for smoking of large pieces of meat and muscle tissue.
- Hot smoke reaches higher temperatures, usually 80 to 90 °C and is used for the majority of meat products (Pipek & Pour, 1998; Brennan, 2006).

1.4.3 DEHYDRATION

In general, preservation technique is the most important achievement in human history, because it makes humans less dependent upon a daily food supply even under adverse environmental conditions (for thousands of years, man has dried fish, meat, vegetables and fruits). The preservation of foods by drying is one of the oldest, the most diverse of chemical engineering unit operations and finally most common method used by humans and the food processing industry. Overall, drying of various products is needed for several reasons: to extend its shelf life beyond that of the fresh material, to facilitate preservation and storage (mainly without refrigerator - enables storability of the product under ambient temperatures) and minimize packing, to reduce the cost of transportation, as it brings about substantial reduction in weight and volume (need for easy-to handle) and to achieve desired quality of final product.

In earlier times, drying was dependent on the sun (dawn of civilization used drying for preservation of agricultural surpluses - the cheapest way of preservation), but today there are many types of high capacity, sophisticated spray or freeze drying installations and methods used to dehydrate. Factors on which the selection of a dryer or drying method depends include form of raw material and its properties and characteristics of the product, necessary operating conditions, and operation costs. A very large range of dehydrated foods is available and makes a significant contribution to the convenience food market (Brennan, 2006; Mujumdar, 2006; Rahman, 2007; Visavale, 2012).

Drying is a traditional conservation intervention, during which the activity of microorganisms is limited or stopped by lowering the water activity a_w below a ceratin level. Only a very small fraction of microbes is killed by drying, thus also pathogenic germs can survive. Aside from drying itself, several other additional interventions that can be combined with drying contribute to a stretched shelf life, including especially salting, low temperature treatment, heat treatment, smoking, addition of nitrites, etc. The drying process reduces the activity of enzymes and the rate at which undesirable chemical changes occur and changes the organoleptic properties of the dried product (Pipek & Pour, 1998).

Equilibrium between water evaporation rate from the surface and the water migration rate from inner layers to the surface of the product must be reached during the drying process. Heating the surface too fast can produce a hard crust, in other words, case-hardening is formed (mostly dried soluble protein) (Brennan, 2006; Mujumdar, 2006). If the surface dries too fast, further evaporation is hindered and the material is not uniformly dried, which can lead to microbial spoilage starting in the area where humidity is too high (Pipek & Pour, 1998).

Drying is classified by the water-removing method: osmotic dehydration, mechanical dewatering and thermal drying. In osmotic dehydration, a solvent or solution is applied to remove water, whereas in mechanical dewatering physical force is used. In thermal drying, a gaseous or void medium is used to remove water from the material. Thermal drying is divided into three categories: (a) air drying, (b) low air environment drying, and (c) modified atmosphere drying (Rahman & Perera, 2007).

According to kinetics, two basic phases of the process of thermal drying can be defined:

Phase I: the drying rate is constant (mass reduction of the material is dependent on time), it is influenced only by the rate of transport of humidity into the air and does not depend on the average humidity of the material. The controlling process is the transport of moisture from dried material into the drying medium and the drying rate is thus the highest. The dried surface remains moist as long as capillary forces are strong enough to transport as much water from the centre as is being evaporated from the surface. At the end of phase I, comes the so called critical drying point.

Phase II: drying starts at the critical point. At this time, the surface is mostly rid of moisture and water is being replenished by diffusion from inner layers. The drying rate has to be adjusted to the rate of inner diffusion. Inner diffusion is the controlling process and the drying rate (i.e. transport of moisture into the drying medium) can only be lower at the most equal to the rate of inner diffusion (Pipek & Pour, 1998).

2nd falling period (concerns hygroscopic products) is defined as well: Phase III, represents the second part of falling rate period, where the moisture content continues to drop until equilibrium is reached and drying stops. The drying time of each period varies with the properties of the product and the conditions in which the drying takes place. In most cases, drying of the product is finished before phase III even begins. Many food products do not show the constant-rate phase as many crops have initial moisture content near the critical point and reach quickly the critical point C, see Fig. 1.6 (Belessiotis & Delyannis, 2011) where starts phase II. AB is the time necessary to warm up the material to reach the drying temperature. BC is the constant-rate drying, CE the falling rate drying where removal of moisture from mass is constantly dropping. C is the critical point where surface is not any more saturated and the falling rate period starts. In point E there is still moisture inside the product, moisture is slowly diffusing and drying is finished at point D when the final moisture content is reached (Belessiotis & Delyannis, 2011).

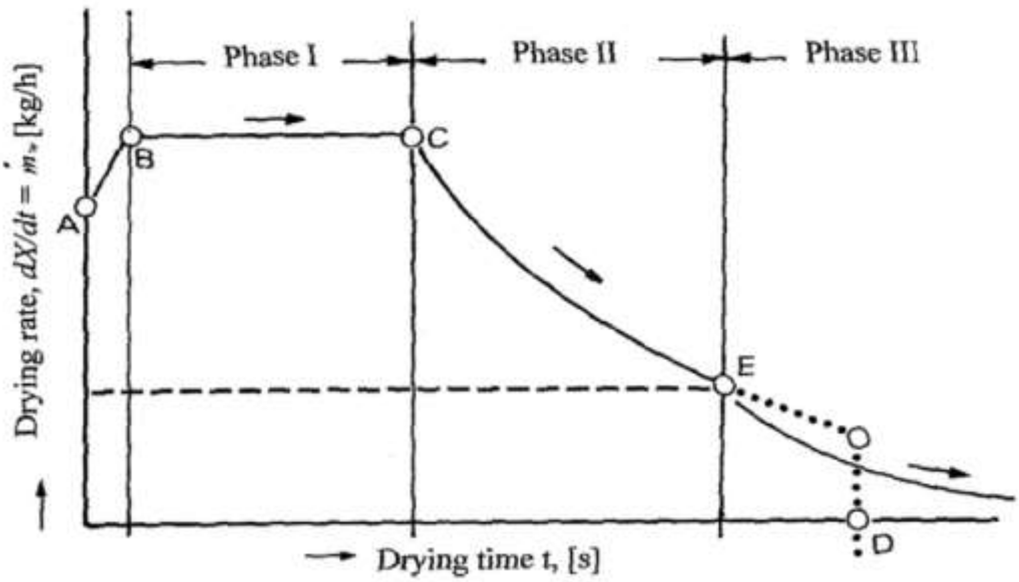


Figure 1.6 Drying rate curves for phase I, II and III.

Water removal from the material surface depends on or can be controlled by several parameters: external conditions of temperature, air humidity and flow, area of exposed surface, and pressure. On the other hand, the movement of moisture internally within the solid is a function of the physical nature of the solid, the temperature, and its moisture content (Pipek & Pour, 1998; Mujumdar, 2006).

Numerous mathematical models have been proposed to represent drying in the mentioned falling rate period. Some models were developed by fitting relationships to data obtained experimentally and are empirical. Other models are based on the assumption that moisture migrates within the solid by diffusion as a result of the concentration difference between the surface and the centre of the solid - Fick's second law of diffusion applies to this (Brennan, 2006). In the industry a reliable mathematical model for dryer and process parameters may prevent or minimize costly mistakes and be utilized for the control of the process. Generally, several parameters are significant and may influence the performance of a drying system. Specifically, they are connected to air conditions (airflow rate, drying air temperature, drying air humidity ratio), directly to dried product (material size, product throughput, initial and final moisture contents) and finally to parameters of the dryer (dryer configuration, length, width, height, or diameter of the dryer, number of passes) (Mujumdar, 2006).

1.5 DRYING TECHNOLOGY

1.5.1 SUN DRYING

Initially, only sun drying has been used and is still used from domestic up to small commercial size drying or drying of plants, seeds, wood, fruit, vegetables, meat and fish and still, throughout the world, drying under the sun is a very popular drying method. In this process of preservation, foods or a thin layer of the product are placed on the land (on leaves or mats) or left hanging in the air (strips of meat and fish). The dried product is heated directly by the sun's rays, moisture is removed by natural circulation of air due to density differences and products are stirred and turned over at intervals. Predominantly, the energy for drying of foods is supplied by direct sun radiation. The best conditions for open-air sun drying are warm and dry weather (Mujumdar, 2006; Visavale, 2012).

While drying in this way, the dried products are exposed to the vagaries of the weather (direct irradiation of the sun/rain, storm), contamination from the environment (rodents, birds, insects, other animals), lack of ability to control the drying process (no uniform drying), large area or floor space requirements, high labour costs, and finally, bad odour. Last but not least, drying times are long and spoilage of the food (degradation due to biochemical or microbiological reactions) could occur before a stable moisture content is attained (Brennan, 2006; Rahman, 2007). The drying time required for a given products can be quite long and result in high post-harvest losses (more than 30 %) (Belessiotis & Delyannis, 2011).

When the climate is not suitable for direct sun drying, or better quality is needed, it is still possible to use the free and renewable energy source provided by the sun. Several attempts have been made to develop solar drying mainly for preserving of agricultural and forest products (Mujumdar, 2006; Rahman, 2007). Solar drying in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods (Belessiotis & Delyannis, 2011).

1.5.2 SOLAR ENERGY DRYING

As was mentioned in the previous chapter, solar energy may be treated as a free energy, non-polluting and abundant energy source that cannot be monopolized, but like sun radiation, its application for drying is also limited geographically. In warm, dry countries of Asia and Africa a commercial dryer is too expensive and not essential enough for a single farmer to consider its purchase and solar drying can be used as an alternative drying method. Countries of these continents are examples of places where solar drying by a cheaply constructed collector is employed, and whereby given solar collectors are used to heat air, which then supply heat to the food by convection (Brennan, 2006; Mujumdar, 2006). Generally, solar drying is an extension of sun drying that uses radiation energy from the sun and it is used mainly for coffee beans, cocoa, ground nuts, maize, rice, cassava, salt, grapes, barley, wheat, and pepper. The cost of solar drying varies from 0.1 % of product value up to 15 %. It is obvious, that the additional costs involved in installing solar dryers may be returned by the increased profits. Solar like sun drying has very basic problem of the periodic character of solar radiation - if it is necessary to be in process continuously, it is needed to install a storing part of the energy gained during radiation periods - heating by oil or gas flames may be used in conjunction with solar drying and this enables heating to continue when sunlight is not available (Brennan, 2006; Mujumdar, 2006).

The advantages compared to solar drying are evident. A higher temperature may be reached compared to direct exposure to the sun. In solar drying system the food is covered with glass or a transparent plastic material and thus is achieved the 'greenhouse effect', which leads to shorter drying times compared to time attained in uncovered food exposed to sunlight – most of the radiation within the enclosure will be of longer wavelength and thus will not readily pass outwards through the transparent cover. The intensity of incident radiation is a function of time. This is a circumstance that demands adequate control strategy and the means necessary for the control. Another problem is caused by the low energy density of solar radiation, which requires the use of large energy-collecting surfaces (collectors) (Mujumdar, 2006).

The simplest form of solar dryer is shown in Fig. 1.7. In this type of direct solar dryer, the dried material is placed in an enclosure with a transparent cover or side panels. It is shown, that air contributes to the drying by its movement by natural convection through the layer of food (Brennan, 2006). Heat is generated by absorption of solar radiation on the product itself as well as on the internal surfaces of the drying chamber. This heat evaporates the moisture from the dried product. In addition it serves to heat and expand the air, causing the removal of the moisture by the circulation of air (Mujumdar, 2006).

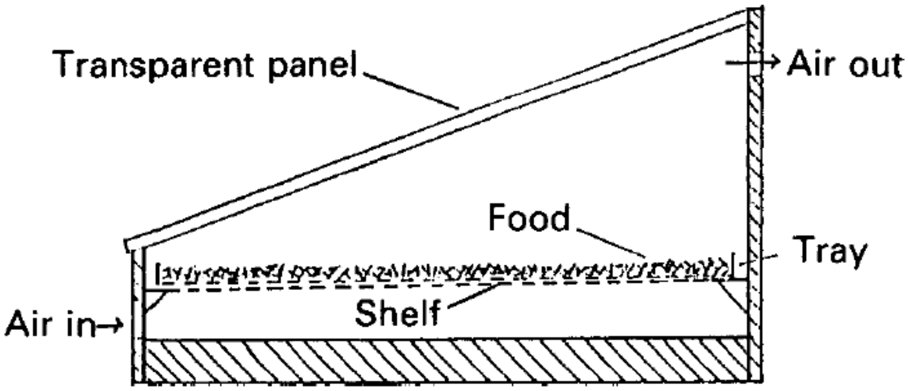


Figure 1.7 The simplest solar dryer (Brennan, 2006)

The capacity of a simple dryer may be increased by incorporating a solar collector. The warm air from the collector passes up through a number of perforated shelves (drying space, where the material is placed) and where the drying takes place supporting layers of food and is exhausted near the top of the chamber. A chimney, one part of heat transfer equipment for keeping the drying air in flow, may be fitted to the air outlet to increase the rate of flow of the air. The taller the chimney, the faster the air will flow. The second part of the heat transfer equipment should be a power supply if it is available – a fan may be incorporated (Brennan, 2006). Mujumdar (2006) presented three main groups of solar dryers according to the energy sources used: a) *Solar natural dryers*, that use ambient energy sources only b) *Semiartificial solar dryers* with a fan with an electric motor for keeping a continuous air flow through the drying space *c) Solar-assisted artificial dryers* able to operate by using a conventional (auxiliary) energy source if needed.

The group of *Solar natural dryers* (Fig. 1.8) has two subgroups: a) the passive, natural convection solar dryers (greenhouse type, chimney-type dryers, cabinet, tent type) and b) active, partly forced convection solar dryers (with a fan using photovoltaic solar cells or wind turbine as an electric energy source) (Mujumdar, 2006). Three distinct sub-classes of either the active or passive solar drying systems can be identified namely: direct-type solar dryers, indirect-type solar dryers; and hybrid solar dryers (Visavale, 2012).

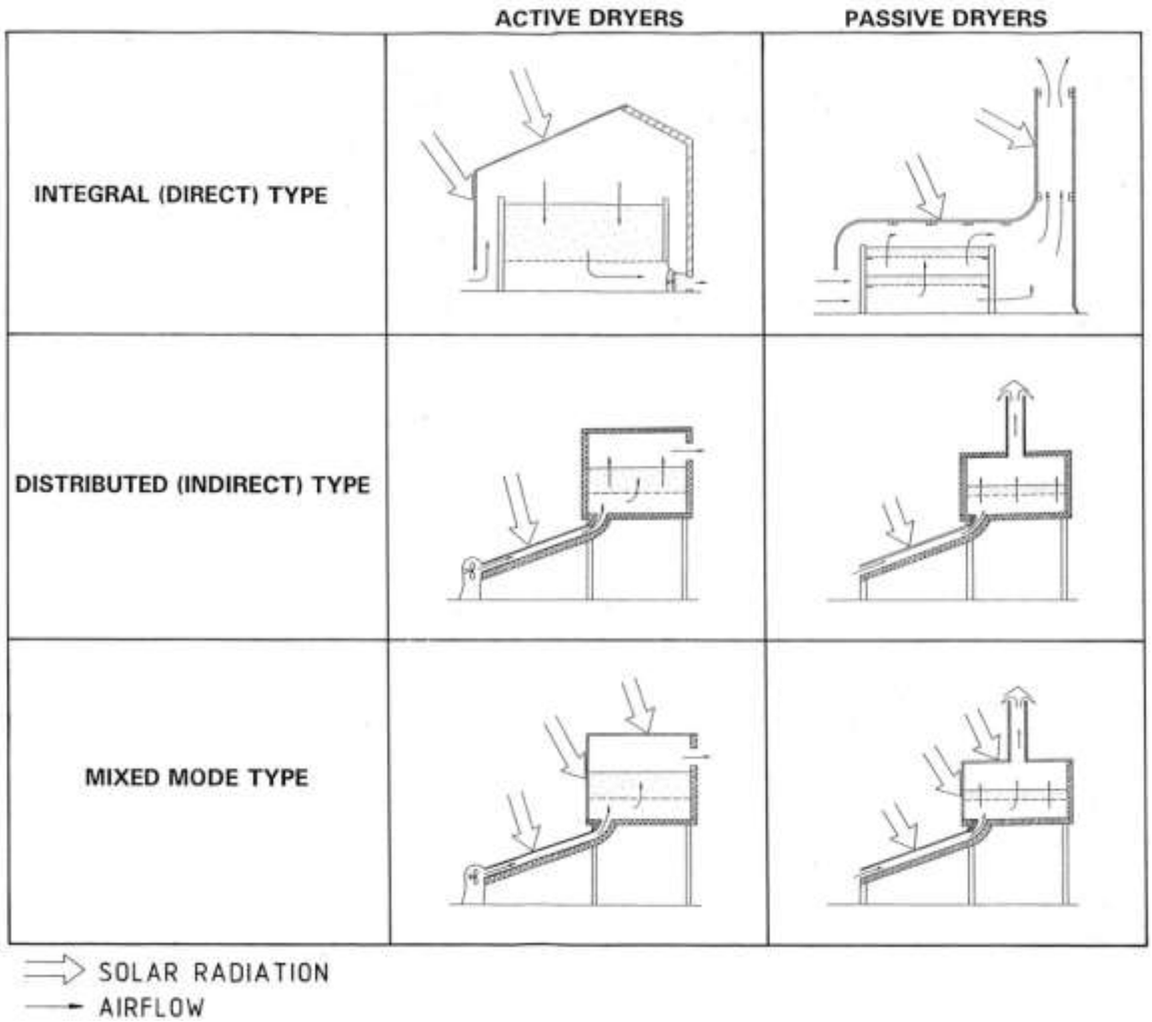


Figure 1.8 Typical solar energy dryer designs (Ekechukwua & Nortonb, 1999)

In the case of solar dryers, it is necessary to mention the function of the solar collector, because it is the primary energy source. The main function is conversion of energy and energy transfer. The so-called absorber (a material of high absorption coefficient) of the collector converts the direct and diffuse radiation from the sun into heat, which is then ducted to the drying chamber to dehydrate the product. Generally flat-plate solar collectors are used for heating the air for low and moderate temperature use. In his type of solar dryer, efficiency is influenced by the design and operating conditions. The main factors that affect collector efficiency are airflow rate, spectral properties of the absorber, heater configuration, air barriers, heat transfer coefficient between absorber and air, and insolation and insulation (Mujumdar, 2006).

1.5.3 ORGANOLEPTIC PROPERTIES OF DRIED MEAT

The basic phase is the determination of an individual’s preference for specific products. The aim during food processing is to find improvements in technology to reduce the damage caused by processing (Rahman & Perera, 2007). The structure of meat and its chemical composition influence its sensory and technological properties such as: flavour, tenderness, texture, shape, colour and water holding capacity (Pipek, 2002).

The texture of foods is determined by the moisture, fat and proteins contents, and the amount of structural carbohydrates (starches, cellulose and pectin materials). Changes in texture are caused by loss of moisture or fat, formation or breakdown of emulsions and gels, hydrolysis of polymeric carbohydrates, and coagulation or hydrolysis of proteins (Fellows, 2000).

Browning reactions change colour, decrease nutritional value and solubility, create off-flavours, and they can be classified as enzymatic or nonenzymatic. Nonenzymatic browning occurs due to the interaction between reducing sugars and amino acids, the loss of protein solubility and development of bitter flavour. In some cases, desirable or undesirable chemical or biochemical reactions may occur (Rahman & Perera, 2007).

Aroma is influenced primarily by the content of volatile substances, that are present in the material and is also formed by various types of heat treatments (Pipek, 2002). Changes in aroma and flavour are the most significant during dry processes as a result of decomposition of substances on the meat surface. The outer layers of meat dry up and are enriched by residual proteins, salts and bases. A yellowish to brown crust is formed inside of the surface myofibrils or is caused by brown to back crystals of melted fat and meat juice containing proteins (Pipek, 1998).

Many favourable qualities and nutritional values of food or feed products may be enhanced by drying. Drying changes sensory characteristics, palatability is improved, and likewise digestibility and metabolic conversions are increased (Fellows, 2000; Mujumdar, 2006). Chemical changes occur during the processing and storage of foods. In addition to composition and temperature, other environmental factors such as oxygen, moisture level, water activity, and pH induce deleterious changes in foods that are catalysed by enzymes (Rahman & Perera, 2007). The main cause of deterioration in such dried products is oxidation of fat leading to rancidity (Brennan, 2006). While development of off-flavours is markedly noticeable in rancid foods, the generation of free radicals leads to other undesirable reactions (alteration of colour, loss of vitamins and degradation of proteins). Light induces some chemical reactions (loss of vitamins and browning of meats) (Rahman, 2007). The oxidation of drying oils (unsaturated fatty acid) is a common problem (rancidity during storage as long as oxygen is available) for commercial drying of fatty fish and other seafood (Rahman, 2007; Mujumdar, 2006).

During postharvest handling, product processing and storage, the texture of fresh fish changes from firm and mushy to dry. These textural changes occur due to tissue softening as a result of myofibrillar disintegration and weakening of connective tissue. During the subsequent storage, the spoiling intracellular and extracellular proteases degrade myofibrillar proteins (Rahman & Perera, 2007).

Antioxidants are used to control oxidation in foods, and they also have health functionality by reducing risk of cardiovascular diseases and cancer, and slowing down the aging process (Rahman, 2007).

2 OBJECTIVES

2.1 GENERAL OBJECTIVE

The overall objective of this study was to investigate the influence of drying and drying pre-treatments on selected Cambodian fresh water fish species.

2.2 SPECIFIC OBJECTIVES:

I. To compare solar and conventional drying in terms of their suitability as low cost technologies in rural areas.
II. To establish the most suitable models describing drying kinetics of selected Cambodian fish species for both drying techniques.
III. To determine the effect of salting on the drying process and stability of the dried product.
IV. To evaluate the organoleptic properties of the final dried product.

3 MATERIALS AND METHODS

3.1 STUDY AREA AND MATERIAL

This study was carried out at campus of Royal University of Agriculture (RUA) in Phnom Penh, Cambodia. Dryers' performance, processing of fish and sensory analyses were conducted at RUA while physicochemical analyses were carried out at Czech University of Life Sciences, Prague (CULS).

Based on local survey conducted in the biggest fish markets in Phnom Penh, four common fish species, namely swamp eel *(Monopterus albus)*, Nile tilapia *(Oreochromis niloticus)*, walking catfish *(Clarias batrachus)* and giant snakehead *(Channa micropeltes)*, were selected for this study as the locally most typical and most frequently sold, see Table 3.1. Samples of above mentioned fish species were purchased during August at the local market near the Royal University of Agriculture in Phnom Penh and the fish ware from aquaculture farm.

Table 3.1 List of fish species

Number	English name	Local name	Latin name	Genus	Family	Order
1	Swamp eel	Antong	*Monopterus albus* (Zuiew, 1793)	*Monopterus*	Synbranchidae	Synbranchiformes
2	Nile tilapia	Tray tilapia chhnout	*Oreochromis niloticus* (Linnaeus, 1758)	*Oreochromis*	Cichlidae	Perciformes
3	Walking catfish	Trey andaing roeung	*Clarias batrachus* (Linnaeus, 1758)	*Clarias*	Clariidae	Siluriformes
4	Giant snakehead	Trey chhdaur/deap	*Channa micropeltes* (Cuvier, in Cuvier & Valenciennes, 1831)	*Channa*	Channidae	Perciformes

3.1.1 SWAMP EEL

DESCRIPTION

A family of eel-like fishes body have slender and anguilliform body and they don´t have pectoral and pelvic fins. Dorsal, caudal and anal fins are also inconspicuous and reduced to a skin fold forming a tapering tail that making the fish it almost looks like a snake, see Figure 3.1. Fish has very small eyes above middle of gape and large mouth. Gill openings merged into single slit underneath the head. It lacks scales and the brownish body surface is covered with mucus. Rice paddy eels are red to brown with a sprinkling of dark flecks across their backs (Kottelat, 1998; Yamamoto & Tagawa, 2000; Tran, et al., 2013; Kubota, et al., 2015). Fish (unsexed) grows more than 80 cm long, maximal length is 100 cm SL (standard length), but common length is 40 cm SL (Allen, et al., 2002).

Figure 3.1 ***Monopterus albus*** **(Fishbase, 2016)**

HABITAT AND BIOLOGY

It lives in a stagnant to slow and standing water and ephemeral waters such as paddies, marshes, lowland wetlands, waterways, small streams, hill streams, streamlets and estuaries, ponds and lakes. The swamp eel occurs near the bottom of the water body, often in holes, can borrow up to 1.5 m down into the mud and can air-breathe so that it survives the waterless dry period. Fish are nocturnal predators devouring fishes with worms, crustaceans, molluscs, and other small aquatic animals and also feed on detritus (Taki, 1978; Baensch & Riehl, 1985; Rainboth, 1996; Menon, 1999; Yamamoto & Tagawa, 2000; Allen, et al., 2002; Vidthayanon, 2002; Riede, 2004; Kubota, et al., 2015).

The swamp eels are protandrous hermaphrodites (sex reversal is completed in 8 to 30 weeks). Male builds a large free-floating bubblenest at the water surface among the submerged vegetation near the shoreline during the rainy season. Fish eggs are spat into the nest after being laid. When it is small, the eel lays eggs as a female, and as it grows larger, it becomes a male and participates in mating. Male guards the nest or burrow and continues to guard the young after hatching until they are independent. Fish are born in freshwater environment, then migrate downstream of still freshwater as juveniles to grow into adults before the second migrating process back upstream to spawn (potamodromous fish) (Chan, et al., 1972; Baensch & Riehl, 1985; Breder & Rosen, 1966; Rainboth, 1996; Yamamoto & Tagawa, 2000; Vidthayanon, 2002; Kubota, et al., 2015)

FISHERIE, USE AND DISTRIBUTION

The eel is taken by dry-pumping a pond or by bare hands in the rainy season, caught by cast net, hook-and-line and traps. During the dry season the deepest parts of swamps are excavated to find them. Sometimes it is dug out from rice field, when a tractor breaks up the soil (Kubota, et al., 2015). Swamp eels have good flesh and their fisheries are important throughout Southeast Asia (Davidson, 1975; Vidthayanon, 2002). They are marketed fresh and can be kept alive for long periods of time as long as the skin is kept moist (Rainboth, 1996). The meat is served fried, roasted, stir-fried, in soup, dried and for unsightly distinct aroma it is cooked with herbs and spices. Smaller sized ones are sometimes used as in mercy release (Kubota, et al., 2015).

Swamp eels are distributed in Indo-China Peninsula, Korean Peninsula, Japan, the Philippines, Malaysia, Taiwan, Indonesia, mainland China. Probably it is occurring in Bangladesh (Kubota, et al., 2015; Fishbase, 2016).

3.1.2 NILE TILAPIA

DESCRIPTION

It has only a single naris on each side of head, continuous dorsal fin with 13 to 19 spines and 10 to 16 soft rays, anal fin with 3 to 4 spines and 7 to 12 soft rays, interrupted lateral line, see Figure 3.2. It grows up to 60.0 cm SL with 20 to 30 cm ones being the most abundant. It has regular vertical stripes throughout depth of caudal fin, 20 to 26 gill rakes on lower limb of first gill arch, jaws of mature male is not greatly enlarged, length of lower jaw is 29 to 37 % of head length (Eccles, 1992; Tran, et al., 2013).

Figure 3.2 *Oreochromis niloticus* (Tran, et al., 2013)

HABITAT AND BIOLOGY

It lives in depth range 0 to 6 m and it is mainly diurnal. It occurs in a wide variety of freshwater habitats like lakes, ponds, rivers, sewage canals, irrigation channels and along waterways among paddy fields (Bailey, 1994; Wudneh, 1998; Kubota, et al., 2015). It is benthopelagic (lives and feeds near the bottom as well as near the surface), feeds mainly on benthic algae or phytoplankton and it is a potamodromous fish (Trewavas, 1983; Riede, 2004; Fishbase, 2016).

Sexual maturity is reached at 3 to 6 months. Males build a circular nest at the bottom of sandy mud from 0.6 to 2 m deep in which females lay eggs during season. Females incubate up to 200 eggs approximately for a week and grow juveniles in their mouth (mouthbrooding) where the larvae hatch and remain until after the yolk-sac is absorbed (Trewavas, 1983; Breder & Rosen, 1966; Kubota, et al., 2015).

FISHERIE, USE AND DISTRIBUTION

It is caught by fishing, draw net, hand-held lift net, gill net and drying ponds. It is served salted, roasted, in soup, fried, steamed (herbs are put into the abdomen to get rid of the smell), in salad (Laap), and used as a fish sauce ingredient. People can obtain fresh tilapia in markets throughout the year, because it is often sold alive in a tank (Rainboth, 1996).

Nile tilapia originates in Yarkon Riverand in coastal rivers of Israel, Niger River system in Western Africa, Nile River system north of Lake Tanganyika and introduced specimens reported from various coastal basins. Exotic species, those found in Southeast Asia are imported. Widely it is introduced for aquaculture, with many existing strains (Trewavas, 1983; Tran, et al., 2013).

3.1.3 WALKING CATFISH

DESCRIPTION

Its body is dull or dark grey sometimes with vertical rows of off-white pin-point spots. Its body is compressed posteriorly, spine of pectoral fins rough on its outer edge and serrated on its inner edge and upper jaw a little projecting, see Figure 3.3. It grows up to 47.0 cm total length (TL), but its common length is 26.3 cm TL (Hugg, 1996; Ahmed, et al., 1998). The walking catfish is capable of moving on land by wriggling from side to side on its erect pectoral fins (Rainboth, 1996).

Figure 3.3 ***Clarias batrachus*** **(Fishbase, 2016)**

HABITAT AND BIOLOGY

It occurs in lowland streams, in stagnant and muddy water such as swamps and sluggish flowing canals, ponds, ditches, rice paddies, other flooded fields and forests, pools left in low spots after rivers have been in flood, medium to large-sized rivers (Taki, 1978; Rahman, 1989; Rainboth, 1996; Vidthayanon, 2002).

It is omnivorous, feeds mainly on benthos and plant matters. It feeds also on insect, small fish, larvae, earthworms, molluscs, shrimps, shells, aquatic plants and debris. The walking catfish undertake lateral migrations from the Mekong mainstream or other permanent water bodies, to flooded areas during the flood season and return to the permanent water bodies at the onset of the dry season. They can leave the water to migrate using its auxiliary breathing organs (Talwar & Jhingran, 1991; Rainboth, 1996; Ukkatawewat, 2005). The pair manifests the 'spawning embrace'. The pair gently nudges each other in the genital region and flicks their dorsal fins; male wraps his body around the female, then the female releases a stream of adhesive eggs into the nest. Spawning period is during the rainy season, the fish excavate nests in submerged mud banks and dikes of flooded areas (Knud-Hansen, et al., 1990; Watanabe, 1994; Yamamoto & Tagawa, 2000).

FISHERIE, USE AND DISTRIBUTION

The walking catfish are taken by seines, cast-nets, push-nets, gill-nets strung along elevated margins of rice paddies and caught by bare hands when in water. They are common in the markets, where they are marketed live, fresh or frozen. They can remain alive for long periods of time when kept moist. They are important for aquaculture, but recently rare, being replaced by introduced African walking catfish (Talwar & Jhingran, 1991; Frimodt, 1995; Rainboth, 1996; Ahmed, et al., 1998; Vidthayanon, 2002).

They are common in Upper-Lower Mekong, Thailand, Myanmar, Malaysia, Cambodia, Indonesia (Ahmed, et al., 1998; Fishbase, 2016).

3.1.4 GIANT SNAKEHEAD

DESCRIPTION

It has elongate body, depressed head, long-based dorsal and anal fins, no fin spines, projecting lower jaw, strong teeth on jaws, rounded caudal fin and 2 bold and black irregular stripes or split into variously shaped spots on side of body, see Figure 3.4. Juveniles have the space between the stripes coloured bright orange (Kottelat, 1998; Vidthayanon, 2002; Tran, et al., 2013; Kubota, et al., 2015).

Figure 3.4 ***Channa micropeltes*** **(Tran, et al., 2013)**

HABITAT AND BIOLOGY

It lives in slowly flowing or stagnant water as lowland river, swamp, large streams and canals. It is usually associated with deep water bodies (Talwar & Jhingran, 1991;

Kottelat, 1998; Rainboth, 1996; Vidthayanon, 2002; Kubota, et al., 2015). It is the largest of the snakeheads, at least in weight. It predates mainly on fish but also takes some crustaceans. It spawns in small streams with dense vegetation (Rainboth, 1996; Kottelat, 1998; FAO, 1992).

FISHERIE, USE AND DISTRIBUTION

The giant snakeheads are caught with seines, by draw net, long-line fishery, gill-nets, traps, and baited hooks. It is an economically important food fish mainly from capture fisheries (Vidthayanon, 2002). It is marketed fresh and sometimes alive. It is served roasted, steamed, fried, cooked in a pot, dried, and in soup (Rainboth, 1996; Kubota, et al., 2015).

It occurs in slowly flowing waters from India to Indonesia, it means in Laos, Vietnam, Thailand, Myanmar, Malaysia, Cambodia, Sumatra and Borneo (Rainboth, 1996; Tran, et al., 2013; Kubota, et al., 2015).

3.2 PRETREATMENTS OF THE MATERIAL

The pre-treatments process of fish material was done in a ventilated room with a temperature of 29 °C and air humidity 47 %. Above mentioned fish species were cleaned and sliced into pieces of approximately 5 by 2 cm. The experimental procedure was carried out twice. Once without salting and once the fish samples were salted by dry salting method.

Fish meat was dry-salted proceeding for three different periods of salting: 2 hours, 4 hours and over one night. First, a layer of salt was spread over the bottom of the pot. Then the fish samples were spread on top and covered by another layer of salt. For fish salting a table salt (sodium chloride NaCl) was used. When fish samples were covered by salt, the salt began to dissolve in the water on the surface of the fish and gradually diffused into the centre of the fish (Beatty & Fougere, 1957).

3.3 EXPERIMENTAL PROCEDURE

The salted and unsalted samples were placed into two types of dryers, the electric oven (UFE 500 type, Memmert, Germany) and the solar dryer (SD). The drying process in an electric oven (E0) was done with a constant temperature and relative humidity, see in Table 3.2.

Table 3.2 Drying conditions of the drying process in electric oven for fish that were unsalted and treated by salting for 2 hours, 4 hours and over one night

Pre-treatments of fish samples	Temperature [°C]	Relative Humidity [%]
Without salt	50	26.0
Salted 2 hours, 4 hours and overnight	50	30.8
Salted 2 hours, 4 hours and overnight	60	18.9

The solar drying system was classified as a natural convection direct type. A picture of the solar dryer is shown in Figure 3.5. The solar dryer consisted of a drying chamber with drying trays and a passive venting turbine, connected to the top of the drying chamber. The collector width, length, and height were 1.50 m, 1.47 m, and 0.12 m, respectively. The solar collector array consisted of a solid transparent plastic cover, an insulator, and a black painted aluminium absorber. Air entered into the drying chamber trough the collector by natural convection mode. The chamber dimensions were 1.50 m long, 0.60 m wide and 1.10 m high.

Figure 3.5 Photograph of a natural convection solar dryer

Solar drying experiments started at 1:00 PM during the first day of drying and at 9:00 AM during the next two days. The drying was stopped always at 5:00 PM in all drying tests. At night, the samples were collected and placed in a room in plastic boxes. During the drying process, moisture loss was monitored at hourly intervals using a digital weight (Soehnle Professional, Backnang, Germany) with a 0.1 g precision uncertainty.

Apart from the moisture loss, additional operational parameters were monitored at hourly intervals. Ambient and drying air relative humidity and temperature were measured by Minidataloggers Testo 174H (Testo, Lenzkirch, Germany) installed outside the solar dryer and in the drying chamber. Insulation on the collector of the dryer was measured by pyranometer CMP 6 with a solar integrator

(KippZonen, Delft, the Netherlands) with an uncertainty ± 5 %. Anemometer Testo 425 (Testo, Lenzkirch, Germany) with an uncertainty of ± 0.03 m · s^{-1} was used to determine the air velocity.

3.4 PERFORMANCE OF THE SOLAR DRYER

To evaluate drying performance of solar dryer, thermal efficiency, evaporative capacity and system drying efficiency (η_p) were calculated from the data obtained in this study. The most important parameters affecting performance of the dryers were measured every hour by measurements mentioned above as follows: intensity of solar radiation [W · m^{-2}], temperature *T* [°C], air velocity [m · s^{-1}], relative humidity RH [%] and weight of the product *m* [kg].

Equation 3.1 relates the thermal efficiency of a solar collector *(η_c)* to the ratio of useful heat gain to the solar radiation acting on the plane of solar collector (Fudholi, et al., 2013)

$$\eta_c = \frac{m_\mathrm{f} \cdot C\ (T_0 - T_\mathrm{i})}{A_\mathrm{C} \cdot I} x100$$

Equation 3.1

Jannot & Coulibaly (1998) established solar air heater evaporative capacity which is the measure of the effect of air temperature and humidity, see Equation 3.2. Consider air that is heated by a solar collector and passes through the dryer. Air enters the collector where it is heated at a constant pressure. Then air enters the drying enclosure, where it is humidified before leaving the dryer. If a_w is the water activity of food in the dryer, the maximum rate at which water can be extracted by the air flow from the product is 1 a_w (Jannot & Coulibaly, 1998).

$$E = m_\mathrm{f}\ (X_{2\mathrm{m}} - X_\mathrm{a})$$

Equation 3.2

The system drying efficiency *(η_p)* describes how effectively the input energy to the drying system is used in conventional drying. η_p is defined as the ratio of energy required to evaporate moisture to the heat supplied to the dryer. For collector type natural convection solar dryers the heat supplied to the dryer is the solar radiation incident on the plane of solar collector and following expression for Equation 3.3 were used (Sotocinal, 1992):

$$\eta_p = \frac{W \cdot L}{A_C \cdot I} x100$$

Equation 3.3

The quantity of moisture evaporated from the dried material was calculated as mass of water evaporated from the product (W) and the following equation was used (Fudholi, et al., 2013):

$$W = \frac{g_0 \, (M_\mathrm{i} - M_\mathrm{f})}{100 - \, M_\mathrm{f}}$$

Equation 3.4

Moisture content of the materials at a certain time was expressed as a wet basis moisture content (Eq. 3.5) and kilogram of water per kilogram of dry matter (Eq. 3.6). The equations are presented below (Fudholi, et al., 2013):

$$M = \frac{m - d_\mathrm{m}}{m_0}$$

Equation 3.5

$$MC = \frac{m - d_\mathrm{m}}{d_\mathrm{m}}$$

Equation 3.6

See Figure 3.6 for the relationship between the dry- and wet-weight bases (Green & Perry, 2008). Drying rate is a fundamental parameter in description of the drying process and basically comprises of two fundamental and simultaneous processes: (i) heat is transferred to evaporate liquid, and (ii) mass is transferred as a liquid or vapour within the solid and as a vapour from the surface (Visavale, 2012).

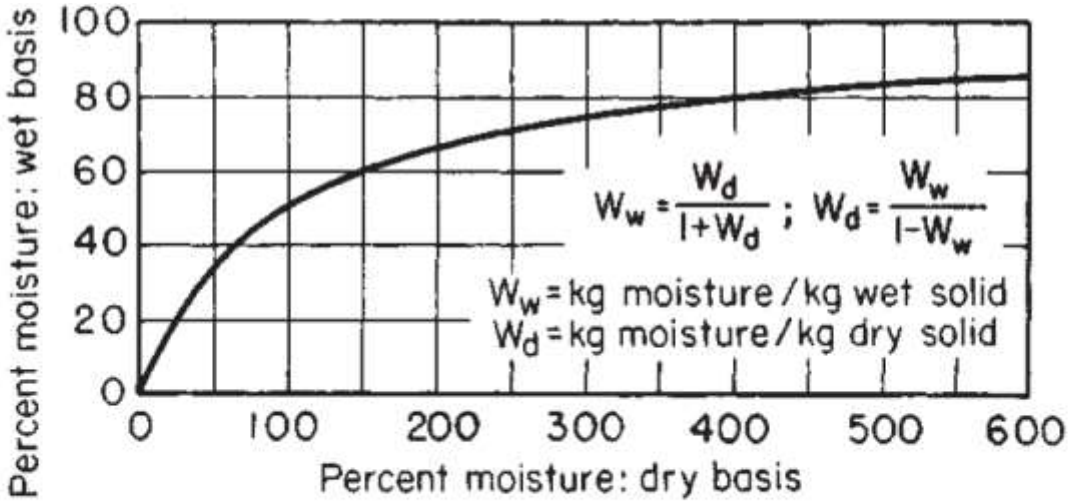


Figure 3.6 Relationship between the dry- and wet-weight bases

Kituu, et al. (2010) defined the drying rate (*DR*) as the decrease of the water concentration during the time interval between two subsequent measurements divided by the time interval, as seen in Equation 3.7

$$DR = \frac{\Delta M}{\Delta T}$$

Equation 3.7

3.5 MATHEMATICAL MODELLING OF DRYING CURVES

The Fick's diffusion equation for solid materials with slab geometry was applied to the experimental data gathered during drying of our samples. The assumption made for the slab shape of dried sliced fish samples was that moisture is initially distributed throughout the mass of a sample. Surface moisture content of the sample instantaneously reaches equilibrium with the condition of surrounding air. Resistance to mass transfer at the surface is negligible compared to internal resistance of the sample. The equation is as presented below (Tunde-Akintunde, 2011):

$$MR = \frac{MC - MC_{\mathrm{e}}}{MC_{\mathrm{i}} - MC_{\mathrm{e}}} = \frac{8}{\pi^2} exp\left(\frac{-\pi^2 D_{\mathrm{eff}} t}{4L^2}\right)$$

Equation 3.8

The drying data were graphically analysed in terms of reduction in moisture content and moisture ratio with drying time (t). The moisture ratio *MR* expressed in Equation 3.9 was taken instead of the moisture ratio presented in Eq. 3.10 (Evin, 2012):

$$MR = \frac{MC}{MC_{\mathrm{i}}}$$

Equation 3.9

$$MR = \frac{MC - MC_e}{MC_{\mathrm{i}} - MC_{\mathrm{e}}}$$

Equation 3.10

The reason for this simplification was that in the solar drying, the relative humidity of the drying air continuously fluctuated. *MR* data were plotted against t and inserted into 5 nonlinear regression mathematical models (Babalis, et al. 2006; Karathanos & Belessiotis 1999; Yagcioglu, et al., 1999) presented in Table 3.3. Regression analyses were performed using software SigmaPlot 11.0.

Table 3.3 Mathematical models used to describe the drying characteristic of fish samples

Nonlinear Regression	Models
Logarithm	$MR = y_0 + a \ln\lvert x - x_0 \rvert$
Hyperbola; Single Rectangular, 2 Parameter	$MR = \frac{ax}{(b + x)}$
Exponential Decay; Single, 2 Parameter	$MR = a \exp(-bx)$
Polynomial; Cubic	$MR = y_0 + ax + bx^2 + cx^3$
Polynomial; Quadratic	$MR = y_0 + a\,\mathrm{x} + b\,\mathrm{x}^2$

The coefficient of determination (R^2) was used as one of the primary criteria for selecting the best mathematical model describing the solar drying curve of fish samples. In addition to R^2, standard error of estimate (*SEE*), root-mean-square error (*RMSE*) was used to analyse the relative goodness of fit. The model with the highest coefficient of determination and the lowest *SEE*, *RMSE* was selected as the best model describing the drying behaviour of fish. Coefficient of determination is defined by Eq. 3.11 (Wang, et al., 2007).

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} \left(MR_{\mathrm{exp,i}} - MR_{\mathrm{pre,i}} \right)^2}{\sum_{i=1}^{N} \left(\bar{M}\bar{R}_{\mathrm{exp,i}} - MR_{\mathrm{pre,i}} \right)^2} \right)$$

Equation 3.11

Standard error of estimate is expressed by Eq. 3.12 (Abbaszadeh, et al., 2011).

$$SEE = \frac{\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \left(MR_{exp,i} - MR_{pre,i} \right)^2}{d_{\mathrm{f}}}$$

Equation 3.12

Root-mean-square error is expressed by Eq. 3.13 (Chavan, et al., 2011).

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} \left(MR_{\mathrm{exp,i}} - MR_{\mathrm{pre,i}} \right)^2 \right]^{\frac{1}{2}}$$

Equation 3.13

3.6 PHYSICO – CHEMICAL ANALYSIS

The dry matter content of fish samples was analysed by drying at 105±3.08 °C of meat with sea sand – reference method ČSN ISO 57 6021:1997 in three replications (ISO, 1444).

3.6.1 REHYDRATION RATIO AND RECOVERY RATIO ANALYSIS

In certain food processing or food preparation applications, it is important to know how much water the salted and dried food can absorb. This ability of dried food to re-absorb water can by characterised be described, namely the rehydration ratio and the recovery ration. The rehydration process of salted fish samples consists of three simultaneous steps: absorption of water into the fish samples, swelling of the rehydrated product, and diffusion of soluble components (Dadali, 2008). The final rehydration ratio and the final recovery ratio ware calculated using Equation 3.14 and Eq. 3.15 (Duan, et al., 2011). Rehydration ratio (Rreh) was computed to describe the rehydration process, and it is defined as the ratio of mass of the absorbed water to the mass of the dried sample. Recovery ratio (Rrec) is defined as the ratio of the mass of the rehydrated sample to the mass of the fresh sample. The Each sample was measured three times and the average value was calculated. For calculation of rehydration the samples were put a water bath at 40 °C to rehydrate for 30 minutes and they were removed from water for weighing. Rehydration ability of a dehydrated salted product shows total damage to tissues caused by salting and drying process after rehydration.

$$R_{\mathrm{reh}} = \frac{m_{\mathrm{r}} - m_{\mathrm{t}}}{m_{\mathrm{t}}}$$

Equation 3.14

$$R_{\mathrm{rec}} = \frac{m_{\mathrm{r}}}{m_{0}}$$

Equation 3.15

3.6.2 WATER ACTIVITY ANALYSIS

Equilibrium relative humidity, or water activity, is a critical factor that determines the shelf life of the product (Visavale, 2012). The values were measured with water activity meter (Pawkit, Decagon Devices Inc., Washington, USA) calibrated against saturated salt solutions. Measuring of water activity was done after finishing the drying process, which took 20 hours. The dried samples were crushed into small pieces and placed into the water activity measurement cup and the readings were noted. Measurements were taken in three replicates. Water activity is defined as the ratio of the vapour pressure of water in a food to the saturated vapour pressure of water at the same temperature and was calculated using Equation 3.16 (Fellows, 2000).

$$\mathrm{a_w} = \frac{p_{\mathrm{H_2O}}}{p^0{}_{\mathrm{H_2O}}}$$

Equation 3.16

3.6.3 COLOUR ANALYSIS

Colour is one of the most relevant attributes with respect to the quality of dried foods and it is determined mostly by the content and the conditions of hem pigments.

During drying, colour may change due to a number of chemical and biochemical reactions (Tsotsas & Mujumdar, 2011).

Colour measurements were carried out by using the MiniScan® XE Plus, colorimeter in CIE (Commission Internationale d'Eclairage). Lab chromaticity coordinates. L*, a* and b* represent black to white, green to red and blue to yellow colours, respectively. Out of five available colour systems, the L*a*b* and L*C*systems are usually selected because these are the most used systems for evaluation of the colour of dried food materials (Bala & Hossain, 2012).

The instrument was calibrated against a white tile before each measurement. Instrumental colour determination was made by three measurements in different areas of the surface of the samples.

3.6.4 SALT CONTENT ANALYSIS

Fish samples were frozen and mashed by homogenizer RETSCH Grindomix 100. Salt was determined following the ISO recommended Volhard method 1841-1 (ISO, 1996). After the extraction in hot water and protein precipitation the homogenized fish sample was filtered. After acidification of samples excess silver nitrate content was determined by adding the potassium thiocyanate solution. All measurements were performed in triplicate and data was presented as mean values.

3.6.5 FAT CONTENT ANALYSIS

Total fat content in % was determinated in accordance with the standard ČSN ISO 1444 (ISO, 1444). Fat content was determined from 8 g dried homogenized fish samples by using petroleum ether and a Soxtherm extraction unit (Gerhardt, Bonn). The solvent was evaporated and the extracted fat was weighted.

3.7 ORGANOLEPTIC PROPERTIES AND SENSORY ANALYSIS

Organoleptic properties and sensory analysis of samples of dried fish were conducted in Department of Food Biotechnology, Faculty of Agro-Industry, RUA by trained sensory panel of 19 assessors, comprising 9 males and 10 females with age ranging from 18 to 25 years. Following criteria were judged during the analysis: appearance, odour, flavour and texture. The facility used for the sensory evaluation was a large room and each panellist was supplied with a questionnaire, a pencil, a glass of water, and all the panellists were allowed into the room together and had unlimited time to complete the tasting. Each sample of fish was evaluated using a five point hedonic scale (1 - excellent, 5 - poor). Data was subjected to one-way analysis of variance (ANOVA) and differences were considered significant at an alpha value of 0.05. Analyses were performed using the *R* statistical package. Results are presented with the mean and standard deviation of triplicates and differences between means were determined by Tukey’s HSD (honestly significance difference) test.

4 RESULTS AND DISCUSSION

4.1 DRYER PERFORMANCE

Sets of drying experiments were carried out in RUA, Phnom Penh, Cambodia. In drying experiments four different species of fish were used. Products were dried in electric oven and in solar dryer, where the only heat source for drying was solar energy. The following is an analysis and discussion of the performance of the components of the solar dryer as well as of the overall performance of the system.

The values of ambient temperature, ambient relative humidity (RH), and solar radiation ranged between 26.3 °C and 37.6 °C, 30.6 % and 55.8 %, and 236.2 $W \cdot m^{-2}$ and 873.4 $W \cdot m^{-2}$, respectively, see Figure 4.1.

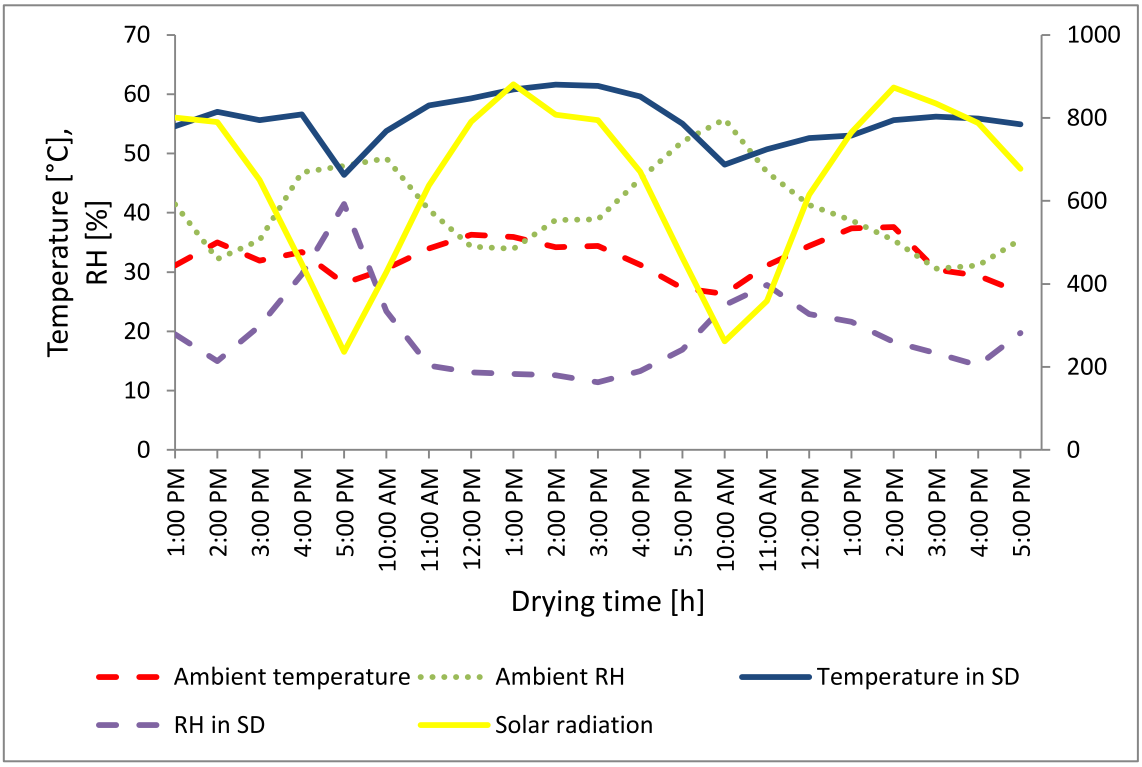


Figure 4.1 Air temperature [°C], air relative humidity [%] compared to solar radiation [$W \cdot m^{-2}$] during drying experiment

All drying conditions of the solar drying process were also monitored and they are presented in Figure 4.2. Temperature and relative humidity of the drying air ranged between 46.4 °C and 61.4 °C and 11.4 % and 29.6 %.

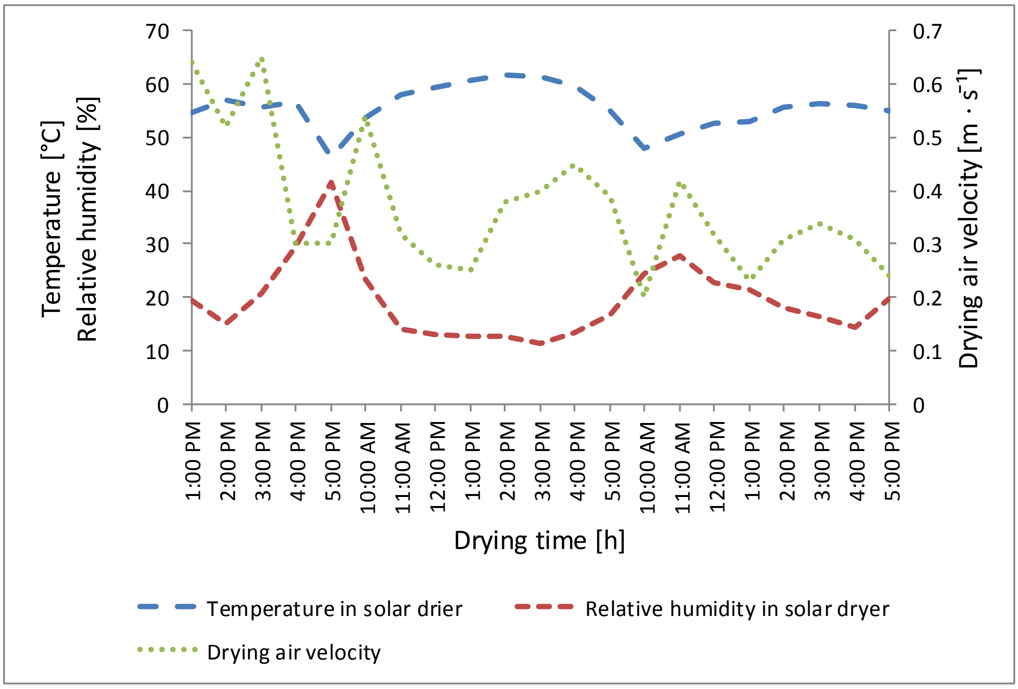


Figure 4.2 Air temperature [°C], air relative humidity [%]

From the curves it is clear that drying air temperature and drying air relative humidity have a contradictory run. Moreover, it is evident that the maximum drying temperatures did not exceed 70 °C which is considered the maximum temperature for fish drying (Rahman, 2006). It was observed that the mean drying temperature and drying air relative humidity in the solar dryer were on average about 72.48 % higher and 51.96 % lower than the ambient ones.

A performance of solar dryer was calculated according to Equation 3.1 – Eq. 3.4 that used average value of drying air velocity 0.37 $m \cdot s^{-1}$. In the natural convection solar dryer the airflow is usually established by buoyancy induced airflow (Bala & Hossain, 2012). The effect of variation of air temperature inside the dryer was thereby minimized, resulting in the uniform drying of the fish samples. The overall drying efficiency and thermal efficiency varied during the whole drying process from 1.56 % to 23.85 % and from 13.16 % to 53.56 %, respectively. Figure 4.3 shows that maximal solar radiation corresponds to lower drying and thermal efficiency. Similar observations were reported by Fudholi, et. al. (2013). Furthermore, the overall average dryer efficiency was 12.37 %. Obtained drying efficiency represents the upper limit from 10 % to 15 % which is typical for natural convection drying (Rahman, 2006).

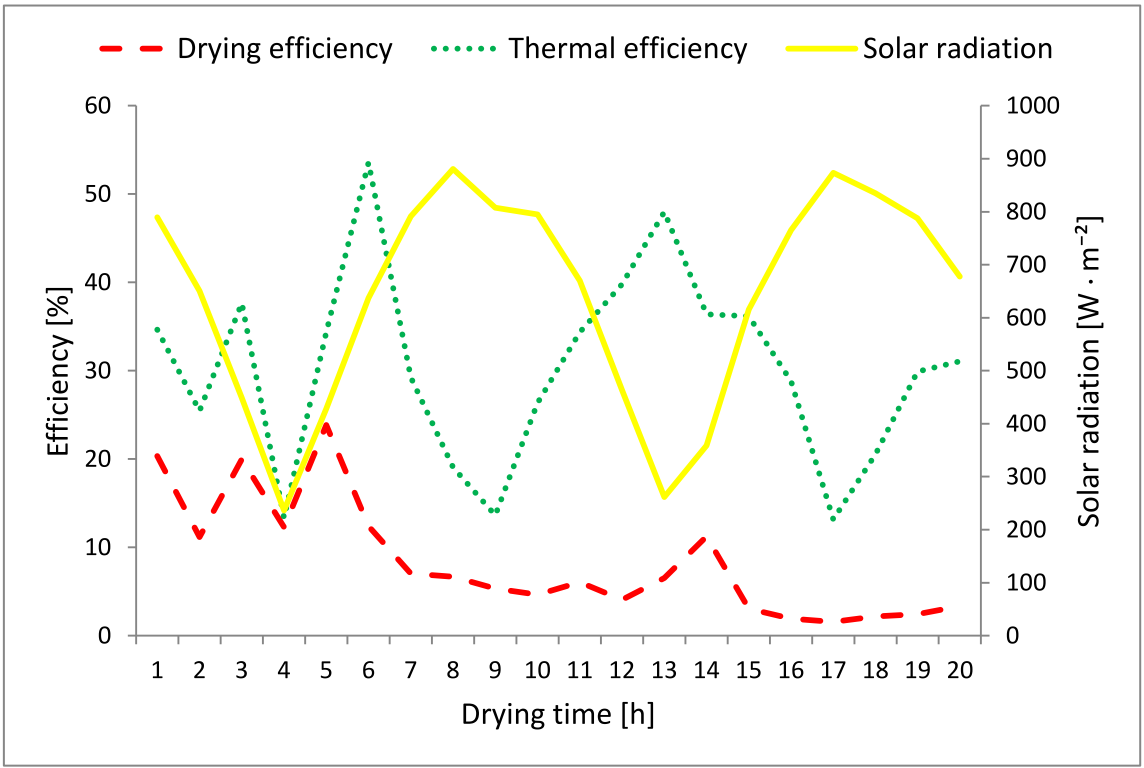


Figure 4.3 Thermal efficiency [%] and drying efficiency [%] compared to solar radiation [W · m^{-2}] during drying experiment in solar dryer

Evaporative capacity helps to evaluate the influence of meteorological conditions on solar dryer performance. In some cases the evaporative capacity is more precise measure of the solar dryer performance compared to traditionally used thermal efficiency, especially when particular use with preheated air is considered. An average evaporative capacity of solar dryer was calculated using Equation 3.2 and it was equal to 0.049 kg · h^{-1}. The evaporative capacity increased with increasing solar radiation. For comparison, traditional fish-drying in Cambodia is practiced on the ground. The drying process of open sun drying takes usually about 1 week depending on the climatic conditions (Bala & Hossain, 2012).

4.2 KINETICS OF DRYING PROCESS

4.2.1 DRYING RATE OF FISH SAMPLES WITHOUT PRE-TREATMENTS

The average initial moisture content (MC) of tested fish species without salt pre-drying treatment varied between 3.32 and 4.92 g · g^{-1} dry basis (db) which correspond to 79.01 % and 84.60 % wet basis (wb). For comparison, the initial MC in Bala & Hossain (2012) of silver jewfish and ribbon fish is almost same (73 to 74 %).

Figure 4.4 and Fig. 4.5 present the reduction of moisture content from tested fish samples without salt treatment which are with respect to total time in solar dryer (SD) and electric oven (EO) with temperature 50 °C. After 20 hours of drying, the average final moisture content decreased to 1.54 and 1.65 (db) which corresponds to 32.10 % and 34.21 % (wb) in solar dryer and electric oven, respectively. The moisture content of a good quality dry fish should be less than 40 % by mass (Sivashanthini & Thavaranjit, 2012)

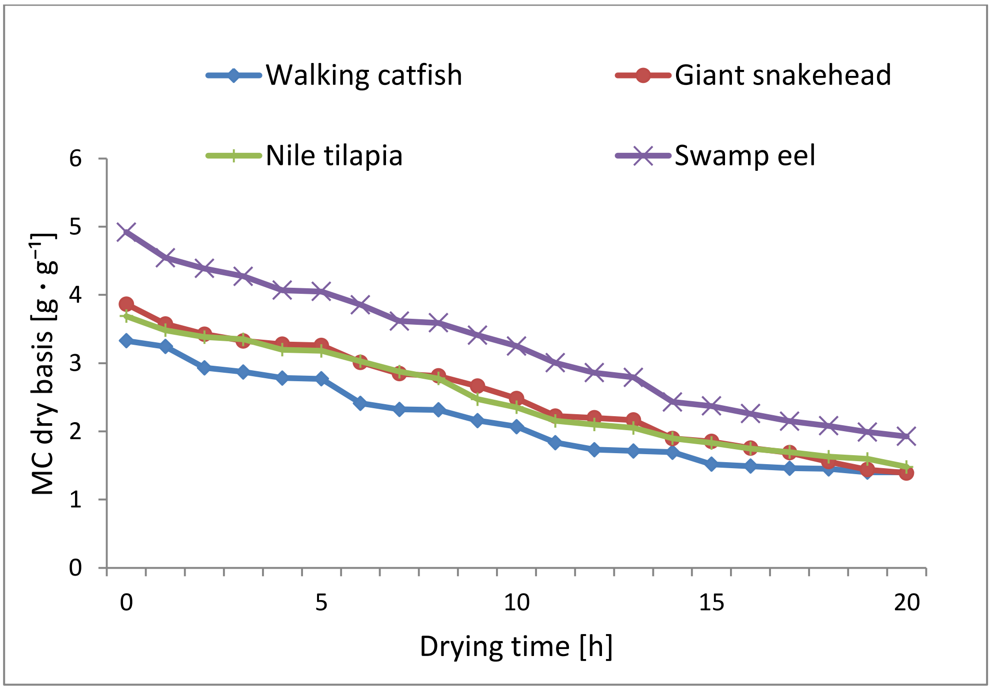


Figure 4.4 Changes of moisture content dry basis (db) of fish meat samples with drying time for a typical experimental run in solar dryer (SD)

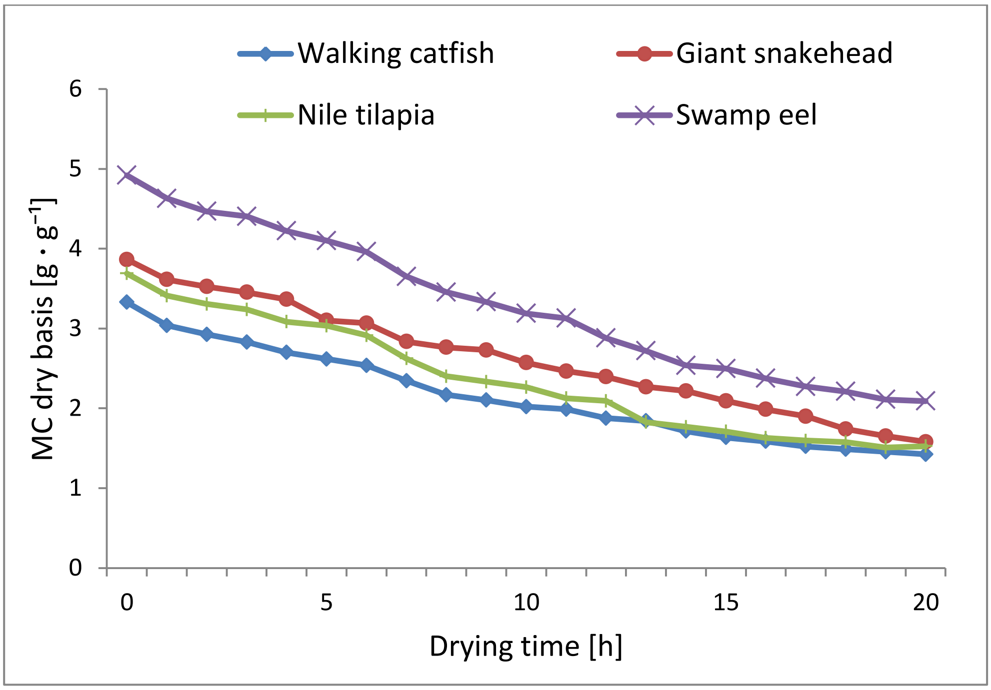


Figure 4.5 Changes of moisture content (db) of fish meat samples with drying time for a typical experimental run in electric oven (EO)

From Figure 4.4 and Fig. 4.5 it is evident that in general a higher drying rate was achieved in solar dryer as compared to electric oven. This fact corresponds to higher drying air temperature and lower relative humidity (RH) during solar drying. Focusing on the drying curves of different fish species dried under constant temperature in electric oven (Fig. 4.5), we may see slight differences among fish samples. The highest drying rate was observed in case of the giant snakehead followed by Nile tilapia.

Drying rates were plotted with moisture contents for solar drying and drying in electric oven and results are presented in Figure 4.6. The drying rates were higher at the beginning of the drying process and later decreased with decreasing moisture content. Similarly, as in case of Figure 4.4 and Fig. 4.5, a higher drying rate was observed during solar drying of fish mainly in the initial stages. The drying rates were fitted by exponential trend lines and DR Equation 4.1 and Eq. 4.2 were developed for solar drying and electric oven drying, respectively:

$DR = 0.0253e^{0.5721x}$ ($R^2 = 0.8816$), **Equation 4.1**

$DR = 0.0176e^{0.6579x}$ ($R^2 = 0.8915$) **Equation 4.2**

During the drying process, variations of DRs were observed which are caused by different shape, size, and nature of selected fish species. Similar results were reported by Jain & Pathare (2007).

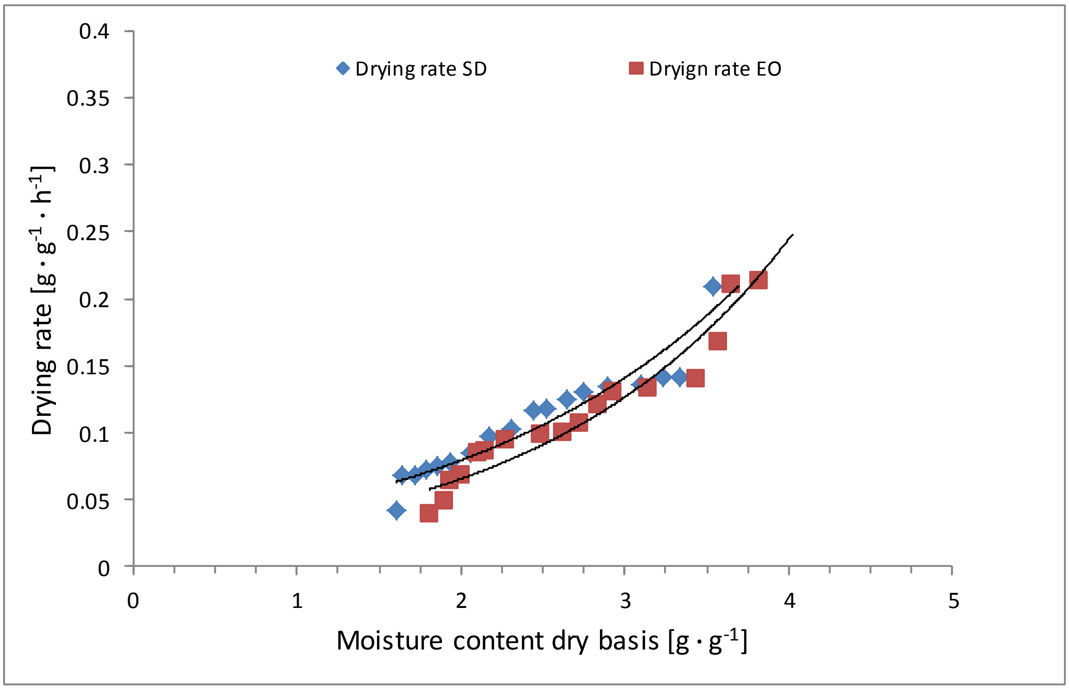


Figure 4.6 Drying rate curves of fish meat dried in solar dryer and electric oven

According the Bala & Hossain (2012), the natural convection solar drying has disadvantages over forced convection solar drying as it is difficult to control the drying temperature and drying rate.

4.2.2 DRYING RATE OF FISH SAMPLES WITH PRE-TREATMENTS

After the pre-treatment by dry salting and before the drying process, moisture content in the fish samples dry basis was determined. In samples salted overnight the moisture content was lower than in samples salted 2 and 4 hours.

The average initial dry moisture content (MC) regardless of the fish species after being salted for 2 hours, 4 hours and overnight was 3.05, 2.92 and 2.73 g · g^{-1} (db) which corresponds to 2.62.2 %, 59.3 % and 56.2 % and it is shown in Table 4.1. In this table the initial MC of unsalted fish samples is also shown. Similar results were presented by Sivashanthini & Thavaranjit (2012). Hwang, et al. (2012) determined the water content related to the effect of salt concentrations and drying methods in dried milkfish (*Chanos chanos*). The lowest initial moisture content was calculated for fish samples that were highest in salt concentration (Table 4.13).

Table 4.1 An initial moisture content wet basis [%] of the four fish species before drying process

Fish species	Unsalted MC (wb) in %±SD	Salting: 2h MC (wb) in %±SD	Salting: 4h MC (wb) in %±SD	Salting: night MC (wb) in %±SD
Walking catfish	79.01±0.03	59.87±0.04	57.22±0.09	52.27±0.07
Giant snakehead	83.97±0.12	61.94±0.06	57.18±0.05	55.20±0.06
Nile tilapia	81.26±0.04	62.46±0.11	60.46±0.07	56.39±0.12
Swamp eel	84.60±0.08	64.35±0.07	62.29±0.07	61.09±0.14

Figures from Fig. 4.7 to Fig. 4.18 display the loss in moisture content over time in hours. Drying curves were fitted by mathematical functions. Coefficient of determination (R^2) was used for the selection of fitting function as the primary criterion to select the best equation describing the drying curve (Erbay & Icier, 2010).

Salt concentration in meat affects its ability to bind water in such a way that the maximum water binding ability is reached at about 5 % of salt concentration (Pipek, 2002).

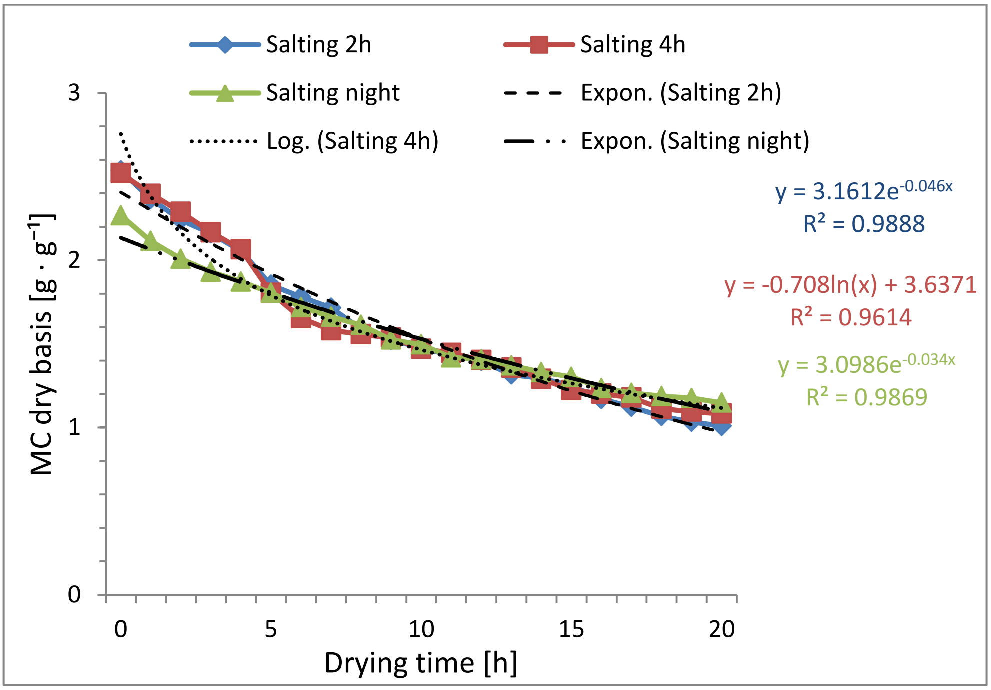


Figure 4.7 Changes of moisture content (db) of walking catfish samples with drying time for experimental run in an electric oven at a temperature of 50 °C

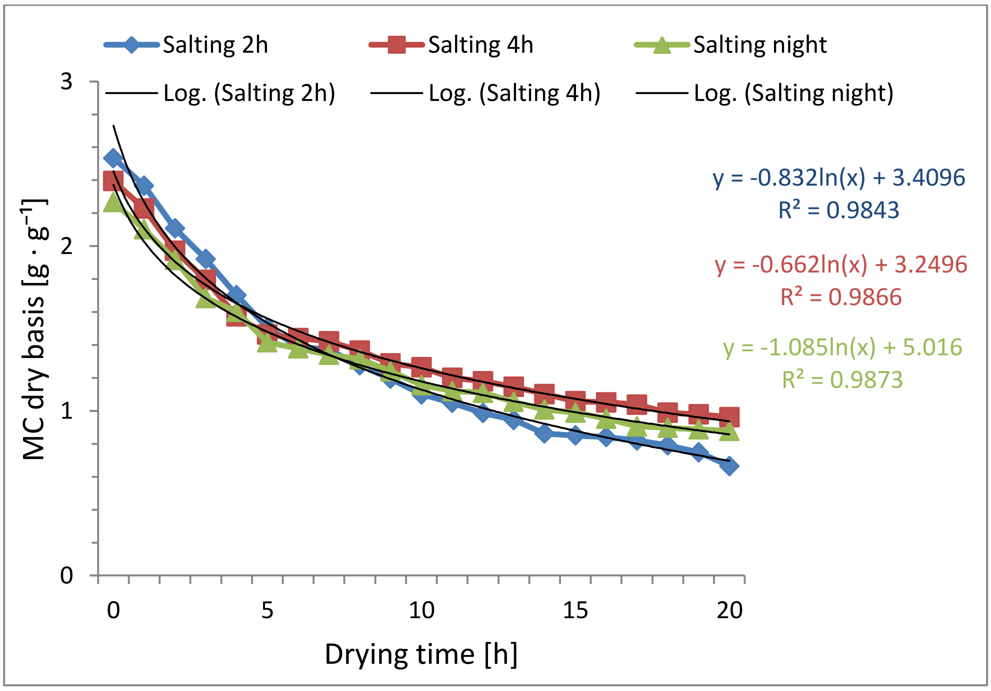


Figure 4.8 Changes of moisture content (db) of walking catfish samples with drying time for an experimental run in an electric oven at a temperature of 60 °C

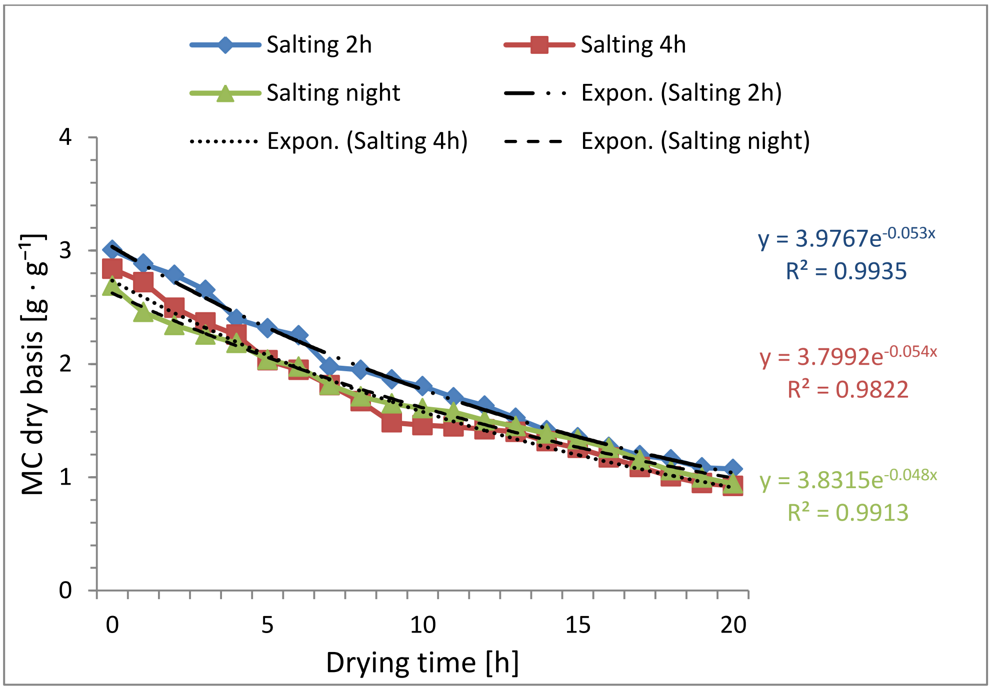


Figure 4.9 Changes of moisture content (db) of giant snakehead samples with drying time for an experimental run in an electric oven at a temperature of 50 °C

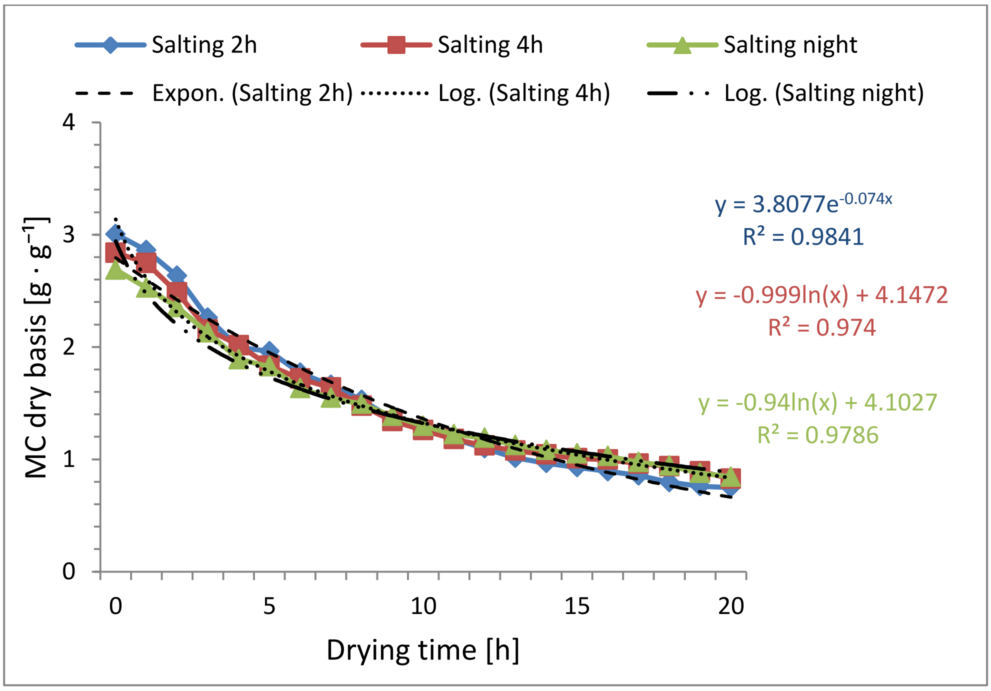


Figure 4.10 Changes of moisture content (db) of giant snakehead samples with drying time for an experimental run in an electric oven at a temperature of 60 °C

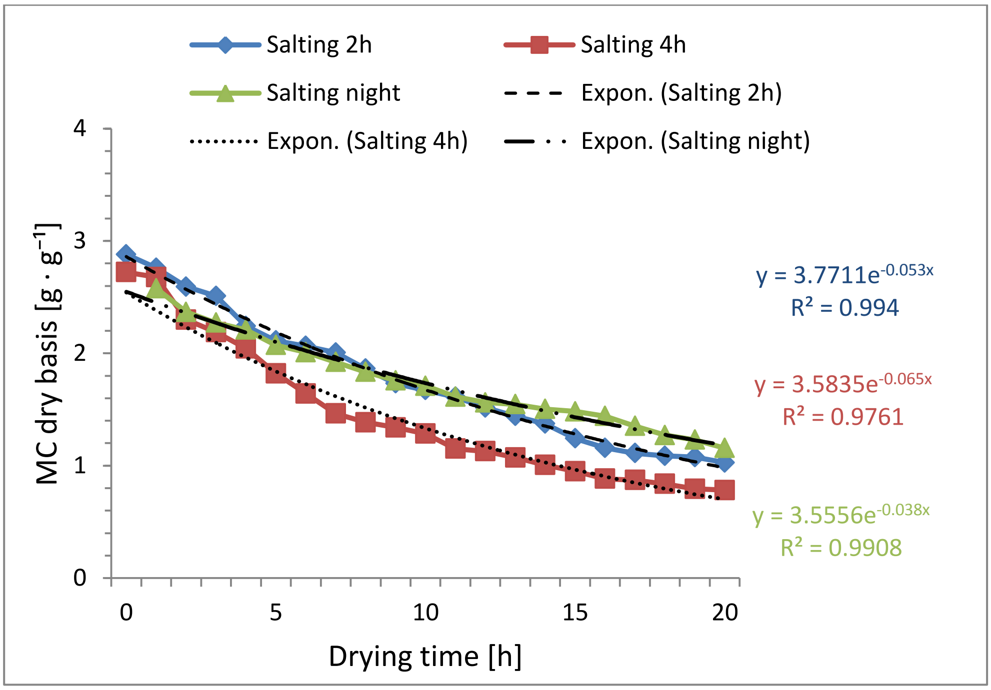


Figure 4.11 Changes of moisture content (db) of Nile tilapia samples with drying time for an experimental run in an electric oven at a temperature of 50 °C

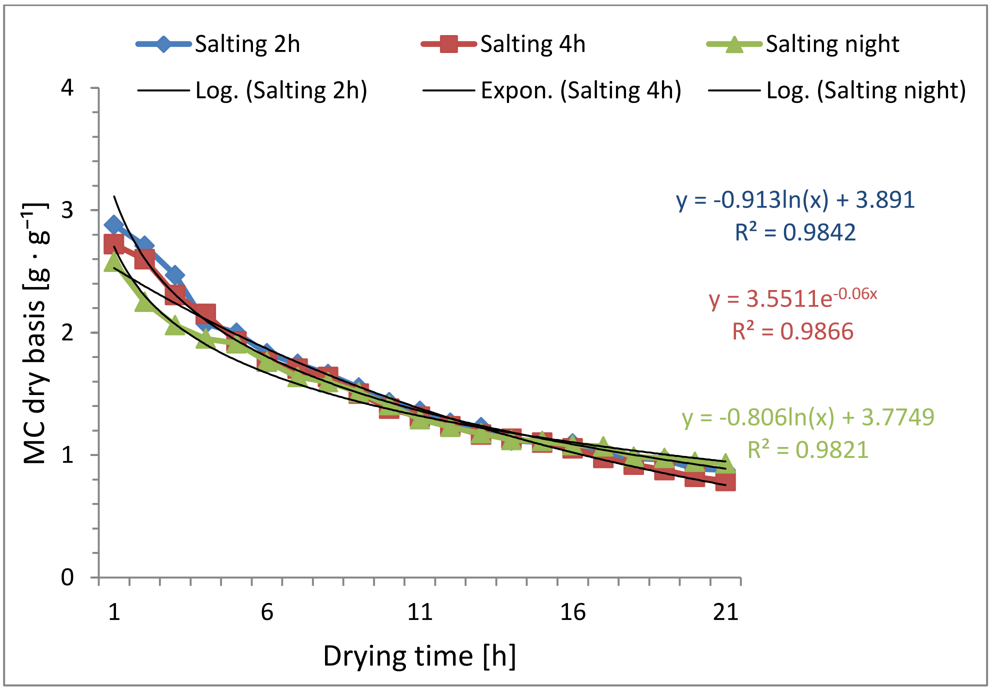


Figure 4.12 Changes of moisture content (db) of Nile tilapia samples with drying time for an experimental run in an electric oven at a temperature of 60 °C

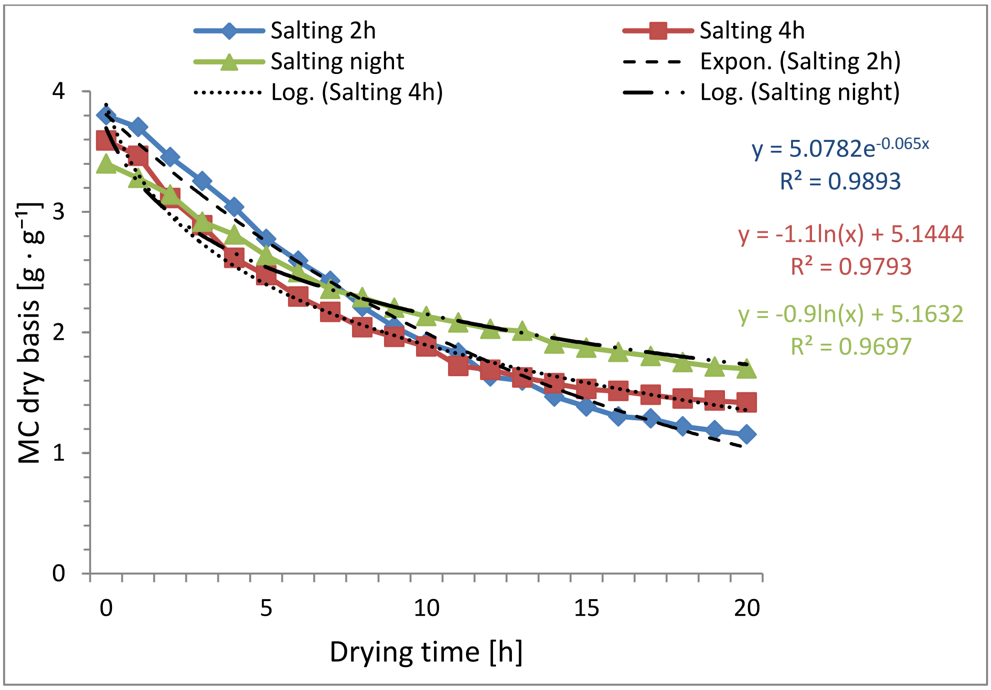


Figure 4.13 Changes of moisture content (db) of swamp eel with drying time for an experimental run in an electric oven at a temperature of 50 °C

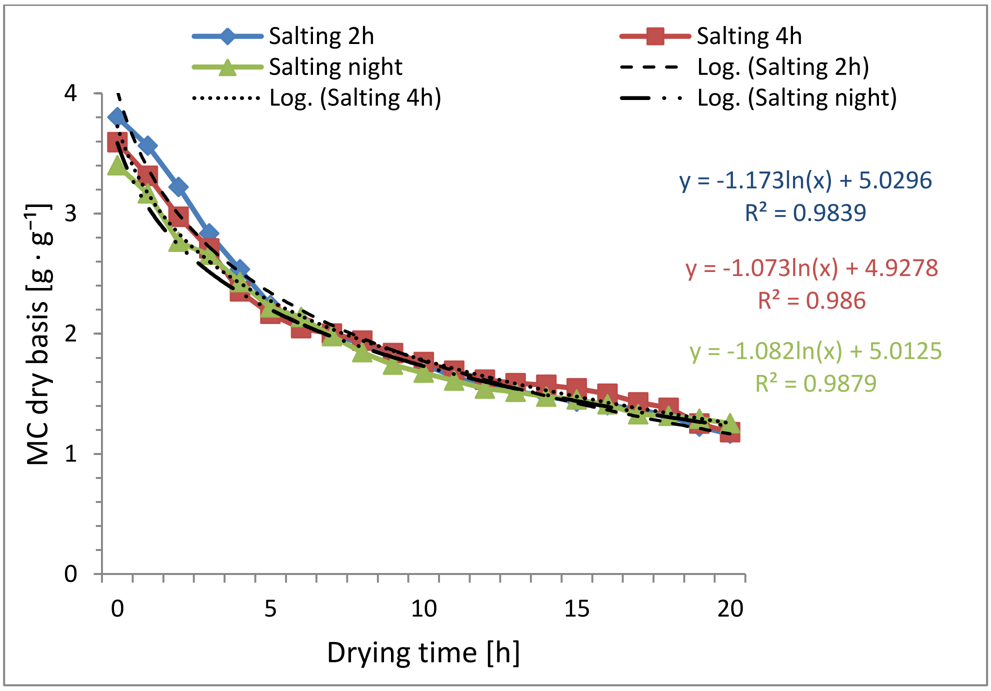


Figure 4.14 Changes of moisture content (db) of swamp eel samples with drying time for an experimental run in an electric oven at a temperature of 60 °C

Figures Fig. 4.7 – Fig. 4.14 show differences between the drying curves of samples dried in an electric oven with a constant temperature of 50 °C and 60 °C. The resulting drying curves are predominantly logarithmic for both. The drying of fish samples at a temperature of 60 °C is faster and the dried samples have a lower final moisture content and a lower final water activity, that is shown in Tab. 4.7 and Tab. 4.8. The final wet basis moisture content [%] of fish samples after drying affected by pre-treatments is shown in Tab. 4.2

Table 4.2 A final moisture content wet basis [%] of the four fish species after drying process

Fish species	Unsalted EO 50 °C MC (wb) in %±SD	EO 50 °C, salting 2h MC (wb) in %±SD	EO 50 °C, salting 4h MC (wb) in %±SD	EO 50 °C, salting night MC (wb) in %±SD
Walking catfish	34.15±0.07	24.22±0.13	25.99±0.15	27.54±0.13
Giant snakehead	33.25±0.17	22.55±0.19	19.43±0.21	19.86±0.22
Nile tilapia	33.09±0.15	22.34±0.17	17.01±0.14	24.91±0.08
Swamp eel	36.36±0.21	20.06±0.13	24.66±0.19	29.55±0.17

Table 4.2: Continued

Fish species	EO 60 °C, salting 2h MC (wb) in %±SD	EO 60 °C, salting 4h MC (wb) in %±SD	EO 60 °C, salting night MC (wb) in %±SD
Walking catfish	15.95±0.09	23.09±0.17	21.08±0.22
Giant snakehead	15.76±0.11	17.35±0.16	17.77±0.06
Nile tilapia	19.07±0.04	17.13±0.08	20.26±0.12
Swamp eel	20.26±0.08	20.51±0.14	21.79±0.07

Based on the differences between initial and final MC for individual fish species, it is possible to determine optimal salting times for drying at 50 and 60 °C. When dried at 50 °C, walking catfish and swamp eel are best salted for the period of 2 hours, while giant snakehead and Nile tilapia are best salted for the period of 4 hours. When dried at 60 °C, all four species are best salted for the period of 4 hours. These results show that, salting fish meat for the period of 2 to 4 hours is sufficient and it is not necessary to salt them overnight. Figures Fig. 4.15 – Fig. 4.18 show the influence of different salting times in four different fish species during the drying process in a solar dryer.

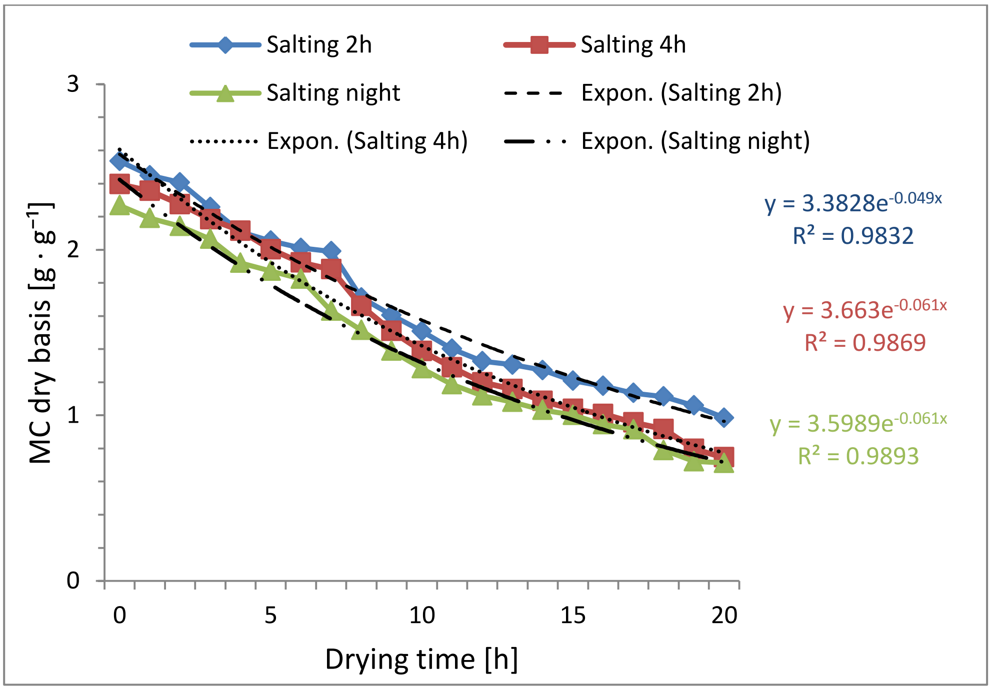


Figure 4.15 Changes in moisture content (db) of walking catfish samples for three salting times with drying time for experimental run in a solar dryer (SD)

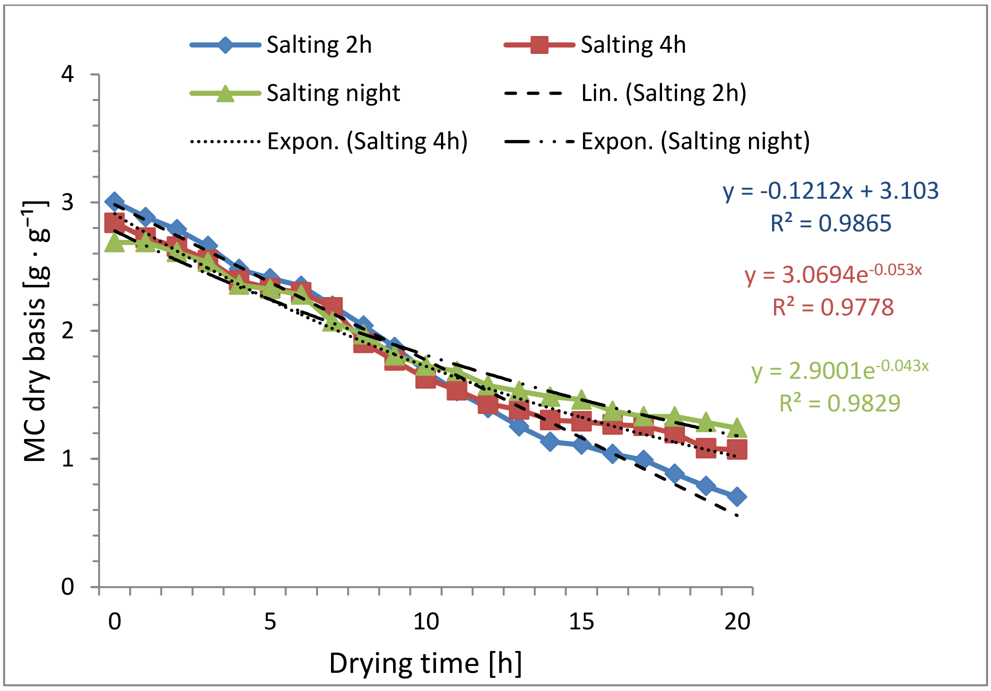


Figure 4.16 Changes in moisture content (db) of giant snakehead samples for three salting periods with drying time for experimental run in a solar dryer (SD)

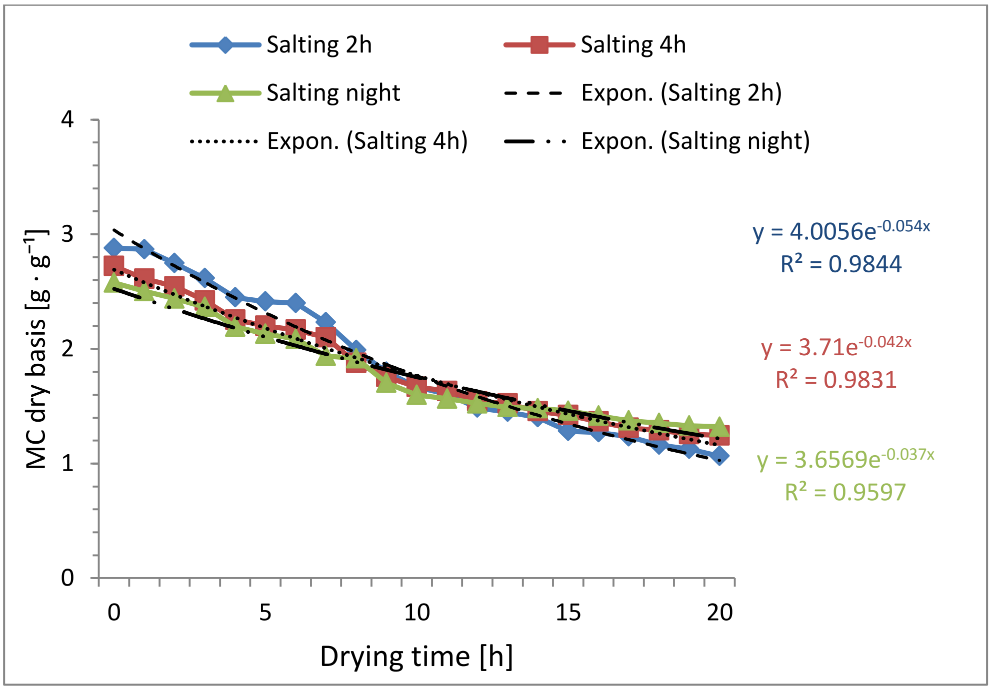


Figure 4.17 Changes in moisture content (db) of Nile tilapia samples for three salting periods with drying time for experimental run in a solar dryer (SD)

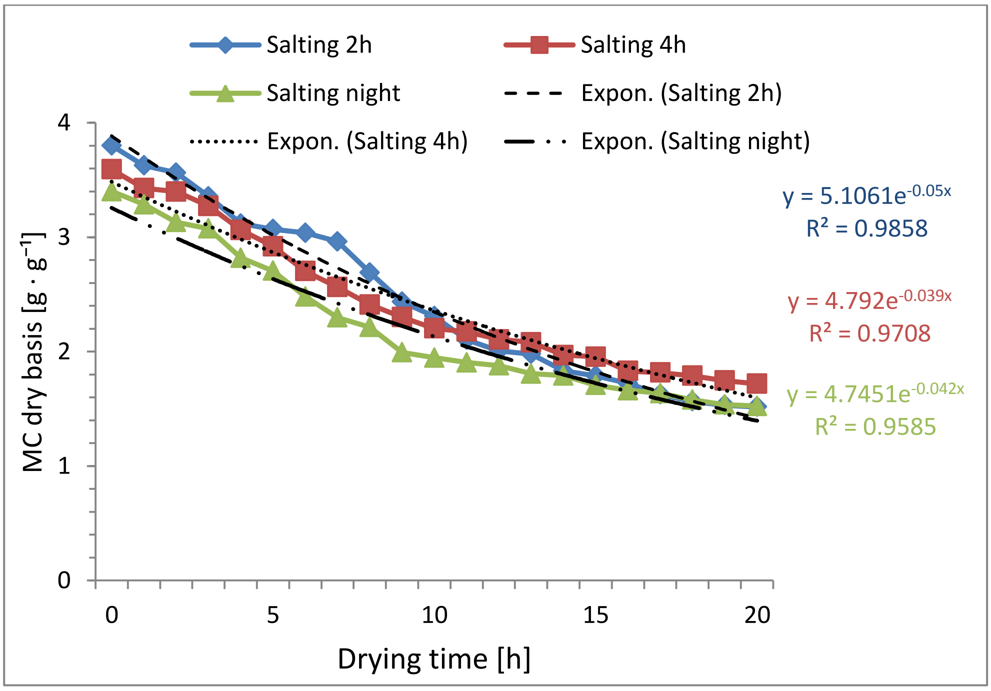


Figure 4.18 Changes in moisture content (db) of swamp eel for three salting times with drying time for experimental run in a solar dryer (SD)

The changing pattern of moisture content of tested fish reduced during the falling rate period, due to acceleration of water migration inside the fish, the same process is given in Bala & Hossain (2012). From the curves it is obvious that, at first, moisture is being removed from the surface of the fish. Once all the surface moisture has been carried away, the rate of drying falls. As the concentration of moisture in the fish falls, the rate of movement of moisture to the surface is reduced and the drying rate becomes slower. As mentioned above, drying curves are affected by the salting process before drying. The weight reduction is connected to the salt concentration (Pipek, 2002).

The final wet basis moisture content (MC) of fish samples after drying in solar dryer affected by pre-treatments is shown in Tab. 4.3. In this table the final MCs of unsalted fish samples are also recorded. In dried samples in electric oven and solar dryer the difference between initial and final MC was calculated in Tab. 4.4. Table 4.4 shows that drying in the solar dryer required 20 hours to dry tested fish salted for 4 hours from 59.29 % (wb) to 24.46 % (wb) moisture content as compared 20 hour drying in electric oven 50 °C and 60 °C to dry fish samples salted for 4 hours from 59.29% (wb) to 21.77 % (wb) and to 19.52 % (wb) moisture content, respectively. Bala & Hossain (2012) published drying in the solar tunnel dryer tested in the fields in Bangladesh required 3 days to dry silver jewfish from 74.45% (wb) to 14.29 % (wb) as compared to 74.4 % (wb) to 20.29 % (wb) in 3 days in traditional sun drying. Sobukola & Olatunde (2011) investigated an effect of dry salting and salting techniques on salt uptake and drying kinetics of African catfish. Authors published that samples with lower final moisture content during salting gave a slower rate of reduction of moisture and higher final moisture content during drying. They presented that this can be attributed to water movement to the surface accompanied by salt migration.

Table 4.3 A final moisture content [%] of the four fish species after drying process in solar dryer

Fish species	Unsalted MC (wb) in %±SD	Salting 2h MC (wb) in %±SD	Salting 4h MC (wb) in %±SD	Salting night MC (wb) in %±SD
Walking catfish	33.60±0.19	23.62±0.13	17.90±0.25	17.09±0.27
Giant snakehead	29.22±0.23	14.78±0.24	22.52±0.22	26.09±0.17
Nile tilapia	32.12±0.14	23.17±0.17	27.06±0.19	28.70±0.13
Swamp eel	33.48±0.22	26.63±0.16	30.37±0.13	26.74±0.21

Table 4.4 An average differences regardless of the four fish species between initial and final moisture content [%]

	Salting 2 hours	Salting 4 hours	Salting overnight
Electric oven 50 °C	64.14±0.32	63.28±0.26	54.71±0.28
Electric oven 60 °C	71.42±0.45	67.07±0.42	64.04±0.61
Solar dryer	64.53±0.37	58.40±0.31	56.49±0.35

4.2.3 EFFECT OF PRE-TREATMENTS TO THE FINAL REHYDRATION RATIO AND THE FINAL RECOVERY RATIO

The rehydration process is aimed at the restoration of raw material properties when dried materials are immersed in water (Dadali, 2008). The changes in weight for the dried fish samples and rehydrated products are given in figures Fig. 4.19 – Fig. 4.24. The rehydration ratio in time were fitted by linear trend lines and rehydration ratio rates (Rreh) equations (Eq. 4.3 – Eq. 4.14) were calculated for fish samples salted for 2, 4 hours, salted overnight and dried in electric oven at 60 °C and average rehydration ratio rates ($\bar{R}$reh) were established.

An increase rate is a parameter, which gives the information about how quickly a mass changes in time. An average value of a rate of increase was also calculated.

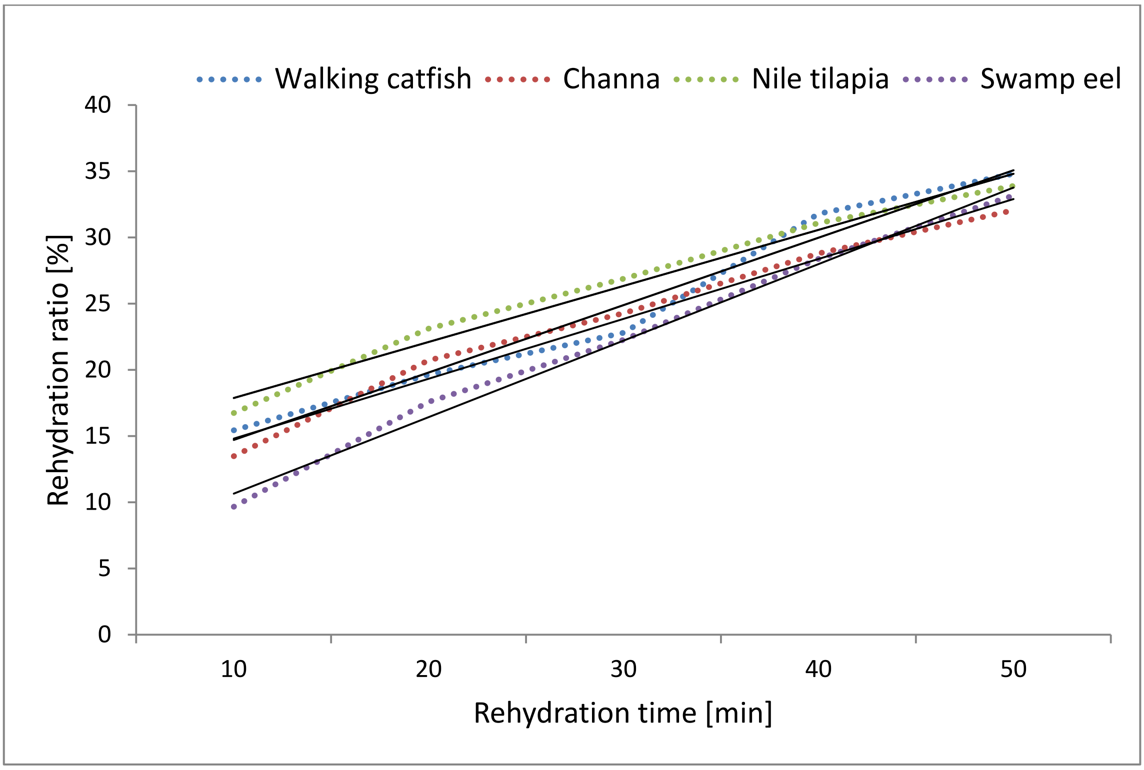


Figure 4.19 The rehydration ratio curves for fish dried in electric oven at 60 °C and salted for 2 hours

Walking catfish:	Rreh = 5.0903x + 9.6267 (R^2 = 0.9691)	**Equation 4.3**
Giant snakehead:	Rreh = 4.525x + 10.293 (R^2 = 0.9773)	**Equation 4.4**
Nile tilapia	Rreh = 4.2299x + 13.656 (R^2 = 0.9797)	**Equation 4.5**
Swamp eel:	Rreh = 5.782x + 4.8735 (R^2 = 0.9917)	**Equation 4.6**

$\bar{R}$reh = 4.91

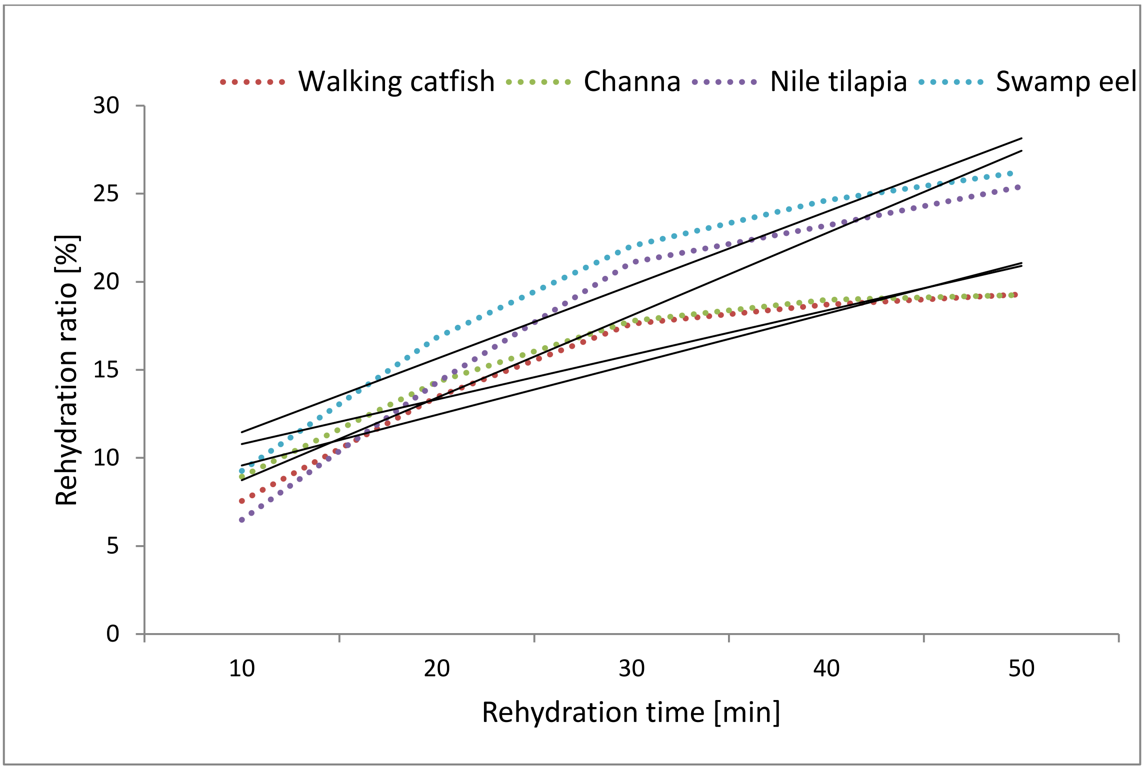


Figure 4.20 The rehydration ratio curves for fish dried in electric oven at 60 °C and salted for 4 hours

Walking catfish:	Rreh = 2.8709x + 6.7081 (R^2 = 0.8558)	**Equation 4.7**
Giant snakehead:	Rreh = 2.5286x + 8.2661 (R^2 = 0.8503)	**Equation 4.8**
Nile tilapia	Rreh = 4.6755x + 4.068 (R^2 = 0.9194)	**Equation 4.9**
Swamp eel:	Rreh = 4.1722x + 7.2814 (R^2 = 0.9192)	**Equation 4.10**

$\bar{R}$reh = 3.56

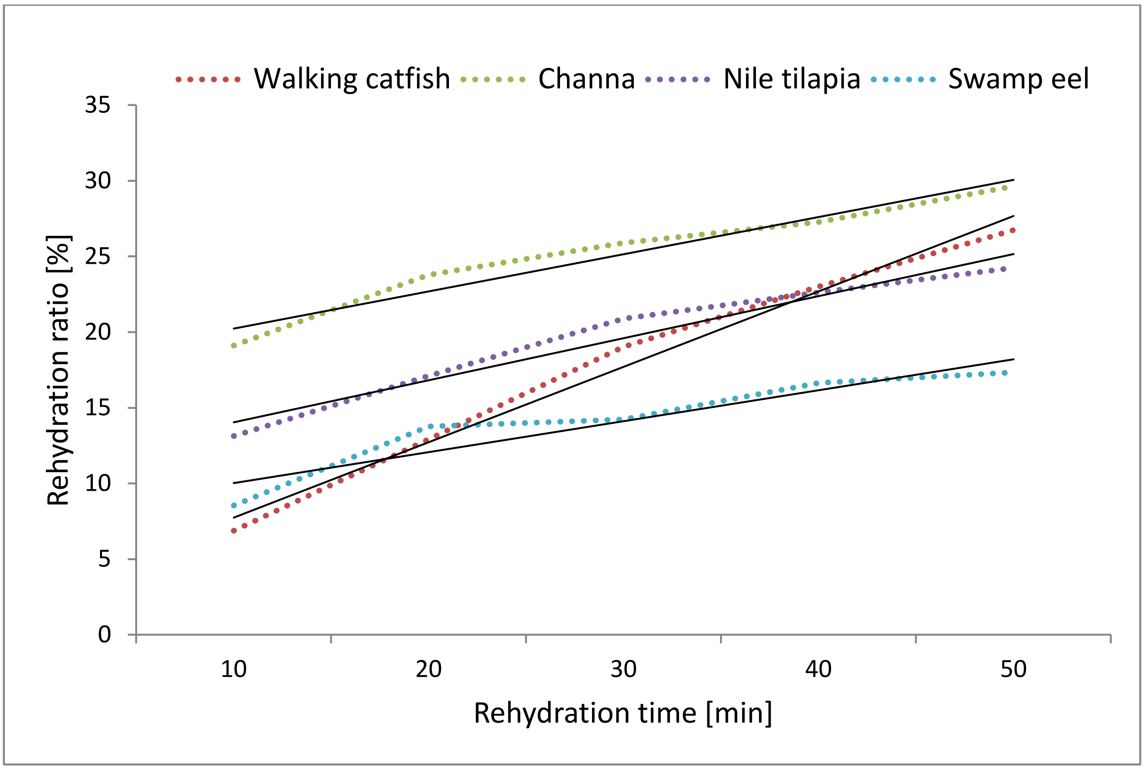


Figure 4.21 The rehydration ratio curves for fish dried in electric oven at 60 °C and salted overnight

Walking catfish:	Rreh = 4.9851x + 2.753 (R^2 = 0.9861)	**Equation 4.11**
Giant snakehead:	Rreh = 2.4569x + 17.77 (R^2 = 0.9477)	**Equation 4.12**
Nile tilapia:	Rreh = 2.7758x + 11.273 (R^2 = 0.9569)	**Equation 4.13**
Swamp eel:	Rreh = 2.0458x + 7.97 (R^2 = 0.8738)	**Equation 4.14**

R̄reh = 3.07

The influence on rehydration of salted samples is given in figures Fig. 4.22 to Fig. 4.24. The recovery ratio in time were fitted by linear trend curves and the recovery ratio rates (Rrec) equations (Eq. 4.15 – Eq. 4.26) were developed for fish samples salted for 2, 4 and overnight in electric oven in 60 °C, respectively and average recovery ratio rates (R̄rec) were established.

An increase rate is a parameter, which gives the information about how quickly a mass changes in time. An average value of a rate of increase was also calculated.

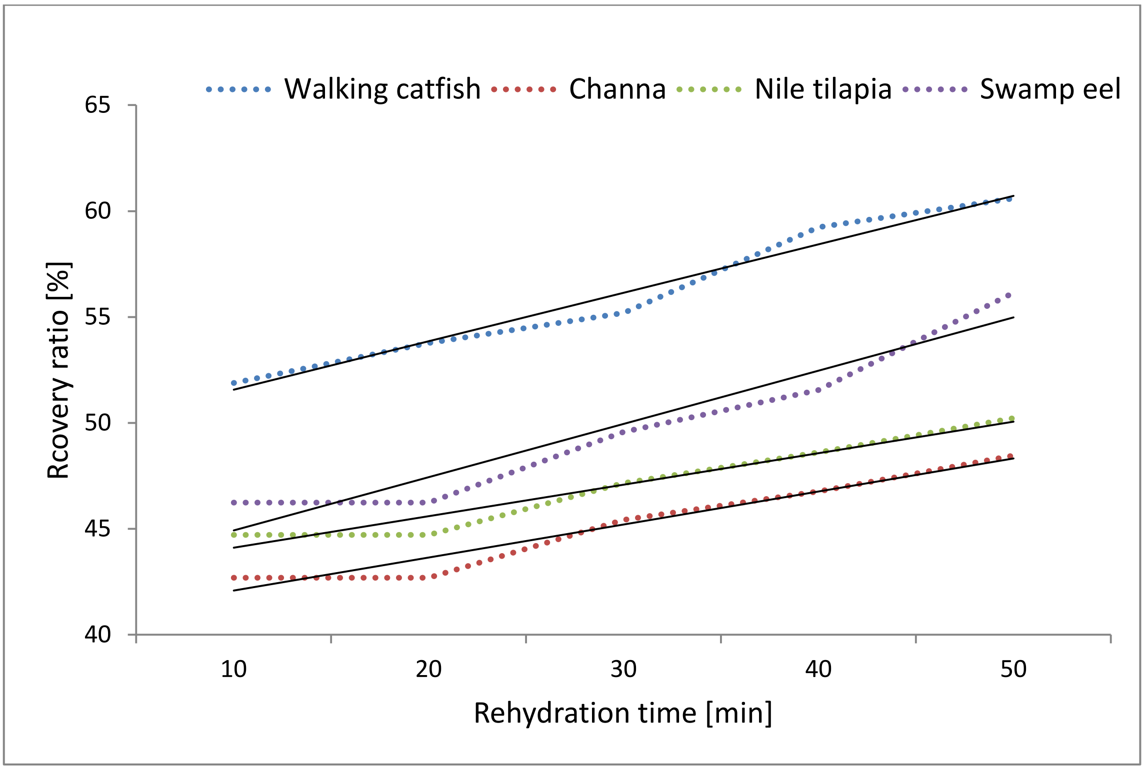


Figure 4.22 Recovery ratio lines for fish dried in electric oven with temperature 60 °C and salted for 2 hours

Walking catfish:	Rrec = 2.2879x + 49.273 (R^2 = 0.969)	**Equation 4.15**
Giant snakehead:	Rrec = 1.5593x + 40.527 (R^2 = 0.9478)	**Equation 4.16**
Nile tilapia:	Rrec = 1.4891x + 42.618 (R^2 = 0.9497)	**Equation 4.17**
Swamp eel:	Rrec = 2.514x + 42.403 (R^2 = 0.9198)	**Equation 4.18**

$\bar{R}$rec = 1.96

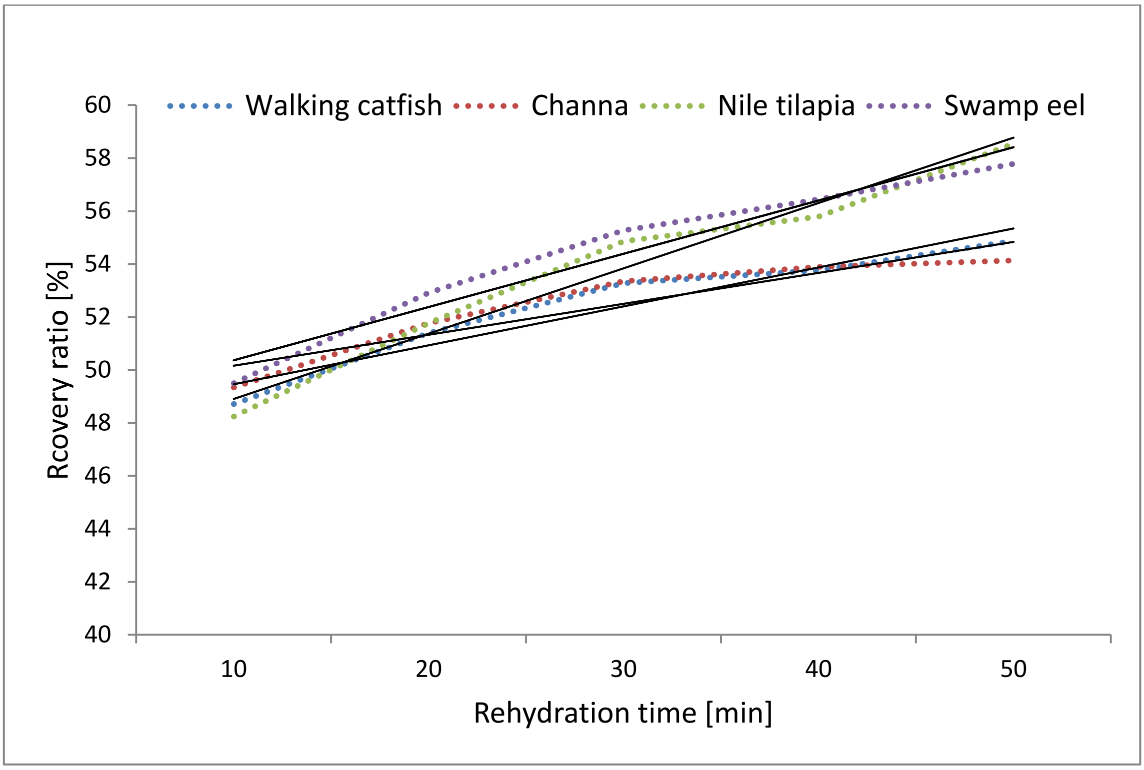


Figure 4.23 Recovery ratio curves for fish dried in electric oven at 60 °C and salted for 4 hours

Walking catfish:	Rrec = 1.4692x + 47.995 (R^2 = 0.9242)	**Equation 4.19**
Giant snakehead:	Rrec = 1.1694x + 48.99 (R^2 = 0.865)	**Equation 4.20**
Nile tilapia:	Rrec = 2.4658x + 46.441 (R^2 = 0.969)	**Equation 4.21**
Swamp eel:	Rrec = 2.0112x + 48.349 (R^2 = 0.9476)	**Equation 4.22**

$\bar{R}$rec = 1.78

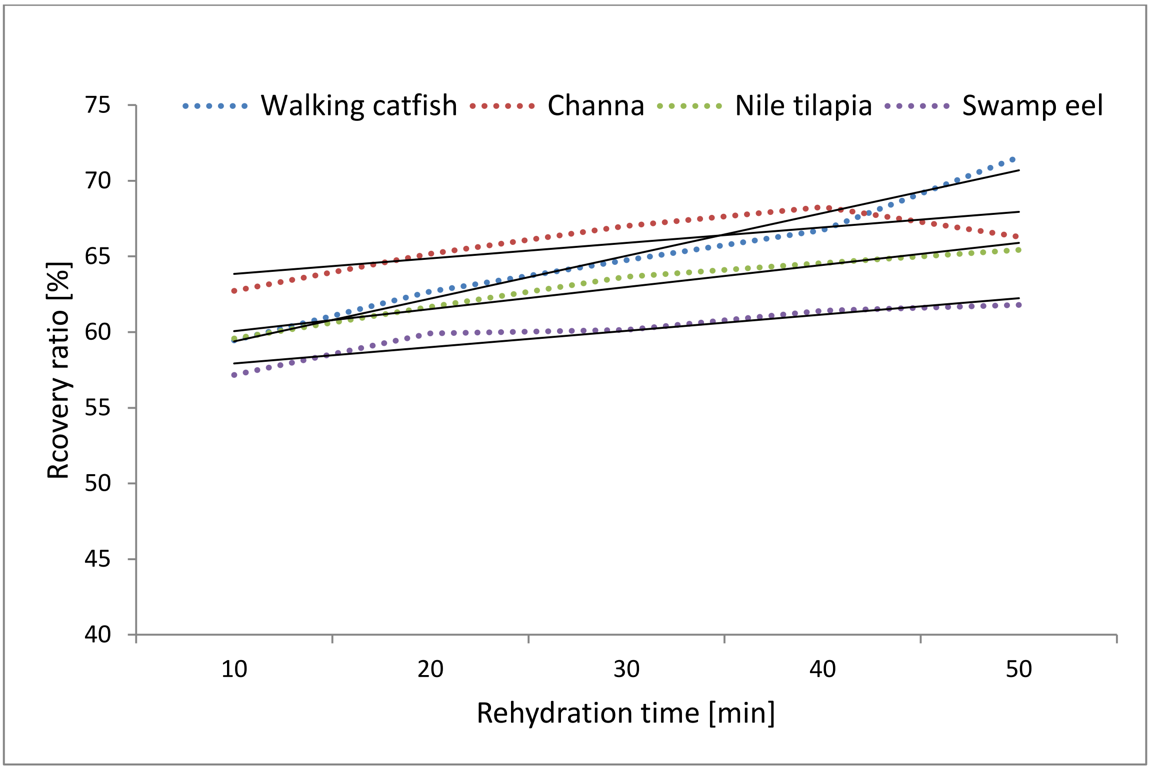


Figure 4.24 Recovery ratio lines for fish dried in electric oven at 60 °C and salted over one night

Walking catfish:	Rrec = 2.8279x + 56.559 (R^2 = 0.9719)	**Equation 4.23**
Giant snakehead:	Rrec = 1.0245x + 62.825 (R^2 = 0.5943)	**Equation 4.24**
Nile tilapia:	Rrec = 1.4617x + 58.596 (R^2 = 0.9569)	**Equation 4.25**
Swamp eel:	Rrec = 1.0773x + 56.857 (R^2 = 0.8738)	**Equation 4.26**

$\bar{R}$rec = 1.59

The storage conditions, like humidity, affected moisture content in dried samples. As we can see in figures Fig. 4.19 - Fig. 4.24 rehydration characteristics are influenced by salting. The less salted fish have higher rehydration and lower recovery ratios than fish with greater salt concentrations. That is because samples with lower salt content have a greater capacity to bind water (Jangam, et al., 2010). According Nuwanthi, et al. (2016) is an inverse relationship between water uptake and quantity of salt lost during rehydration. This agreed favourably with the investigation of Debnath, et al. (2004) when increased salt solution frequently gives a lower rehydration and recovery ratio for dried food products.

Rehydrated products salted for 2 hours are much closer to fresh meat than the fish samples salted for 4 hours and over one night. Wang, et al. (2013) confirmed that products rehydrated faster had higher rehydration ratio and as well as lower water hold capacity. For the purposes of storage in unstable conditions or high relative humidity it is advisable to use greater salt content, which prevents rehydration to a certain degree. Muñoz, et al. (2012) published rehydration kinetics at 5 and 15 °C of dry salted meat.

Wang, et al. (2010) investigated rehydration conditions of incubating the dry tilapia (*Oreochromis niloticus*) skin in lactic acid. Rehydration is usually carried out by soaking the dried product in large amounts of water, even though, some authors have used air with high relative humidity (Khaskheli, et al., 2014) because rehydration is a process of moistening. Duan, et al. (2011) found that rehydration ratio increased as the drying (microwave) power and air temperature increased. However, the recovery ratio decreased as the drying power and air temperature increased.

4.3 MATHEMATICAL MODELLING OF DRYING CURVES

The experimental data of moisture ratio versus drying time was fitted with 5 drying models. The acceptability of the drying models was performed by correlation coefficient (R), coefficient of determination (R^2) and standard error of estimate (SEE) and root-mean-square error ($RMSE$) as proposed by Erbay & Icier (2010).

The results of statistical analyses are given in Tab. 4.5 for unsalted fish samples tested in solar dryer. Data from drying of fish samples in electric oven is listed in Tab. 4.6. The values of R^2, SEE and $RMSE$ for selected models in Tab. 4.6 ranged from 0.9933 to 0.9970, 0.0172 to 0.0111 and 0.0110 to 0.2551 respectively for samples dried in electric oven. The values of R^2 for drying in solar dryer (Tab. 4.5) ranged from 0.9911 to 0.9932 and values *SEE and RMSE* ranged from 0.0197 – 0.0175 and 0.0149 to 0.2599.

As may be seen in the case of solar drying and drying in electric oven, the Cubic, Quadratic and Logarithm nonlinear regression, best describe the drying kinetics of the tested fish. Fig. 4.26 and Fig. 25 show the variations of experimental and predicted moisture ratio values in case of solar and oven drying, respectively. In both figures, only the most suitable models with the highest R^2 and lowest *SEE*, *RMSE* are presented.

All the models gave better fits for oven drying than for solar drying, which is due to more uniform drying conditions in electric oven. In case of selected models, the R^2 values were greater than 0.96 indicating a good fit.

Considering the uniform drying conditions and R^2, *SEE* and *RMSE* values for oven thin-layer drying, the Cubic model shows the best results. The articles published so far on the subject utilised polynomial regression of the second degree at maximum, which highlights the question as to whether utilisation of polynomial regression of the third degree is adequate, or not. In the end utilisation of polynomial of the third degree was not deemed without use. An article has emerged lately (Ikrang, et al., 2014) which utilises regression using a polynomial of the n-th degree. This leads us to believe that even polynomials of the second degree or higher might be utilised for regression.

Modelling of thin layer drying kinetics of salted fish fillets (*Tilapia Zilli*) in a direct passive solar dryer was conducted by Ikrang, et al. (2014). They developed an empirical model $MR = y_0 + a * x^{\mathrm{b}} + c * x^{\mathrm{n}}$ for the salted fish filets.

In the study of Jain & Pathare (2007) the drying kinetics of open sun drying of fish was investigated. The logarithmic regression model that could adequately describe the drying of prawn and chelwa fish was chose as best one. Sobukola & Olatunde (2011) published effect of dry salting and brine salting on drying kinetics of African catfish. In this study was published that The Page and modified Page models (Overhults, et al., 1973) predicted appropriately the drying kinetics. The Midilli model (Midilli, et al., 2002) was selected for drying of fish samples by microwave drying presented by Darvishi, et al. (2013). The data was confronted against a hyperbole curve which did not coincide in any significant way with the data generated in the experiment. The article (Alibas, 2014) also did not point out connection to a hyperbole. Therefore, it was established that despite the fact that the course bears in theory close resemblance to a hyperbole, it is in fact completely unsuitable to be processed using a hyperbole regression. Several authors, Bala, et al. (2003), Doymaz (2005), Koua, et al. (2009) Togrul & Pehlivan (2002), investigated mathematical modelling of fruits and vegetables by using thin layer drying models encountered in literature.

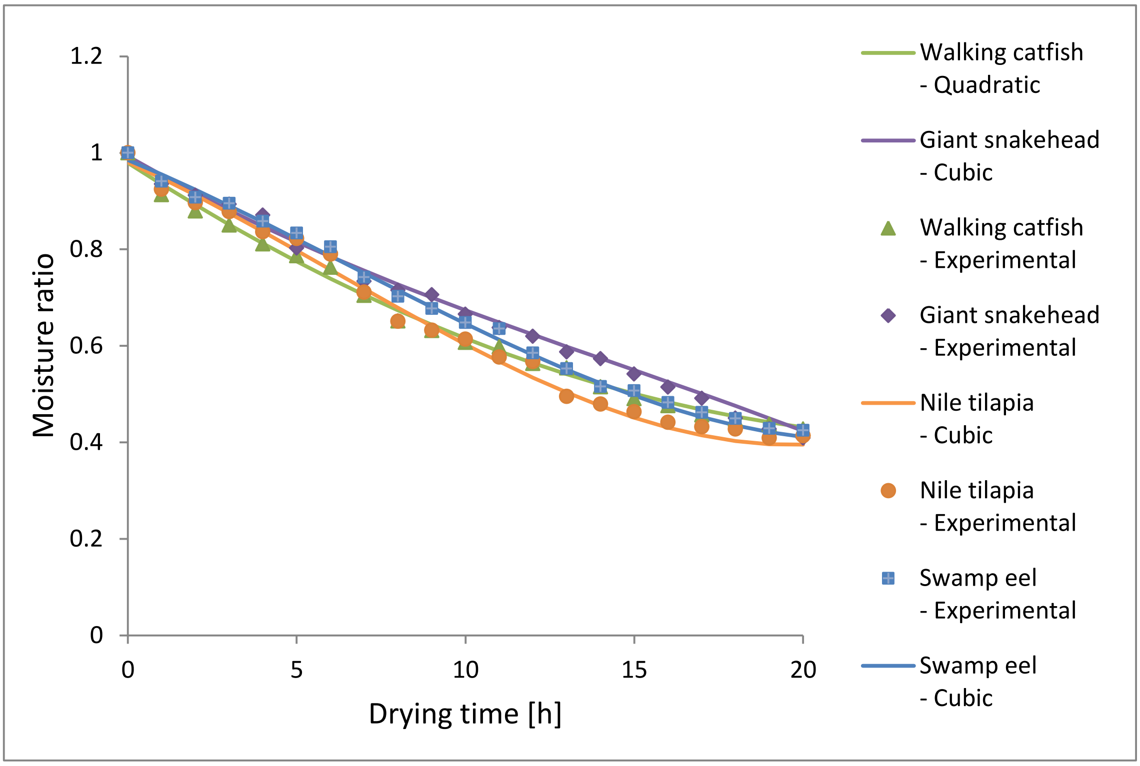


Figure 4.25 Experimental and predicted moisture ratio for electric oven drying of selected fish species

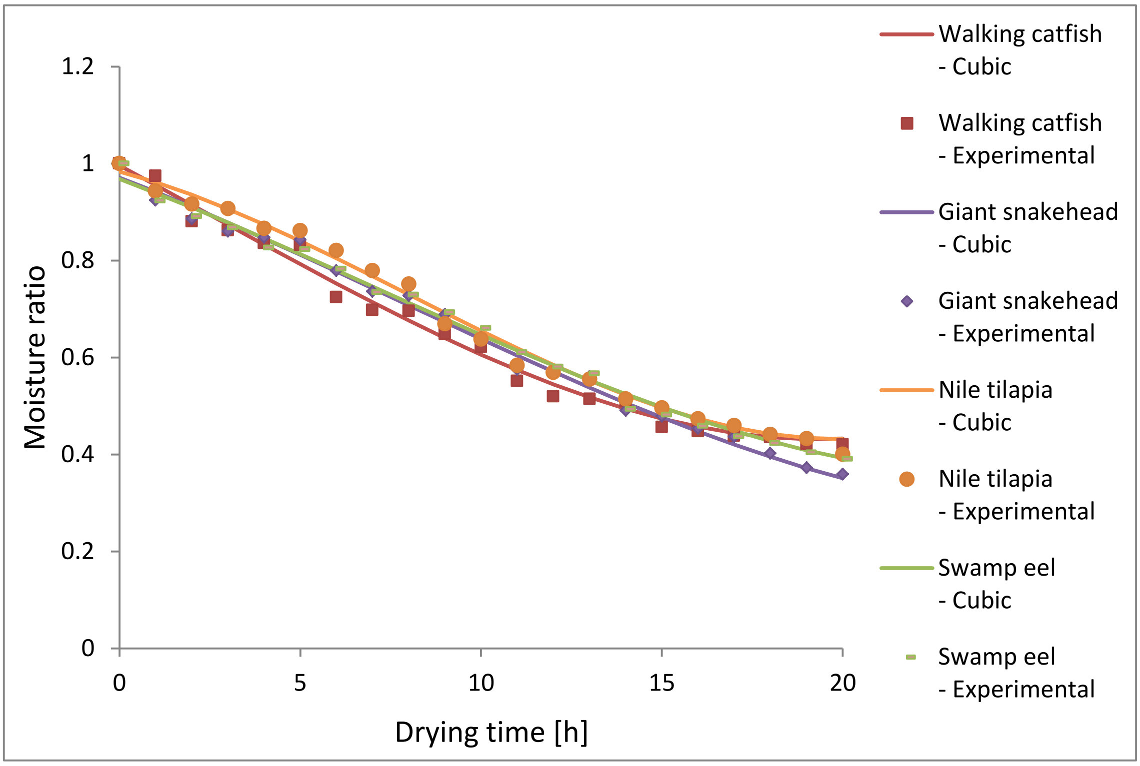


Figure 4.26 Experimental and predicted moisture ratio for solar drying of selected fish species

Table 4.5Curve fitting criteria for various mathematical models and selected fish species during solar drying

Fish	Nonlinear regression	*R*	R^2	R^2_{adj}	*SEE*	*RMSE*	Coefficient				
							a	*b*	y_0	*c*	x_0
Walking catfish	Quadratic	0.9945	0.9890	0.9878	0.1213	0.0211	-0.0515	0.0011	1.0127	–	–
	Cubic	**0.9955**	**0.9911**	**0.9895**	**0.0197**	**0.0183**	**-0.0399**	**-0.0004**	**0.9958**	**4.9350E-05**	**–**
	Logarithm	0.9922	0.9848	0.9827	0.0253	0.0234	-0.5301	–	2.1636	–	-0.6962
	Exponential Decay	0.9924	0.9848	0.9840	0.0244	0.0231	1.0007	0.0487	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2639	0.2510	0.5626	0.4712	–	–	–
Giant snakehead	Quadratic	0.9960	0.9920	0.9911	0.0187	0.0191	-0.0367	0.0002	0.9828	–	–
	Cubic	**0.9964**	**0.9929**	**0.9917**	**0.0181**	**0.0166**	**-0.0287**	**-0.0008**	**0.9711**	**3.4230E-05**	**–**
	Logarithm	0.9959	0.9919	0.9910	0.0189	0.0174	-0.2603	–	10.64	–	-61.3315
	Exponential Decay	0.9916	0.9833	0.9824	0.0263	0.0250	1.0123	0.0486	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2733	0.2599	0.5742	-0.4412	–	–	–
Nile tilapia	Quadratic	0.9933	0.9866	0.9851	0.0240	0.0221	-0.0412	0.0005	1.0145	–	–
	Cubic	**0.9966**	**0.9940**	**0.9929**	**0.0175**	**0.0166**	**-0.0199**	**-0.0022**	**0.9835**	**9.0795E-05**	**–**
	Logarithm	0.9926	0.9852	0.9836	0.0251	0.0232	-1.2179	–	5.1336	–	-29.5115
	Exponential Decay	0.9916	0.9832	0.9824	0.0260	0.0247	1.0289	0.0467	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2724	0.2591	0.5956	-0.4340	–	–	–
Swamp eel	Quadratic	0.9933	0.9866	0.9851	0.0240	0.0227	-0.0412	0.0005	1.0145	–	–
	Cubic	**0.9970**	**0.9932**	**0.9921**	**0.0175**	**0.0149**	**-0.0279**	**-0.0008**	**0.9681**	**3.7826E-05**	**–**
	Logarithm	0.9926	0.9852	0.9836	0.0251	0.0173	-1.2179	–	5.1336	–	-29.5115
	Exponential Decay	0.9916	0.9832	0.9824	0.0260	0.0259	1.0289	0.0467	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2724	0.2561	0.5956	-0.4340	–	–	–

Table 4.5: Continued

Fish	Nonlinear regression	*SEE*				
		a	*b*	y_0	*c*	x_0
Walking catfish	Quadratic	0.0029	0.0001	1.0127	–	–
	Cubic	**0.0065**	**0.0008**	**0.0146**	**2.5010E-05**	**–**
	Logarithm	0.0963	–	0.3657	–	2.8151
	Exponential Decay	0.0125	0.0014	–	–	–
	Hyperbola	0.0630	0.1508	–	–	–
Giant snakehead	Quadratic	0.0026	0.0001	0.0112	–	–
	Cubic	**0.0059**	**0.0007**	**0.0134**	**2.2958E-05**	**–**
	Logarithm	0.2662	–	0.3657	–	39.5274
	Exponential Decay	0.0135	0.0015	–	–	–
	Hyperbola	0.0663	0.1695	–	–	–
Nile tilapia	Quadratic	0.0033	0.0002	0.0143	–	–
	Cubic	**0.0057**	**0.0007**	**0.0129**	**2.2136E-05**	**–**
	Logarithm	0.5025	–	2.3368	–	15.7189
	Exponential Decay	0.0133	0.0015	–	–	–
	Hyperbola	0.0660	0.1668	–	–	–
Swamp eel	Quadratic	0.0033	0.0002	0.0143	–	–
	Cubic	**0.0152**	**0.0006**	**0.0118**	**2.2136E-05**	**–**
	Logarithm	0.5025	–	2.3368	–	15.7189
	Exponential Decay	0.0133	0.0015	–	–	–
	Hyperbola	0.0660	0.1668	–	–	–

Table 4.6 Curve fitting criteria for various mathematical models and selected fish species during drying in electric oven

Fish	Nonlinear regression	R	R^2	R^2_{adj}	*SEE*	*RMSE*	Coefficient				
							a	b	y_0	c	x_0
Walking catfish	**Quadratic**	**0.9977**	**0.9954**	**0.9949**	**0.0126**	**0.0117**	-0.0454	0.0009	0.9794	–	–
	Cubic	0.9977	0.9954	0.9946	0.0129	0.0121	**-0.0455**	**0.0009**	**0.9794**	**-1.9732E-07**	**–**
	Logarithm	0.9972	0.9944	0.9937	0.0139	0.0140	-0.4728	–	1.24	–	-8.3354
	Exponential Decay	0.9962	0.9925	0.9921	0.0156	0.0148	0.9686	0.0441	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2581	0.2454	0.5723	-0.4320	–	–	–
Giant snakehead	Quadratic	0.9979	0.9958	0.9953	0.0122	0.0113	-0.0345	0.0003	0.9846	–	–
	Cubic	**0.9982**	**0.9964**	**0.9958**	**0.0116**	**0.0110**	**-0.0404**	**0.0011**	**0.9932**	**-2.5185E-05**	**–**
	Logarithm	0.9980	0.9960	0.9955	0.0119	0.0137	-1.3137	–	5.08	–	-36.4409
	Exponential Decay	0.9964	0.9929	0.9925	0.0154	0.0188	1.0030	0.0420	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2631	0.2502	0.6078	-0.4138	–	–	–
Nile tilapia	Quadratic	0.9945	0.9891	0.9879	0.0213	0.0197	-0.0487	0.0009	1.0050	–	–
	Cubic	**0.9967**	**0.9933**	**0.9922**	**0.0172**	**0.0179**	**-0.0319**	**-0.0013**	**0.9805**	**-7.1663E-05**	**–**
	Logarithm	0.9925	0.9851	0.9834	0.0250	0.0222	-0.6522	–	2.82	–	-12.2385
	Exponential Decay	0.9934	0.9869	0.9862	0.0228	0.0206	1.0013	0.0490	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2682	0.2551	0.5650	-0.4506	–	–	–
Swamp eel	Quadratic	0.9973	0.9947	0.9941	0.0143	0.0156	-0.0409	0.0006	1.0025	–	–
	Cubic	**0.9985**	**0.9970**	**0.9965**	**0.0111**	**0.0115**	**-0.0290**	**-0.0010**	**0.9852**	**5.0773E-05**	**–**
	Logarithm	0.9967	0.9935	0.9927	0.0159	0.0146	-0.9214	–	3.41	–	-21.6174
	Exponential Decay	0.9966	0.9933	0.9930	0.0156	0.0148	1.0110	0.0449	–	–	–
	Hyperbola	0.0000	0.0000	0.0000	0.2663	0.2532	0.5951	-0.4300	–	–	–

Table 4.6: Continued

Fish	Nonlinear regression	*SEE*				
		a	***b***	y_0	***c***	x_0
Walking catfish	Quadratic	0.0017	8.3799E-05	0.0075	–	–
	Cubic	**0.0042**	**0.0005**	**0.0095**	**1.6362E-05**	**–**
	Logarithm	0.0501	–	0.1891	–	1.5968
	Exponential Decay	0.0079	0.0009	–	–	–
	Hyperbola	0.0626	0.1656	–	–	–
Giant snakehead	Quadratic	0.0017	8.1368E-05	0.0073	–	–
	Cubic	**0.0038**	**0.0004**	**0.0085**	**1.4667E-05**	**–**
	Logarithm	0.3330	–	1.6049	–	11.4693
	Exponential Decay	0.0077	0.0009	–	–	–
	Hyperbola	0.0643	0.1685	–	–	–
Nile tilapia	Quadratic	0.0030	0.0001	0.0127	–	–
	Cubic	**-0.0319**	**-0.0013**	**0.9805**	**7.1633E-05**	**–**
	Logarithm	0.1434	–	0.5757	–	4.3152
	Exponential Decay	0.0117	0.0014	–	–	–
	Hyperbola	0.0645	0.1639	–	–	–
Swamp eel	Quadratic	0.0020	9.5692E-05	0.0086	–	–
	Cubic	**0.0036**	**0.0004**	**0.0082**	**1.4005E-05**	**–**
	Logarithm	0.1984	–	0.8756	–	6.4253
	Exponential Decay	0.0079	0.0009	–	–	–
	Hyperbola	0.0646	0.1654	–	–	–

4.4 PHYSICO – CHEMICAL PROPERTIES OF DRIED FISH

4.4.1 FAT AND DRY MATTER CONTENT ANALYSIS

Values of fat content for walking catfish, giant snakehead, Nile tilapia and swamp eel were 14.34 ± 0.81, 2.44 ± 0.09, 11.07 ± 1.47, 1.15 ± 3.65 g/100g of wet muscle, respectively. In the analysed fish species there were two species with lower volume of fat content: giant snakehead and swamp eel. These two fish species had higher values of water content. Fat content analysis is in agreement with Chukwu (2009) and Rahman (1995), Nurhasan, et al. (2010) for Nile tilapia and swamp eel, respectively. The fat content in muscle from giant snakehead is the very low and this observation is confirmed by the fastest weight loss during the tested drying period of giant snakehead. Rahman (1995) published lower fat content for walking catfish and higher fat content for giant snakehead. These differences are influenced by age and sex of the fish and also by its environment and season. These differences may be accounted due to the removal of skin, under which a fat accumulates. In this work, skin was not removed from the samples. The fat content in the samples is a significant factor which needs to be considered when designing a drying process.

Dry matter content was analysed by gravimetric analysis and was made by four replications. Values are 21.74 ± 0.65, 17 ± 95, 18.7 ± 1.0, 14.4 ± 1.34 g for walking catfish, giant snakehead, Nile tilapia and swamp eel, respectively.

4.4.2 WATER ACTIVITY ANALYSIS

The water-related criteria that have been used in this study of the stability of food include water content and water activity (a_w). A_w is a very important physical property of food and is described by Samapundo, et al. (2010), it is not proportional to the water content (Doe, 1998) and is the most useful expression of the "free" water requirements for, microbial growth and enzyme activity (Troller & Christian, 1978).

Water activity was measured in salted samples dried in electric oven at two temperatures 50 °C (Tab. 4.7) and 60 °C (Tab. 4.8) and in solar dryer (Tab. 4.9). There was a general reduction in a_w in all dried samples. A_w of samples were significantly lower ($p<0.05$) than the a_w of fresh fish at 95 % confidence level. Water activity values were analysed using ANOVA and Tukey´s HSD test.

Table 4.7 Water activity of fish dried in electric oven at 50 °C

	Salting 2 hours	Salting 4 hours	Salting night
Walking catfish	0.67±0.01	0.70±0.01	0.69±0.02
Giant snakehead	0.67±0.01	0.67±0.02	0.68±0.01
Nile tilapia	0.67±0.01	0.66±0.01	0.68±0.02
Swamp eel	0.66±0.01	0.64±0.01	0.62±0.03

Table 4.8 Water activity of fish dried in electric oven at 60 °C

	Salting 2 hours	Salting 4 hours	Salting night
Walking catfish	0.65±0.02	0.62±0.01	0.63±0.06
Giant snakehead	0.59±0.01	0.57±0.02	0.62±0.05
Nile tilapia	0.62±0.06	0.56±0.03	0.58±0.09
Swamp eel	0.59±0.06	0.62±0.03	0.51±0.16

Table 4.9 Water activity of fish dried in solar dryer

	Salting 2 hours	Salting 4 hours	Salting night
Walking catfish	0.60±0.01	0.61±0.01	0.65±0.01
Giant snakehead	0.64±0.01	0.69±0.01	0.68±0.01
Nile tilapia	0.62±0.01	0.64±0.02	0.59±0.01
Swamp eel	0.61±0.02	0.63±0.02	0.54±0.04

Different values were determined between groups of fish species while dried at various temperatures. The lowest values of water activity were determined for swamp eel during all drying processes and on the other hand the highest values were measured on samples of walking catfish.

An average values of a_w for samples dried in electric oven at 50 °C were 0.67 ± 0.01, 0.66 ± 0.2 and 0.67 ± 0.03 for 2h, 4h and overnight salting, respectively. A_w values for samples dried in electric oven at 60 °C were determined 0.61 ± 0.04, 0.59 ± 0.4, 0.59 ± 0.1 for 2h, 4h and overnight salting. Water activity values for drying in electric oven at 60 °C were lower than at 50 °C. Very similar results with values from electric oven at 60 °C were determined for samples dried in solar dryer: values of all fish species were for 2h, 4h and over one night salting 0.62 ± 0.3, 0.64 ± 0.3, 0.62 ± 0.7, respectively. Statistically significant differences among drying temperatures for all fish species (5 % confidence level) were successfully determined as shown in Figure 4.27. The best score in tested categories (EO 60 °C, EO 50 °C, SD) was obtained in the case of drying in electric oven 60 °C. This agreed favourably with Chen & Mujumdar (2008). Authors published that for the same moisture content, the water activity is lower at higher temperature.

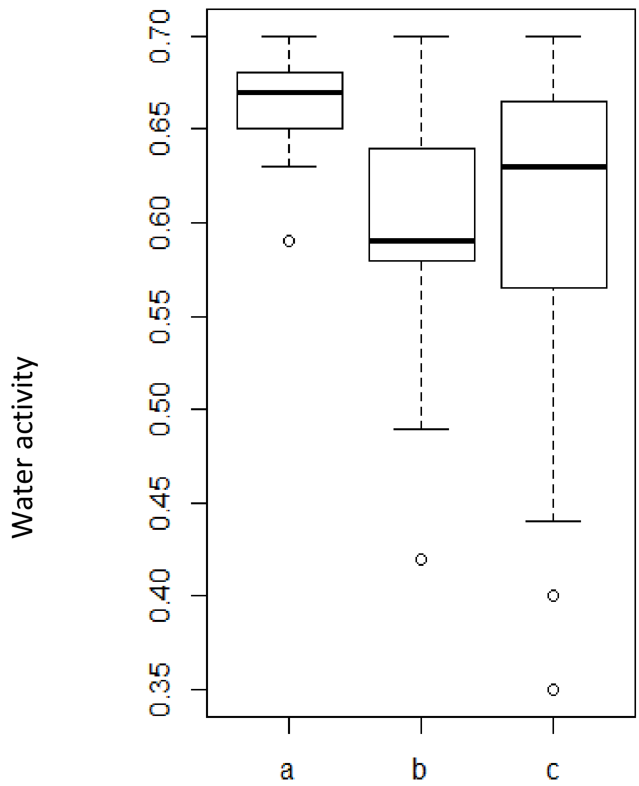
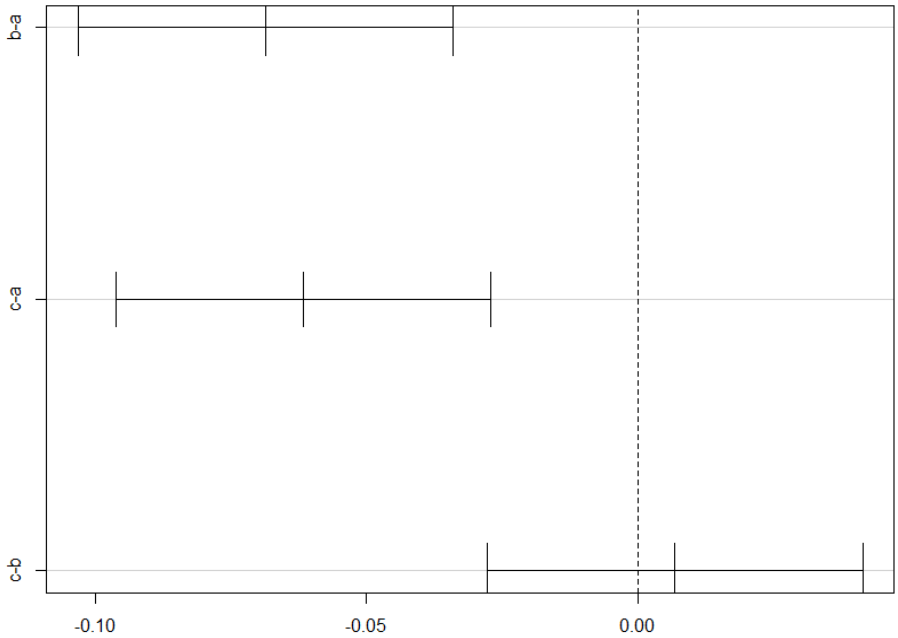


Figure 4.27 Box plot of Water activity based on drying temperature in electric oven

a: EO 50 °C, b: EO 60 °C, c: SD

Based on Tukey HSD multiple comparisons of means test it is evident that statistically there are differences between samples dried in electric oven at 50 °C and 60 °C, samples dried in solar dryer and electric oven for temperature 50 °C and samples dried in solar dryer and electric oven for 60 °C as is shown in Figure 4.28.



Differences in mean levels of water activity

Figure 4.28 Tukey HSD multiple comparisons on 95 % confidence level test of water activity based on drying temperature in electric oven and in solar dryer

b-a: EO 60 °C – 50 °C, c-a: SD – EO 50 °C, c-b: SD-EO 60 °C

Water activity in tested final products ranged from 0.58 to 0.70. Troller & Christian (1978) published water activity of 0.85 or below will prevent the growth and toxin production of most pathogens, including bacteria and fungi. Also according to Fontana (2007), Hii & Ong (2012) these levels should be sufficient to prevent mycotoxin production and bacterial growth. Microorganisms are usually not killed, however they are able to 'wait' for more acceptable conditions to grow again (Doe, 1998). Some of these quality attributes can be found in articles published by Hii & Ong, (2012) and Hwang, et al.(2012).

Historically, combinations of salting and drying ware used commonly for foods of animal origin, and later were utilized for the preservation of vegetables (Troller & Christian, 1978). Obtained results were not in agreement with Nuwanthi, et al. (2016), whose published a_w values were significantly lower of samples treated by salt in their research. This assertion was not confirmed in this dissertation thesis.

4.4.3 COLOUR ANALYSIS

The colour of fish muscle meat depends on the kind of fish, type of muscle, percentage of hem proteins, chemical composition and freshness (Ingr, 2004). Multiple factors are responsible for colour changes in these dried fish samples that undergo wide changes mainly in moisture content, proteins and pigment concentration, structure during the drying (Vega-Gálvez, et al., 2011; Wang, et al., 2013). Louka, et al. (2004) presented that although the Maillard reaction leads to browning and is a common candidate to explain the yellow–brown colour after processing, the low amounts of reducing sugar, particularly at the beginning of processing, make this hypothesis less convincing. However, a small degree of browning results from the degradation of L-methyl-methylhistidine, even in the absence of sugar. The loss of water can reduce light scattering and it can lead to loss of transparency, and the consequence of this is the increase of lightness (L*) (Brás & Costa, 2010). The presence of calcium and magnesium ions in the salt can contribute to whitening of the muscle surface (Martínez-Alvarez & Gómez-Guillén, 2005).

The colour of dried fish samples was measured by colorimeter and results are shown in tables 4.10, 4.11 and 4.12. The relations of lightness (L*) between the salting time (2 hours, 4 hours and overnight), drying conditions (EO 50 °C, EO 60 °C and SD) and kind of fish were determined by the ANOVA ($p<0.05$) method and Least Significant Difference (LSD) test.

Higher L* values of fish samples were determined in samples salted overnight this in agreement with Brás & Costa (2010). The surface was light, slightly rough, and showed a distinct salt surface. Significantly lower values of lightness (lower by 32.4 % than the samples salted over one nigh) were measured in samples that were salted for 2 hours.

The difference between (L*) values measured in fish samples dried in electric oven at 60 °C, 50 °C and solar dryer was determined. Upon the increasing drying temperature, L* values for all dried samples decreased significantly, this agreed with Bala & Hossain (2012), Wang, et al. (2013). The lowest values were measured on fish samples dried at 60 °C in an electric oven and the highest values were determined in the case of solar drying.

The highest value of L* was determined in Nile tilapia samples dried in solar dryer and salted overnight. High pressure can be used in food processing even though it causes denaturation of proteins as it inactivates microorganisms without darkening of colour (Ashton, 2002). Fish muscle has a high content of pigments and non-structural lipids which strongly affect the flavour and colour during the processing of fish samples and also affect consumer acceptability (Chaijan, 2011). In the case of drying vegetables and fruits Hossain & Bala (2007) recommend using blanching of samples that leads to better quality in terms of colour with pungency and also leads to partial reduction in drying time. Hossain, et al. (2005) made investigations on the optimisation of solar tunnel dryer for drying of chilli without colour loss in Bangladesh. A novel colorimetry analysis used to compare different drying fish processes was reviewed by Louka, et al. (2004). Smith & Hole (1991) reviewed browning of salted sun-dried fish in tropical conditions. Optimization of process conditions and quality of salted dried tilapia (*Oreochromis niloticus*) using response surface methodology was developed by Nketsia-Tabiri & Sefa-Dedeh (1995).

Table 4.10 Colour values *L of fish samples dried in electric oven in temperature 60 °C

	Salting: 2 hours	Salting: 4 hours	Salting: overnight
Walking catfish	37.74±3.31	34.58±2.34	56.87±0.26
Giant snakehead	49.08±4.84	55.32±0.98	69.12±0.99
Nile tilapia	40.31±0.82	54.33±1.60	64.00±1.60
Swamp eel	54.09±1.39	55.51±0.93	65.75±2.05

Table 4.11 Colour values *L of fish samples dried in electric oven in temperature 50 °C

	Salting: 2 hours	Salting: 4 hours	Salting: overnight
Walking catfish	32.98±1.15	39.49±1.72	43.17±1.54
Giant snakehead	49.36±1.47	53.95±0.21	60.36±0.95
Nile tilapia	45.72±0.82	52.65±2.73	63.55±1.40
Swamp eel	35.18±1.39	45.90±1.34	62.76±1.39

Table 4.12 Colour values *L of fish samples dried in solar dryer

	Salting: 2 hours	Salting: 4 hours	Salting: overnight
Walking catfish	31.12±2.70	32.77±2.42	56.90±1.71
Giant snakehead	50.97±2.49	31.62±0.92	63.84±2.04
Nile tilapia	45.83±1.87	46.75±0.29	70.03±2.74
Swamp eel	62.59±1.07	68.66±1.42	69.37±1.79

4.4.4 SALT CONTENT ANALYSIS

Meat salting refers to curing meat with either brine or dry salt with the aim of suppressing the microbial growth and preventing spoilage. In most of the developing countries, about 40 % of fish landing is still preserved by salt curing and drying (Hii & Ong, 2012)

Salting (the amount of salt) also alters organoleptic and technological properties of the meat product (Beatty & Fougere, 1957; Pipek, 1998). During salting, meat undergoes physicochemical and biochemical processes that influence the raw material components associated with antimicrobial activity (Ferreira, et al., 2013). It means the concentration of salt necessary for adequate suppression of microbial growth varies between foodstuffs and the method used for their preservation. Foodstuffs, that were not heat-treated, for example, have about two to three times greater salt concentration at the time of consumption, partly because of the increase in concentration due to water loss, see Table 4.13. In samples salted for two hours we measured in average a salt content of 3.65 g ± 0.47 per 100 g of wet muscle. The highest value was determined 4.23 ± 0.03 g/100g of wet muscle in samples of Nile tilapia. An average a salt content was determined 4.83 ± 0.16 g/100g of wet muscle for samples salted for 4 hours and in this case Nile tilapia has also the highest value of salt content. The highest salt content values of fish samples were determined on samples salted overnight. In comparison with salting for 2 hours the values were higher by 77.54 %. Based on our results we propose a salting time for 4 hours as sufficient. Hwang, et al. (2012) reported similar results of salt content in dried fish in his study.

Table 4.13 Salt content in dried fish samples in %

Kind of fish	Salting time	Salt content of dried muscle in %	Salt content of wet muscle) in %
Walking catfish	2 hours	8.02	3.47
Giant snakehead	2 hours	8.35	3.12
Nile tilapia	2 hours	8.35	4.23
Swamp eel	2 hours	9.69	3.77
Walking catfish	4 hours	8.42	3.59
Giant snakehead	4 hours	9.36	5.28
Nile tilapia	4 hours	10.02	5.65
Swamp eel	4 hours	10.35	4.83
Walking catfish	night	11.36	5.50
Giant snakehead	night	12.37	7.39
Nile tilapia	night	13.53	8.68
Swamp eel	night	15.55	8.47

4.5 ORGANOLEPTIC PROPERTIES AND SENSORY ANALYSIS

Dried fish (tested and other common fish, seasoned squid products, dried shrimp) is popular in Cambodia because of its special taste and flavour.

Organoleptic testing is done to a certain extent subjective, since perceptions among different persons vary, depending on the state of the body (Bala & Hossain, 2012). The organoleptic characteristics of tested dried fish were determined to find the suitable fish for drying by solar tested dryer. The quality of the fish samples dried in solar dryer was assessed on the basis of Appearance, Odour, Flavour, Consistency and Notes. Analysed values were expressed in means, see Table 4.14. Four panellists wrote into notes "Odour was very natural in all tested fish samples".

Analysed data were subjected to the one-way analysis of variance (ANOVA). Differences among groups of Salting 2 hours, Salting 4 hours and Salting overnight were considered significant at an alpha value of 0.05. Statistically significant differences among fish species (5 % confidence level) were determined in every tested group.

The best score in all tested categories was obtained in case of swamp eel followed by walking catfish and in case of samples salted for 4 hours, see Figure 4.29. Dried samples have excessively salty taste; in fact the fish with salt content 10.35 %

cannot be consumed as a snack in dry form. Similar results have been reported for silver carp by Wang, et al. (2013). Conversely, the worst scores were observed in the case of giant snakehead. Swamp eel had better results than giant snakehead by 37.62 %. Nuwanthi, et al. (2016) published in his research the consumer preference the low salt and spicy taste of dried fish. For using the salted dried fish samples is recommend combination with local spices by author of this dissertation thesis. Because salting process consists not only in water loss and is not only like preservative, but completely changes the flavour and consistency. This is in agreement with Brás & Costa (2010).

Table 4.14 Results of sensory analysis of samples dried in solar dryer

Kind of fish	Salting time	Appearance	Odour	Flavour	Consistency
Walking catfish	2 hours	3.45±0.60	3.28±0.65	3.12±0.89	3.51±0.80
Giant snakehead	2 hours	2.14±0.95	2.63±0.79	2.84±0.94	3.14±0.91
Nile tilapia	2 hours	2.70±0.68	3.02±0.69	3.12±0.96	3.21±0.75
Swamp eel	2 hours	3.75±0.79	3.58±0.89	3.88±0.60	4.16±0.75
Walking catfish	4 hours	3.14±0.74	3.18±0.68	3.63±0.64	3.39±0.82
Giant snakehead	4 hours	2.49±0.98	2.63±0.99	2.73±0.86	3.07±0.99
Nile tilapia	4 hours	2.71±0.82	2.94±1.06	3.26±0.98	3.36±0.58
Swamp eel	4 hours	3.49±0.87	3.39±0.92	3.56±0.85	3.81±0.83
Walking catfish	night	3.74±0.74	3.47±0.66	3.67±0.58	3.48±0.69
Giant snakehead	night	2.14±0.93	2.51±0.71	2.75±0.79	2.91±0.93
Nile tilapia	night	3.36±0.83	3.35±0.83	3.61±0.77	3.47±0.83
Swamp eel	night	3.84±0.96	3.67±0.87	4.07±0.75	3.86±0.90

Values are mean±SD of three replicate determinations sensory analysis of 19 panellists. Evaluation scale: 1 - excellent, 2 - very good 3 - good, 4 - satisfactory, 5 - poor

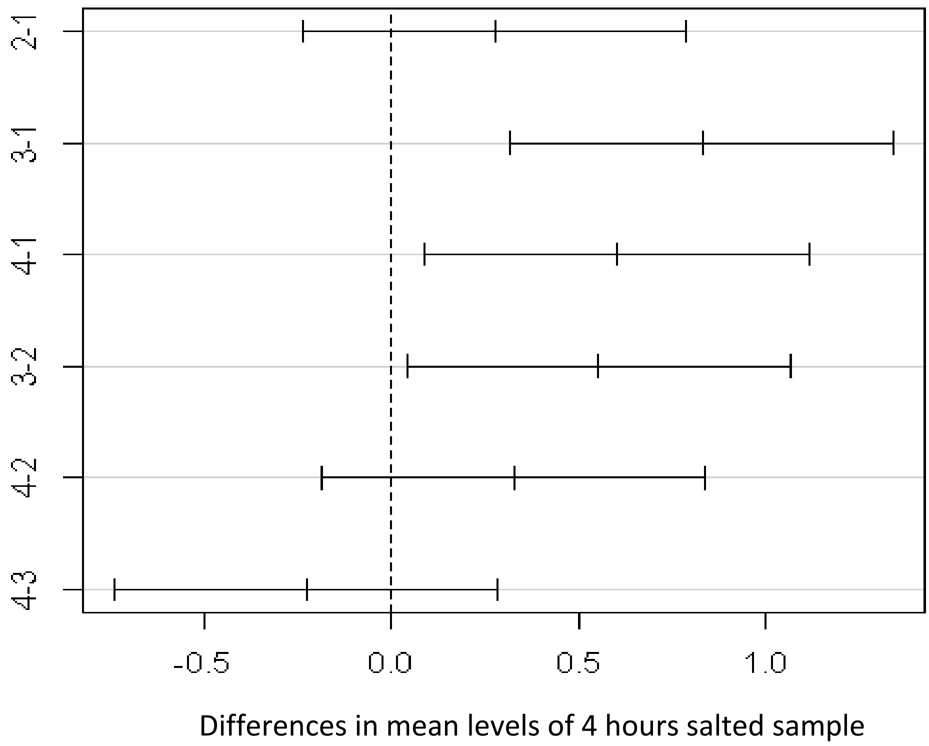


Figure 4.29 Evaluation of the sensory analyses of dried fish in the group Salting 4 hours in 95 % family-wise confidence level

2 - 1: Nile tilapia – Giant snakehead, 3 - 1: Walking catfish – Swamp eel, 4 - 1: Walking catfish – Giant snakehead, 3 -2: Swamp eel – Giant snakehead, 4 - 2: Walking catfish – Nile tilapia, 4 – 3: Nile tilapia – Swamp eel

Like in Bala & Hossain (2012) it was observed that the Flavour and Appearance are important factors influencing the overall consumer acceptance. Appearance plays an important role in the overall quality. Change of appearance in solid foods is an important cause of quality deterioration during drying. Hii & Ong (2012) published that tested prawns were treated with boiling water prior to drying to reduce the microbial flora to improve the flavour of dried prawns.

5 CONCLUSION

Cambodia's geographical position brings the comparative advantage of an abundant solar radiation that allows utilisation of solar dryers as a free energy and non-polluting technology for fish drying. Four typical Asian fish species were selected for solar drying experiments in this study. Some of the tested samples were pre-treated by using the dry salting method, meaning that they were cured with dry salt for either 2 hours, 4 hours or overnight, before the drying process. One group of samples was dried in a solar dryer, the second group in an electric oven at either 50 °C or 60 °C.

In the solar dryer, the average drying temperature and drying air relative humidity was 55.6 °C and 19.9 %, respectively. The thermal and drying solar efficiency was 8.31 % and 30.27 % and corresponded to the final moisture content (wb) 32.11 %. This is the typical range for natural convection solar dryers. The average evaporative capacity of a solar dryer was 0.049 $kg \cdot h^{-1}$. The drying rate equations for typical drying runs were developed for solar dryer and electric oven drying. By comparing the drying process of unsalted fish in the solar dryer and a controlled drying in an electric oven we may conclude that, in general, the drying rates were higher during solar drying. Considering the uniform drying conditions and coefficient of determination R^2, standard error of estimate (*SEE*) and root-mean-square error (*RMSE*) values for solar dryer and electric oven thin-layer drying for unsalted samples, the cubic model shows the best results.

Initial moisture content of pre-treated fish was lower compared to that of unsalted fish. Dry salting demonstrated the advantage of removing moisture, but suffered from the irregular salt absorption that negatively affected the drying process and final product quality. It has been determined that curing fish in salt for 2 to 4 hours is sufficient, based on the drying curves from both drying methods.

Drying curves for the electric oven drying were mostly logarithmic. At 60 °C the drying rates were higher and dried samples had lower final moisture content and water activity compared to 50 °C.

The study confirmed that the temperature at which the drying takes place influences the final water activity of the samples. Drying at 50 °C produced samples with higher a_w, however even this value of a_w was sufficient for suppression of microbial activity. The research proved that species-specific factors, such as fat content or tissue composition of the fish, play a role in the drying process. An increase in fat content resulted in a decrease of drying rates.

Computing the rehydration and recovery ratios to describe the rehydration process showed that the less salted fish have higher rehydration and lower recovery ratios than fish with greater salt concentrations.

The results from the sensory evaluation of the dried fish samples have demonstrated that the most preferred fish was swamp eel followed by walking catfish. Samples that have been cured for 4 hours achieved the best score in the sensory analysis.

Finally, we consider solar drying as an alternative drying technology suitable for fish processing in Cambodia that brings comparable results to conventional and standard electric oven drying technique.

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