Czech University of Life Sciences Prague

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Drying Characteristics of Selected Fish Species in Southeast Asia

Bachelor thesis

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Declaration

I hereby declare that this thesis entitled Drying Characteristics of Selected Fish Species in Southeast Asia is my own work and all the sources have been quoted and acknowledged by means of complete references.

In Prague 15.4. 2016

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Ivana Lošková

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Abstrakt

Využívání alternativních způsobů sušení je vhodné ve většině rozvojových zemí. Solární sušárny zlepšují kvalitu sušeného produktu, zkracují dobu sušení až o 50 % než je tomu u sušení na slunci a ztráty při skladování jsou omezeny na minimum.

Tato práce se zabývala sušením tří druhů ryb běžně dostupných v Kambodži, jmenovitě Lezoun indický (*Anabas testudineus*), Hrotočelec ozbrojený (*Mastacembelus armatus*) a Hrdložábřík bílý (*Monopterus albus*). Vzorky z těchto ryb byly zkoumány ve dvou variantách: solené a pro srovnání kontrolní vzorky nesolené. Následně byly usušeny ve třech sušárnách: elektrická trouba, plastová solární sušárna a hybridní solární sušárna.

Výzkum ukázal, statisticky významný rozdíl ($p < 0,05$) mezi sušením vzorků v elektrické troubě a v solárních sušárnách. Rovněž předúprava v solném roztoku zásadně ovlivnila průběh sušení, kdy se tyto vzorky sušily oproti kontrolním vzorkům bez předúpravy rychleji. Naopak mezi sušením vybraných druhů ryb nebyl nalezen žádný statistický rozdíl. Solný roztok měl statisticky významný vliv ($p < 0,05$) na následnou rehydrataci. Vzorky naložené do solného roztoku měly menší poměr rehydratace než kontrolní vzorky bez úpravy.

Klíčová slova:

Solární sušení, ryby, Kambodža, poměr rehydratace

Abstract

An alternative to traditional methods of drying can be used in most of developing countries. Use of solar dryers reduce the drying time up to 50 % and to a significant improvement of the product quality and the storage losses can be reduced to a minimum.

This thesis was performed with three fish species common in Cambodia, namely Climbing Perch (*Anabas testudineus*), Spiny eel (*Mastacembelus armatus*) and Swamp eel (*Monopterus albus*). These fish samples were investigated in two variants: salted and unsalted samples as a control and were dried in three different types of dryers: electric oven, solar plastic dryer and solar hybrid dryer.

Research showed statistical differences ($p < 0.05$) between drying behaviour of fish samples dried in electric oven and solar dryers. Saline solution had as significant impact on drying process, samples with saline pretreatment were dried faster. Contrary between selected fish species were not statistical differences (95% confidence level). Saline solution had a statistical significant impact on the rehydration of dried samples. Samples loaded in saline solution had a smaller rehydration ratio than samples without pretreatment.

Key words:

Solar drying, Fish, Cambodia, Rehydration ratio.

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CP	Climbing perch
EO	electric oven
$\mathrm{MC}_{\mathrm{w.b.}}$	moisture content wet basis
$MC_{d.b.}$	moisture content dry basis
m_d	mass of dry solid (kg)
M_e	equilibrium moisture content (kg water/kg dry matter)
M_i	initial moisture content (kg water/kg dry matter)
MR	moisture ratio
M_t	moisture content at any time of drying (kg water/kg dry matter)
m_w	mass of water (kg)
m_0	weight before rehydration (kg)
m_1	weight after rehydration (kg)
P_a	partial vapour pressure of the water in the proximate air
P_s	saturated vapour pressure of water at the surface temperature
SD	solar dryer
SHD	solar hybrid dryer
SpE	Spiny eel
SwE	Swamp eel

1. Introduction

1.1. Overview of study area

1.1.1. Location

The Kingdom of Cambodia is situated in Southeast Asia, between Thailand, Vietnam and Laos. Southeast coast bordering the Gulf of Thailand. The terrain is mostly low, but in the southwest and north is located the mountains. All of Eastern part of Cambodia, from north to south, the Mekong river flows (CIA, 2013).

Figure 1: Map of Cambodia (CIA, 2013)

1.1.2. Climate and temperature

The climate is tropical with a monsoon season (May to November) and dry season (December to April), with a little seasonal temperature variation (CIA, 2013). The average annual temperature is 28 ºC. Maximum average temperature is 38 ºC in April and minimum average temperature is 17 ºC in January. The annual average rainfall is 1400 mm, but there is zonal differences in certain coastal zones or highland areas it may be

4000 mm (Thoeun, 2015). In Cambodia average daily solar irradiation is 18.3 MJ/m^2-day (Janjai *et al.,* 2011).

1.1.3. Demography

Cambodia extends on 181,035 km^2 and has 15,205,539 habitants. Cambodia has one of the youngest populations in the world, over 65 % of the population is under 30 years of age. Eighty percent of habitants live in rural areas (UNDP, 2016).

Cambodia belongs to the least developed countries in the world and is characterized by a relatively low Gross Domestic Product (GDP), a high poverty incidence, and a high dependence on natural resources (Nguyen *et al.,* 2015). Poverty continues to fall there, but still there are almost 3 million poor people and over 8.1 million who are near-poor (in 2012). About 90 % of them live in the countryside (World Bank, 2015).

1.1.4. Agriculture

The agricultural sector make about 35 % of the GDP (World Bank 2015). The agriculture in Cambodia employed more than half of the total labour force (Hok *et al.,* 2015). Agriculture area makes more than 30 % of total country area of which 22.7 % are arable land, 8.5 % are pastures or permanent meadows and 0.9 % are used for permanent crops. The main crops grown here are rice, cassava, maize, soybeans and vegetables. Rice and cassava are top production crops. In 2011 Cambodia was produced both about 10 million tones and the trend is still increasing. In livestock production are hens and pig on the top (FAO, 2015).

Rural agriculture is primary organized on the basis of small scale farmer communities and families (de Silva *et al.,* 2014). Part of livelihood of rural households are various types of water and forest products, the most popular are fish, bamboo shoots, vegetables, and firewood (Nguyen and others 2015b). In recent years, the country is facing the problem of land degradation (Hok *et al.,* 2015). Fish and forest resources have decreased over time not only due to the growing rural population, but also to the illegal and unsustainable fishing and timber harvesting activities by commercial enterprises, military and local authorities (Nguyen *et al.,* 2015).

1.1.5. Fishery

The main water formations are the Mekong river, the Tonle Sap (Great Lake) and the Tonle–Bassac river, which form together a network of river channels, levees and basins offer fishing opportunities for the rural population (Nguyen *et al.*, 2015).

Tonle Sap is the biggest lake in Southeast Asia and one of the most productive of freshwater fish in the word. But unfair treatments of operators of large scale fishing commercial lots on the lake makes intense competition and limited the benefits available to local communities. From February 2012 are all commercial freshwater fishing lots in Cambodia removed. It is the first step to improving the situation (EIARD and WorldFish, 2013).

Common fish species which are possible to buy on traditional market are for example Swamp eel (*Monopterus albus*), Nile tilapia (*Oreochromis niloticus*), Climbing perch (*Anabas testudineus*), or Walking catfish (*Clarias batrachus*) (Hubackova *et. al.*, 2014), Changwa mool (*Rasbora tornieri*) or Chanteas phluk (*Parachela siamensis*), which are rich of vitamin A and consumed in rural households (Roos *et al.*, 2007).

Because there is still high rates of childhood malnutrition in Cambodia, water resources especially fish meat have great value for local communities (EIARD and WorldFish, 2013).

1.2. Role of fish meat in human diet

Fish and fisheries products play a major role in food and nutrition security. In 2010 the world average fish consumption was 18.9 kg per capita (21.6 kg in Asia) and preliminary estimate says it was 19.2 kg per capita in 2012 (FAO, 2014). Aquaculture has become a main source of high quality animal protein for human consumption and it seems will be of even greater importance for future generations (Pohlenz and Gatlin III, 2014). Fish constitute a rich source of protein, micronutrients (which are much greater in fishes than in terrestrial animal-source foods), essential fatty acids and finally essential fats, main for brain development and cognition (Beveridge *et al.*, 2013). Fish represent a valued source of animal protein, one portion of 150 g of fish gives about 50–60 % of the daily adults protein requirements (FAO, 2014). The general population, fish consumption is beneficial for individual growth and development (Beveridge *et al.*, 2013). Salutary role of fish intake is especially due to its omega-3 polyunsaturated fatty acids content, which have been associated with the prevention of cardiovascular diseases and eicosapentaenoic acid has preventive health effects such as the lowering rates of heart diseases, the decrease of arrhythmias and thrombosis, the lowering plasma triglyceride levels, and the decrease of blood clotting tendency (Pieniak *et al.,* 2008)

Many populations are dependent on fish as part of their daily diet, and this dependency is generally higher in developing countries because fish often represents an available source of animal protein which is a part of local and traditional recipes (FAO, 2014).

1.2.1. Role of fish in Cambodian diet

Fishing has been for a long time as a part of the primary diet of the people in Cambodia (Seng *et al.,* 2004). Cambodia is situated in Mekong river basin which is extremely rich source of fish (Roos *et al.,* 2007). In Cambodia freshwater aquaculture is one of most major sources of food production, it is estimated that more than 2 million people livelihood depends in some way on this sector (Hubackova *et al.,* 2014). Fish represents more than 50 %t of total animal protein intake there (FAO, 2014). Cambodia is one of the poorest countries in the world and the population is burdened malnutrition. People are threatened especially by a lack of micronutrients, such as vitamin A, iron and zinc that causes poor health of people especially of children and woman and this problem can improve consumption of some fish species available in Cambodia (Roos *et al.,* 2007).

In Cambodia, approximately 85 % of the total fish catch is contributed by inland fisheries In addition, inland fisheries generate jobs, especially in rural areas. Inland fisheries in Cambodia are classified according to types of fishing gear and the difference in fishing ground defined by fishery law. In small-scale fishing, spears, hooks with lines, and traps are usually used in rice fields, small lakes, and rivers near villages. Small-scale fishing is recognized as a subsistence activity (Hori *et al.,* 2006)

The processing of freshwater fish has centuries old tradition in Cambodia. Traditional products include: fish paste, fermented fish, dry salted fish, smoked fish, fish sauce, and dried fish for animal feed. These products are both for the domestic and international markets. Marine processed fish commodities include: shrimp, lobster, crab, squid, octopus, cuttlefish, much of which is dried (FAO, 2016). In Cambodia, are fresh fish available in local markets and most often prepared as various traditional soups, not only in households, but also in the popular soup-pot restaurants (Feuer, 2015).

1.3. Fish preservation

Fish are among the high perishable foods, due to the high post-mortem pH, the presence of large amounts of non-protein nitrogen, the high content of unsaturated fatty acids and the presence of autolytic enzymes. The process of degradation is dominated by microorganisms development, hence the application of a preservation method is necessarily (Schelegueda *et al.*, 2015).

Early preservation of fish is necessarily to avoiding postharvest loses after death. Apart of the tradition method chilling or freezing are drying, smoking, salting and marinating (Tawari and Abowei 2011).

1.3.1. Fish preservation techniques

1.3.1.1. Fish smoking

Smoking is old traditional fish preservation method to reduce postharvest losses (Ajani *et al.*, 2013) and create new product with special taste and texture (Sampels, 2015). Smoking of food is performed by formation of smoke from fuel, often from wood. For traditional or directly smoking, smoke is generated from an open fire in the same chamber as the smoked product. It is difficult to control the temperature of smoke and it is usually very high (Duedahl-Olesen *et al.*, 2010). During the pyrolysis of the wood arise various compounds which has antimicrobial effect and get the product the typical flavour. There are two typical techniques, cold smoking, where the temperature is about 30 ºC and hot smoking, where the temperature is above 80 ºC. Smoking is often combined with salting (Sampels, 2015).

1.3.1.2. Fish salting

Fish salting is a very common processing method because most of the pathogenic organisms cannot survive in high salty environment, due to the osmotic pressure. There are different types of salting techniques. For example brining, pickling or wet salting.

During the brining the fish are loaded in salt solution for short time. This method is used as pretreatment for another processing as smoking or drying.

Conversely pickling means loading fish in saline solution for a long time.

Wet salting means the raw fish are placed with dry salt into watertight barrels or similar suitable and left to mature in the developing brine (Sampels, 2015).

1.3.1.3. Fish marinating

Another traditional way of preserving fish is marinating. Fish marinades is product made from solution of acetic acid and salt (Szymczak and Kołakowski, 2012). Vinegar lowers pH and decrease bacterial growth. The fishes are placed in barrels with solution of vinegar and salt for 1-3 weeks. After that fishes are stored in glasses or cans usually with solution of vinegar, salt, sugar and species like pepper (Sampels, 2015).

1.3.1.4. Fish drying

Drying has been used to conserve fish and shrimps for a long time (Bai *et al.*, 2011). The best drying method may not change the nutritional quality of the fish (Mustapha *et al.*,2014). In the traditional drying systems, water products such as fish are dried on mats and in bamboo made structures (Janjai and Bala, 2012). Different drying methods have different effects on the availability of vital nutrients in fish and shelf life of the fish (Mustapha *et al.*,2014). In this time, the drying process of aquatic products include solar drying and hot air drying (Bai *et al.*, 2011). Fresh fish include up to 80% of water, that´s mean it is a highly perishable material. After the reducing of moisture to 25%, contaminants cannot survive and autolytic activity is greatly reduced (Badee *et al.*, 2013).

Figure 2: Fish dried in bamboo structures (Janjai and Bala 2012)

1.3.2. Quality of product

1.3.2.1. Water activity

Water activity (aw), has a great importance for food preservation, because it is a rate and a criterion of microorganism growth and presumably toxin discharge. For all of agricultural products or food there is an activity limit under which microorganisms stop growing. The most of bacteria will grow at about aw = 0.85, mould and yeast about aw = 0.61, fungi at aw < 0.70, etc. Water activity can be regulated, after drying with added of some solution which contains salts, sugars etc. (Belessiotis and Delyannis, 2011).

1.3.2.2. Water holding capacity

Water holding capacity of the post-mortem muscle serves for describing the quality of meat (Kaale *et al.*, 2014). The mechanism of water-holding capacity is focused in the proteins and structures, where is binded and catched water, specifically the myofibrillar protein. The pH, ionic fortress, and oxidation have direct effect on the ability of myofibrillar protein and myofibrils and muscle cells to catch water (Huff-Lonergan and Lonergan, 2005).

Many compounds in aqueous suspensions are generally electrically charged. The pH of the suspension greatly have an effect on charges on the particle surface. The isoelectric point is the pH value resulting in zero net charge. The isoelectric point is an important parameter, used to characterize the adsorption (Zhu *et al.*, 2015)

Minimum of water holding capacity of meat without added salt is at pH 5.0. The pH 5.0 is the average isoelectric pH-value of the meat structural proteins, above this value there is a steep increase in water-holding. The maximum is at pH 10 (no salt), but with added salt there is a maximum in water-holding at pH 6.0 (Puolanne and Peltonen, 2013).

1.4. Drying

Major reasons for food shortages and food supply in developing countries are the soil degradation, the lack of sustainable technology and knowledge and finally incorrect transportation, high post-harvest lost due to pest and spoilage and the lack of suitable drying and storage facilities (Esper and Mühlbauer, 1998). In October 2011, the world human population was reached 7 billion (7×10^9), it is expected that by 2050 will rise to 9 billion, which will have to sustain the Earth. (Beveridge *et al.*, 2013). Most viable solution to the world's food imbalance involves reducing the food losses during the food production, harvest and post-harvest (Esper and Mühlbauer, 1998). Drying is one of the oldest technique of agriculture products preservation in many areas of the world (Banout *et al.*, 2011).

There are lots of different methods of drying, for example direct open sun drying, solar drying and smoke drying with the use of ovens (Mustapha *et al.,* 2014). The use of these methods depends on the product, approach to energy sources, cost and facilities (Mustapha *et al.*, 2014).

1.4.1. Drying process

Drying is defined as the reduction of moisture from the products (Bai and others 2011). During the drying process the moisture contained in the food is removed by heat transfer from the surroundings to the food, which decreases the water activity of the product. Drying also affects food sensory properties, providing unique taste, colour and texture. Water migrates from the interior of the surface of the material by diffusion (Khawas *et al.,* 2015). It is a simple process of residue water elimination from a natural product in order to reach the safe moisture content (Janjai and Bala, 2012; Belessiotis and Delyannis, 2011). It will stop or slow down the growth of microbes, oxidation of fat and autolytic activities in the product with a significant decrease in weight and volume (Kumar *et al.,* 2014; Mustapha *et al.,* 2014). It is an energy intensive process (Belessiotis and Delyannis, 2011). This method increases the durability, improves the product quality, handling and sanitation (Mustapha *et al.,* 2014). The most common drying methods is convective drying, i.e. heated air circulating over the upper side, bottom side or both, or across its mass and hot air heats up the product and remove moisture to atmosphere (Belessiotis and Delyannis, 2011). The drying kinetics and the parameters used for mathematical modelling are generally affected by air temperature, relative humidity, air velocity and material size (Khawas, *et al.*, 2015).

1.4.2. The mechanism of drying

There are two primary phenomena involved in the drying process (Brenndorfer, 1985; Belessiotis and Delyannis, 2011):

1. Moisture evaporation from the surface
2. Movement of moisture from the interior of a particle to the surface

1.4.2.1. Surface evaporation of moisture

Saturated vapour pressure of water at the surface temperature (P_s), which increase with increase in air temperature at constant humidity and the partial vapour pressure of the water in the proximate air (P_a), which increase with humidity at any fixed temperature affected the rate of evaporation. The greater the difference ($P_s – P_a$) the greater the rate of evaporation (Brenndorfer, 1985).

The moisture leaves the surface to the proximate air. So the humidity of the proximate air increase and the evaporation slows. If the surrounding air the particle is not replaced by fresh, dry air, it will be reached an equilibrium between the particle and the air and the evaporation will not continue. The air circulation over the particle surface is great important (Brenndorfer, 1985).

1.4.2.2. Internal migration of moisture

The rate of moisture migration is affected by temperature of the particle, its moisture content, physical dimension, even by internal structure and composition of the material. The rate of drying decrease in particle size (Brenndorfer, 1985).

1.4.3. Drying kinetics

The most illustrating information of drying process has drying rate curves. It is a plot of the change in moisture content with time, against the moisture content. In the beginning of drying is moisture migration from the interior of the particle to the surface so high to maintain the surface completely wetted. It is called as constant rate. In Figure 3. it is shown as part AB. In Figure 3 the point B is the critical moisture content, the drying rate starts decrease there. Below B the drying rate decreases tending to zero at equilibrium moisture content. This is falling rate period, it is part BC in Figure 3 (Brendorfer, 1985).

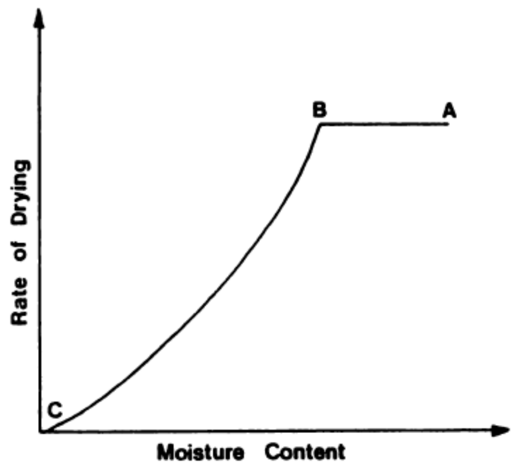

Figure 3: Drying rate curve (Brendorfer, 1985)

1.4.4. Rehydration

Rehydration is a complex process. It is aimed at renovation of the characteristics of the raw product (Cunningham *et al.*, 2008).

Rehydration curves indicate an increase in volume of absorbed water with time. In the initial phases of the rehydration process are higher water absorption rates, with the rehydration rates then decreasing until equilibrium is obtained. The water temperature has a general impact to rehydration rates and equilibrium moisture content. With higher water temperature is obtained more rapid rehydration (Cunningham *et al.*, 2008).

The rehydration must not be complete reversal of the dehydration process. The drying conditions can also cause problems with rehydration. Same of the changes caused by drying are irreversible. The surface of dried product, crushed and deformed during drying, cannot return completely to original size and shape. Rehydration contributing to a loss in nutrients, flavour and aroma, because of soluble constituents leach out into the rehydration water. With dried fish is not important to a rehydrated product had the same appearance as the original form because this product is used in soups or stews by adding directly to the cook pot (Brendorfer, 1985).

1.5. Solar drying

In a lot of rural areas in Asia grid-connected electricity and other non-renewable sources of energy are not available or very expensive to small- scale farmers. The high initial and running costs of fossil fuel powered are unacceptable to them (Kumar *et al.*, 2014). An alternative to traditional methods of drying is the use of solar dryers especially because of the fact that most developing countries are located in climatic zones where the sun radiation is greatly higher than the world average of 3.82 kW h m $^{-2}$ a day (Banout *et al.,* 2011). Solar dryers eliminates some of the major disadvantages of natural drying. Solar energy drying systems is used for the whole drying process (Kumar *et al.,* 2014). So the load on conventional source of energy is not necessary. Solar dryers are generally classified pursuant to the mode of air-flow as natural and forced convection dryers. Natural convection dryers do not require operator to pump the air through the dryer (Banout *et al.,* 2011). The artificial dryers produce an advanced quality of dried products. The velocity and the temperature of the drying air can be controlled (Banout *et al.,* 2011). Use of solar dryers reduce the drying time up to 50 % and to a significant improvement of the product quality in terms of colour, texture and taste in comparison to natural sun drying. The storage losses can be reduced to a minimum (Esper and Mühlbauer, 1998).

Benefits of solar dryers depend on the cost of the overall drying system and the the economy of energy. The biggest advantage of solar energy dryers is using of solar energy, which is completely free. Besides it is renewable energy source, clean and friendly to the environment and widely available. These simple drying systems are low cost (Belessiotis and Delyannis, 2011).

1.5.1. Classification of solar dryers

Solar dryers can by classified by various way, for example by the type of dryer, the operation temperature or the material to be dried, type of operation (Belessiotis and Delyannis, 2011).

According to the drying process solar energy dryers are classified into two major classes:

- active solar-energy drying systems
- passive solar-energy drying systems

Both groups are further divided into three sub-classes, which differ in the design arrangement of system components and the mode of utilisation of the solar heat

- integral-type solar dryers (direct type)
- distributed-type solar dryers (indirect type)
- mixed-mode solar dryers (Ekechukwu and Norton, 1999)

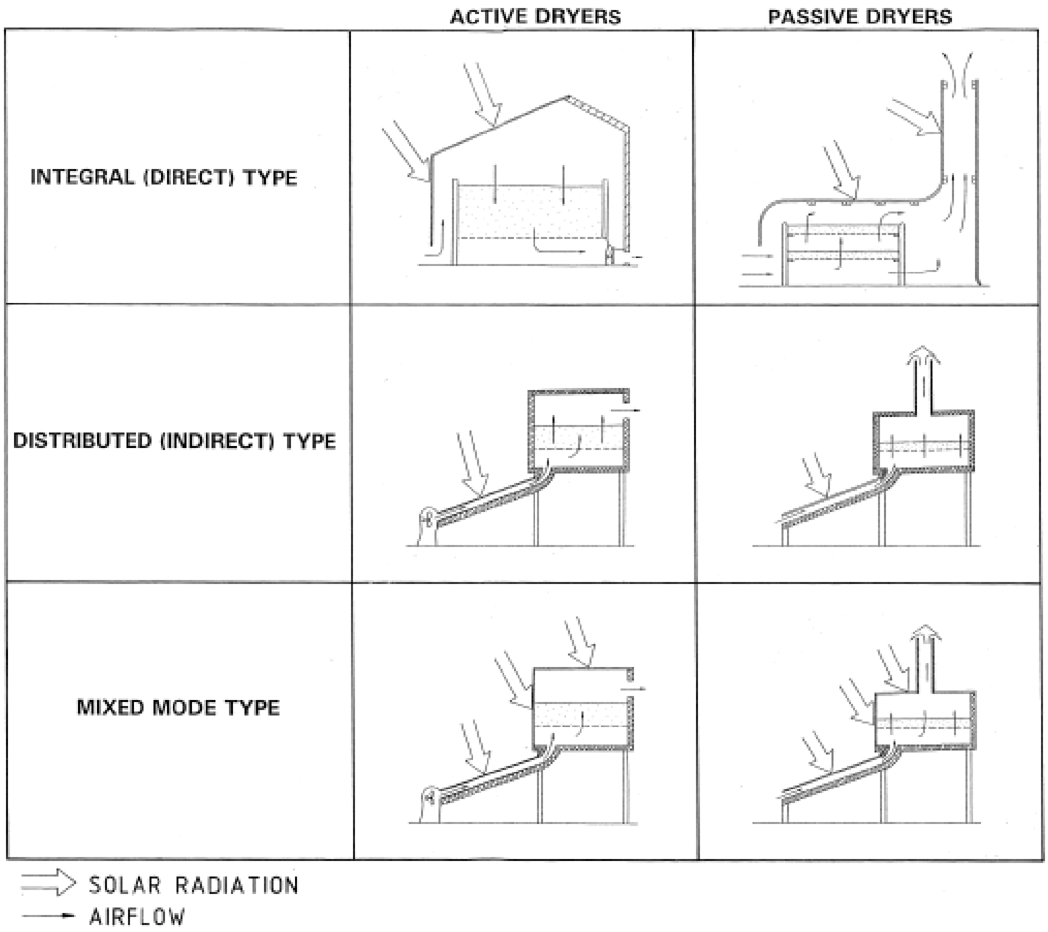

Figure 4: Typical solar energy drier designs (Ekechukwu and Norton, 1999)

Solar dryers can also be classified as

- natural convection solar dryers
- forced convection solar dryers

In the natural convection solar dryers, the airflow is usually established by buoyancy-induced airflow while in forced convection solar dryers, the airflow is provided by using fan either operated by electricity solar module or fossil fuel (Janjai and Bala, 2012).

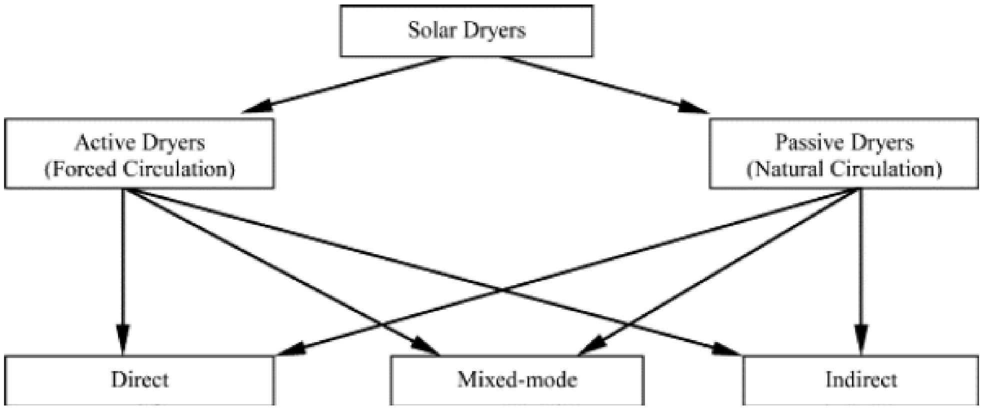

Figure 5: Classification of solar dryers (Belessiotis and Delyannis, 2011)

1.5.1.1. Active solar-energy drying systems

Active dryers use non-renewable source as supplementary heat source or as an auxiliary source to drive the fan for circulation of air (Ekechukwu and Norton, 1999) and are suitable for larger amounts of material. Active solar drying systems are more complex and more expensive than dryers with natural convection as they need ventilators for air circulation (Belessiotis and Delyannis, 2011).

In this case the electricity is needed. That's why these kind of dryers are not suitable and applicable in many developing countries (Mustayen *et al.,* 2014).

1.5.1.2. Passive solar-energy drying systems

These solar dryers use only the renewable energy sources (Ekechukwu and Norton, 1999). Air follow and heating takes place by natural convection of the air (Belessiotis and Delyannis, 2011; Mustayen *et al.,* 2014). .A natural convection solar dryer needs minimum cost for controlling the drying temperature. The passive type solar dryers become popular because of its simple maintenance and operation (Mustayen *et al.,* 2014).

The passive type solar dryers are basic, inexpensive constructions, easy to install and to operate especially at location where electrical grid is not available (Belessiotis and Delyannis, 2011).

1.5.1.2.1. Open air drying

In the traditional drying methods in tropical and subtropical countries are products like cereals, fruits, spices, oil seeds, vegetables and fish laced on beaten earth, mat, concrete and floor and even on roads in the sun (Esper and Mühlbauer, 1998; Janjai and

Bala, 2012). The product is heated right by the sun and moisture is lost by natural circulation of air due to density differences (Belessiotis and Delyannis, 2011). Open air solar drying does not need special appointment and technology, and is not too expensive (Bai *et al.,* 2011). But there is a problem of the contamination with dust, sol, pathogens and insects or destruction due to bad weather. Conditions of drying are difficult to manage (Esper and Mühlbauer, 1998; Kumar *et al.,* 2014). The losses of harvest are 10 – 40 % in developing countries (Esper and Mühlbauer, 1998). Results of the product quality is often insufficient (Bai *et al.,* 2011)

1.5.1.3. Direct solar dryers

Direct solar dryers can be classified as box-type, tent-type, and greenhouse-type solar dryers. In direct solar dryers, the products are placed in the heating unit. Solar radiation is transmitted through the transparent cover and absorbed on blackened interior surface. Due to accumulation of energy, the temperature inside dryer increases, the air enters into the dryer through holes in the front panel and exits out of the dryer through the hole in the back panel due to the buoyancy-induced airflow. Therefore, there is a continuous flow of air over the drying material. This sort of solar dryer is very well suited to dry the small quantities (10–15 kg) of food (Janjai and Bala, 2012).

1.5.1.4. Indirect solar dryers

This oldest sort of solar dryer consists of a separate solar collector with a transparent cover and a drying unit with an untransparent cover, which are connected in series. The drying product is placed in the drying unit in a relatively thin bed, which completely spans the box. Air, which is heated in a simple flat-plate-type solar collector, then flows as a result of the buoyancy forces resulting from the temperature differences up through the drying product bed thereby producing the drying air (Janjai and Bala, 2012)

1.5.1.5. Mixed mode solar dryers

The mixed-mode solar dryer consists of a separate solar collector and a drying unit, both having transparent cover on the top, and the system is connected in series. Solar radiation is received in the collector and in the dryer box at the same time. The solar energy that passes through the transparent cover in the collector heats the absorber that transfers heat to the air. Solar energy that passes through the transparent cover of the drying unit heats the product on the bed that transfers heat to the air passing through the product bed and evaporates the moisture from the product. The increase the air temperature on the top of the product bed increases buoyancy-induced air flow rate. Therefore, drying rate increases due to both increased product temperature and increased buoyancy-induced airflow rate (Janjai and Bala, 2012).

1.5.1.6. Hybrid dryers

Hybrid dryers are dryers in which is used another form of heating the drying air in conjunction with solar heating. There can be used two systems. The solar heating is primary source of energy with additional heat, supplied by electricity or solid fuel. Or conventional energy sources are primary and solar energy is used as a supplement (Brendorfer, 1985).

2. Objective

The main objective of this work was to investigate the drying behaviour of selected fish species.

The specific objectives were to evaluate the influence of three different type of dryer on drying behaviour of selected fish species, to compare drying behaviour of selected fish species with respect to used drying technology and influence of salt pretreatment on the drying behaviour of fish.

3. Material and methods

3.1. Fish samples

Research was carried on three species of fish commonly available in Cambodia. Fresh fishes were bought at the market near the Royal University of Agriculture in Phnom Penh Cambodia in early morning. Fish came from aquaculture Used fishes were namely:

- Climbing Perch (*Anabas testudineus*) (CP)
- Spiny eel *(Mastacembelus armatus)* (SpE)
- Swamp eel (*Monopterus albus)* (SwE)

Climbing perch belongs to *Anabantidae* family. It is possible to find Climbing perch in rice fields in the delta of Mekong river, it is common native fish species, which is important for many households as income and nutrition source. Climbing perch is vulnerable because of using pesticides used during rice cropping (Nguyen *et al.,* 2015a). Climbing perch was included in the category of vulnerable animals by the International Union for Conservation of Nature and Natural Resources (Nadirah *et al.,* 2014).

Figure 6: Climbing Perch (*Anabas testudineus*) (fishbase.org, 2016)

Spiny eel belongs to a family *Mastacembelidae* It occurs in rivers, canals and inundated fields. Spiny eel is popular for his special flavour and texture of meat and has lucrative size (Ali *et al.*, 2013).

Figure 7: Spiny eel (*Mastacembelus armatus*) (britanica.com, 2016)

Swamp eel is general commercial farmed in Southeast Asia (Gao *et al.,* 2016). It is harvested in rice fields, rivers and swamps, in tropical areas, where it burrows in the moist mud during the dry season (Pedersen *et al.,* 2014).

Figure 8: Swamp eel (*Monopterus albus*) (bayou-diversity, 2016)

3.2. Fish samples preparation

Immediately after purchase fresh fishes were cleaned and cut in to samples of approximately size 40×20×10 mm. Afterwards all samples were marinated in saline solution (loading in the 3.5% saline solution for 1 hour). Then were reference samples of each fish species weighted and subsequently were all samples dried in three different dryers:

- Electric oven (EO)
- Solar dryer (SD)
- Hybrid solar dryer (SHD)

In case of drying in electric oven (EO) samples of each fish species intended for drying were treated in saline solution (see above) and as a control samples for comparison served samples without any pretreatment (without marinating in saline solution).

Figure 9: Fish cleaning and fish samples preparation (photo: Anna Hubáčková)

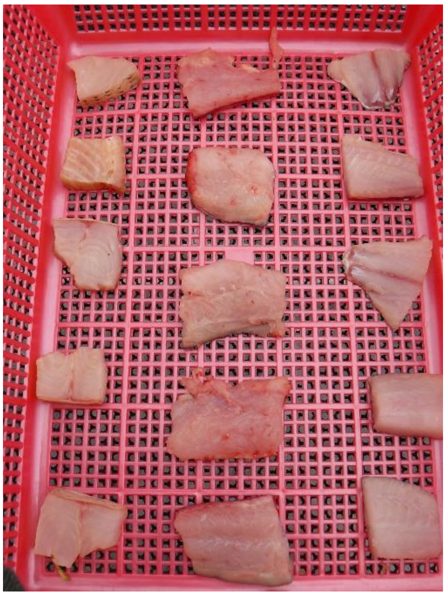

Figure 10: Prepared samples of fishes (photo: Anna Hubáčková)

3.3. Drying experiment

The drying of fish samples was carried out in three different dryers: electric oven (EO), solar dryer (SD) and solar hybrid dryer (SHD). The experimental set of three fish species samples drying was conducted in August at Royal University of Agriculture in Phnom Penh (Cambodia). Drying experiments lasted three days, every day for six hours. In the night, the samples were collected and placed to the room in closed plastic boxes. At hourly intervals were measured parameters as follows weight of reference samples of fish pieces (g) by a digital balance Soehnle with an accuracy ± 0.1 g (Soehnle

Professional, Backnang, Germany), drying air and ambient temperature (ºC), drying air and ambient relative humidity (%) both by Minidataloggers Testo 174H (Testo, Lenzkirch, Germany) installed outside the solar dryer and in the drying chamber further global solar radiation by pyranometer CMP 6 with a solar integrator with daily accuracy ±5%. (KippZonen, Delft, the Netherlands) and inside air velocity ($m \cdot s^{-1}$) by anemometer Testo 425 (Testo, Lenzkirch, Germany) with an accuracy ±0.03 $m \cdot s^{-1}$.

Drying in solar dryer and solar hybrid dryer was compared with drying in a standard electric oven (Conterm, J. P. Selecta, Spain). In electric oven w ere uniform condition for all time, there was 50ºC and 24.4 % relative humidity.

3.3.1. Solar dryer

The solar dryer was constructed of a solar air heater collector, drying chamber with drying trays and a blower, connected to the top of the drying chamber. The collector width was 1.50 m, length 1.47 m, and depth was 0.12 m. The solar collector square constructed of a solid transparent plastic cover, an insulator, and a black painted aluminium absorber. Air enters into the drying chamber trough the collector by natural convection mode. The chamber proportions are 1.50 m long, 0.60 m wide, and 1.10 m high.

Figure 11: Solar dryer (Hubackova *et al.*, 2014)

3.3.2. Solar hybrid dryer

The solar hybrid dryer was constructed of a solar air heater collector and drying chamber with drying trays. The collector width was 1.20 m, length 1.44 m, and depth was 0.13 m. The solar collector square constructed of a solid transparent plastic cover, an insulator, and a black painted aluminium absorber. The chamber proportions are 1.20 m long, 0.60 m wide, and 1.80 m high.

In solar hybrid dryer were burned coal during the first and second day of drying. It was used at the afternoon when the global solar radiation decreased. Every day were burned 7 kg of coal.

Figure 12: Solar hybrid dryer (photo: Ana Hubackova)

3.4. Moisture content and moisture ratio calculation

The dry matter content was determined by the gravimetric method in oven at 105°C for 24 h.

Moisture content is calculated by two methods. Either by wet or dry basis. Moisture content wet basis is the weight of moisture per unit of wet material (Belessiotis and Delyannis 2011):

$$MC_{w.b.} = \frac{m_w}{m_w + m_d} \tag{1}$$

$MC_{w.b.}$ = moisture content wet basis

m_w = mass of water (kg)

m_d = mass of dry solid (kg)

Moisture content dry basis is expressed as the ratio of water content to the weight of dry material. It was used following formula (Belessiotis and Delyannis 2011):

$$MC_{d.b.} = \frac{m_w}{m_d} \tag{2}$$

$MC_{d.b.}$ = moisture content dry basis

m_w = mass of water (kg)

m_d = mass of dry solid (kg)

The reduction of moisture ratio during drying was used to analyse the drying characteristics. Moisture ratio (*MR*) describe the amount of moisture remaining in the samples reported to the initial moisture content (Seremet *et al.*, 2016). *MR* was calculated by the following formula (Tunde-Akintunde and Ogunlakin 2011):

$$MR = \frac{M_t - M_e}{M_i - M_e} \tag{3}$$

MR = moisture ratio

M_t = moisture content at any time of drying (kg water/kg dry matter)

M_e = equilibrium moisture content (kg water/kg dry matter)

M_i = initial moisture content (kg water/kg dry matter)

This formula of moisture ratio calculation can be simplified when the equilibrium moisture content cannot be estimated because the relative humidity od the drying air continually fluctuated in the case of solar drying experiments. M_e compared M_t and M_i so small that the error in the calculation is negligible (Rayaguru and Routray, 2012).

$$MR = \frac{M_t}{M_i} \tag{4}$$

MR = moisture ratio

M_t = moisture content at any time of drying (kg water/kg dry matter)

M_i = initial moisture content (kg water/kg dry matter)

3.5. Rehydration ratio

After drying experiment two dried reference samples of each fish species dried in electric oven were weighted and immersed in the clean 40ºC warm water to rehydrate for 30 minutes. The temperature of water (ºC) was measured by temperature controller (Model 501, Shanghai Experiment Instrument Factory, China, with an accuracy ±5 °C). After soaking all remove samples were weighed again and rehydration ratio was calculated.

Rehydration ratio show an increase in volume of absorbed water with time. Higher water absorption rates are generally observed in the initial stages of the process, with the rehydration rates then declining until equilibrium is obtained (Santos-Sánchez *et al.*, 2012).

$$R_{reh} = \frac{m_0 - m_1}{m_1} \tag{5}$$

m_0 = weight before rehydration (kg)

m_1 = weight after rehydration (kg)

3.6. Data analysis

The final data were analysed using IBM SPSS Statistics 22.0 (IBM, US). To analyse relevant differences between obtained data was used One-way Anova test and Tukey test as a post hoc test.

4. Results and Discussion

4.1. Drying performance

All drying conditions of drying experiment were measured and are shown in Figures 13 –15. Figure 13 shows the data obtained by measuring ambient condition. The average ambient air temperature, ambient air relative humidity and global solar radiation were 33.86 ºC, 59.30 % and 417.48 $W \cdot m^{-2}$, respectively. Minimum ambient air temperature, ambient air relative humidity and global solar radiation were 27.6 ºC, 23.7 % and 172 $W \cdot m^{-2}$, respectively. Maximum ambient air temperature, ambient air relative humidity and global solar radiation were 42.4 ºC, 90.4 % and 675 $W \cdot m^{-2}$, respectively. By Belessiotis and Delyannis (2011) the suitable temperature for drying starts from 30 ºC. The maximum temperature for drying fish is 70 ºC (Hubackova *et al.*, 2014). This temperature range was respected.

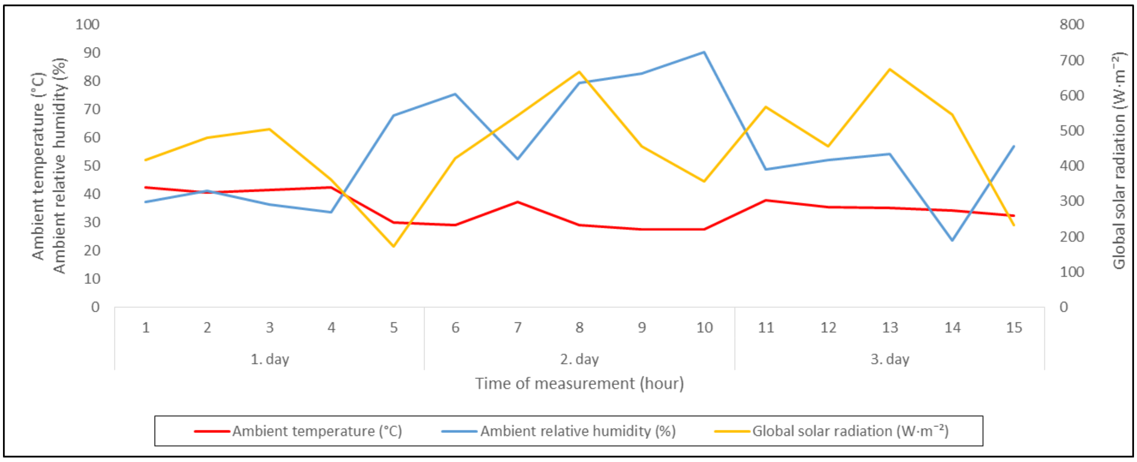

Figure 13: Outside drying condition

In Figure 14 are presented drying conditions in drying chamber of solar dryer (SD). The average drying air temperature, drying air relative humidity and air velocity inside the drying chamber of solar dryer were 40.38 ºC, 47.66 % and 0.25 $m \cdot s^{-1}$, respectively. The minimum drying air temperature, drying air relative humidity and air velocity inside the drying chamber of solar dryer were 28.6 ºC, 27.5 % and 0.01 $m \cdot s^{-1}$, respectively. The maximum drying air temperature, drying air relative humidity and air velocity inside the drying chamber of solar dryer were 53.4 ºC, 83.4 % and 0.52 $m \cdot s^{-1}$, respectively.

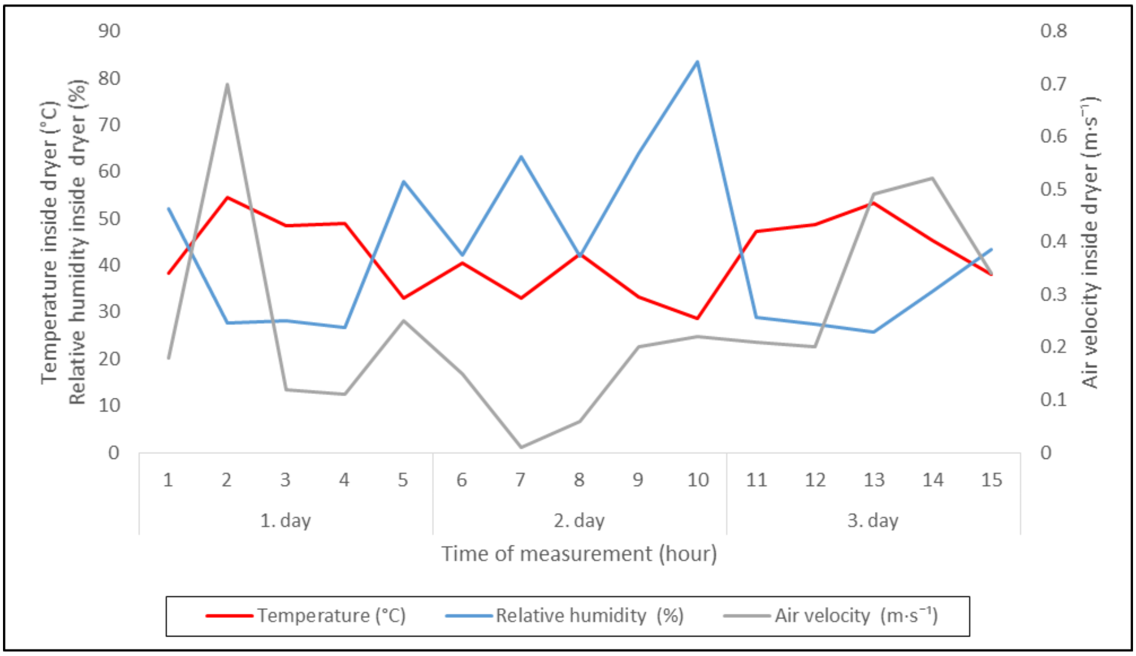

Figure 14: Inside drying condition in chamber of solar dryer (SD)

In Figure 15 are showed drying conditions in drying chamber of solar hybrid dryer (SHD). The average drying air temperature, drying air relative humidity and drying air velocity were 38.70 ºC, 41.77 % and 0.15 $m \cdot s^{-1}$, respectively. The minimum drying air temperature, drying air relative humidity and drying air velocity were 22.4 ºC, 25.8 % and 0 $m \cdot s^{-1}$, respectively. The maximum drying air temperature, drying air relative humidity and drying air velocity were 53.4 ºC, 63.1 % and 0.51 $m \cdot s^{-1}$, respectively

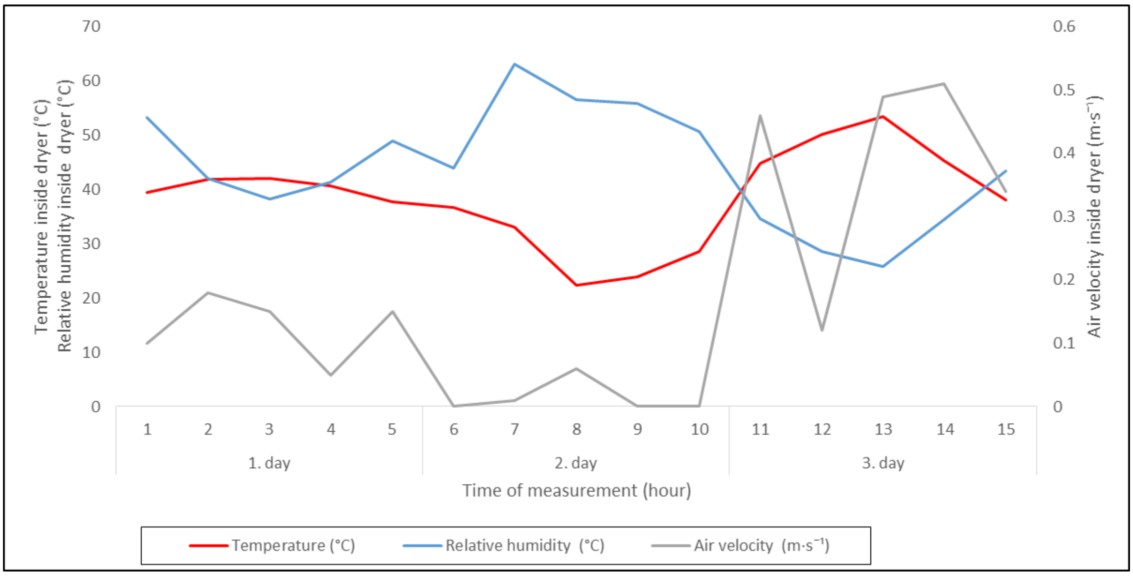

Figure 15: Inside drying condition in chamber of solar hybrid dryer (SHD)

In drying chamber of both solar dryers were measured very low air velocities, which could affect the drying process. It is confirmed, with increase air velocity decrease drying time (Bumrungkeeree *et al.,* 2011). From Figure 14 and 15 is evident the drying air temperature and drying relative humidity have an opposite run, which correspond to ambient air temperature and ambient relative humidity.

4.2. Moisture content and moisture ratio

Final moisture content (w.b.) of samples of all fish species are shown in Table 1 and Table 2. It is obvious that electric oven was the most effective one due to uniform conditions and higher drying air temperature during whole drying experiment. After three days of drying the final moisture contents of fish samples dried in solar dryer are higher than final moisture contents of fish samples dried in electric oven or solar hybrid dryer. This fact, it is not unusual. For example Basri *et al.* (2015) have similar results.

Spiny eel has the lowest moisture content (w.b.) and conversely Swamp eel has the highest one in every used dryers.

The measured data obtained from drying of salted and unsalted samples of three fish species in electric oven demonstrate that salt pretreatment has an influence on the final moisture content of drying product, see Table 2.

Table 1: Moisture content ($MC_{w.b.}$ %) of fish samples dried in electric oven, solar dryer and solar hybrid dryer (salt pretreatment)

Fish species	Electric oven $MC_{w.b}$ (%)± SD.	Solar dryer $MC_{w.b}$ (%)± SD	Solar hybrid dryer $MC_{w.b}$ (%)± SD.
Climbing Perch	19 ± 0.04	34 ± 0.02	26 ± 0.10
Spiny eel	16 ± 0.06	24 ± 0.07	23 ± 0.06
Swamp eel	23 ± 0.02	32 ± 0.02	21 ± 0.03

Table 2: Moisture content ($MC_{w.b.}$ %) of fish samples dried in electric oven (salted and unsalted)

Fish samples	Salted fish $MC_{w.b}$ (%)± SD.	Unsalted fish $MC_{w.b}$ (%)± SD
Climbing Perch	19 ± 0.04	32 ± 0.08
Spiny eel	16 ± 0.06	35 ±0.01
Swamp eel	23 ± 0.02	4 1±0.01

Drying curves of all fish samples dried in EO, SD, and SHD with salt pretreatment are presented in Figure 16. The best drying characteristic have fish samples dried in electric oven. It could be supposed, because in the EO were uniform drying conditions and higher drying temperature for all time of experiment. Based on Anova and subsequent Tukey test, was found, there are statistical differences between MR of fish samples dried in electric oven and MR of fish samples dried in solar dryer ($p < 0.05$) and MR of fish samples dried in electric oven and MR of samples dried in solar hybrid dryer ($p < 0.05$). The comparison between MR of fish samples dried in solar dryer and MR of fish samples dried in solar hybrid dryer there is not a statistical difference (95% confidence level). Compared drying behaviour between Climbing perch, Spiny eel and Swamp eel with respect to use drying technology, there were found no statistical differences between fish species (95% confidence level). Miklos *et al.*, (2014) shows that fat content has an effect on the weight loss during drying, water activity or moisture content, but in the case of these fish species the fat content is almost similar as well as the body composition (Taşbozan *et al.*, 2013; Nurhasan *et al.*, 2009; Kader *et al.*, 2011).

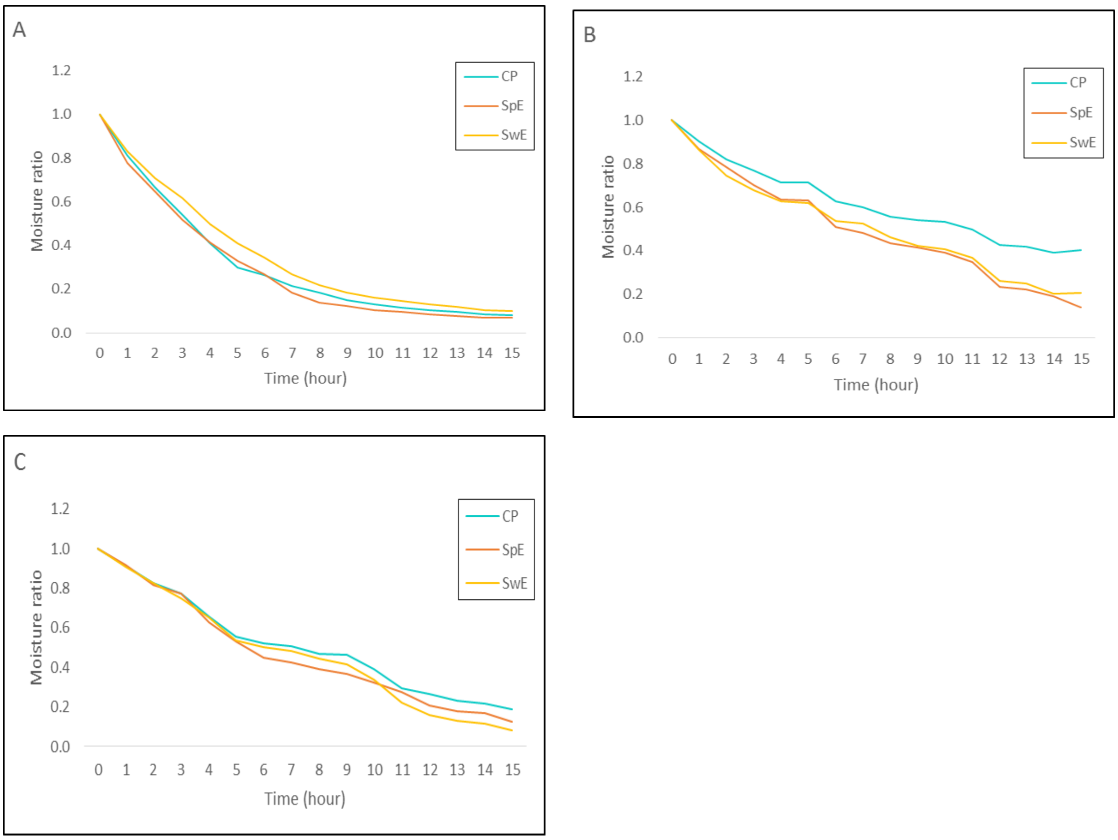

Figure 16: MR of salted fish samples dried in electric oven (A), solar dryer (B) and solar hybrid dryer (C)

Influence of salt pretreatmet on drying behaviour of three different fish species (Climbing perch, Spiny eel and Swamp eel) was analysed. The drying curves (MR versus time) of CP, SpE and SwE in electric oven with salt pretreatment and control samples without salt are presented in Figure 17. This experiment was executed only in electric oven, because of constant conditions in the dryer. In this case, the salt pretreatment has an influence on the drying behaviour of all three fish species samples. There is a statistical significant difference between salted and unsalted fish samples ($p < 0.05$). This finding is in agreement with the result reported by Hwang *et al.*, (2012). Martins *et al.*, (2015) reported, that increase of salt content facilitates the spread of moisture during drying. And İsmail *et al.*, (2015) declare, that in drying of plant has the same results.

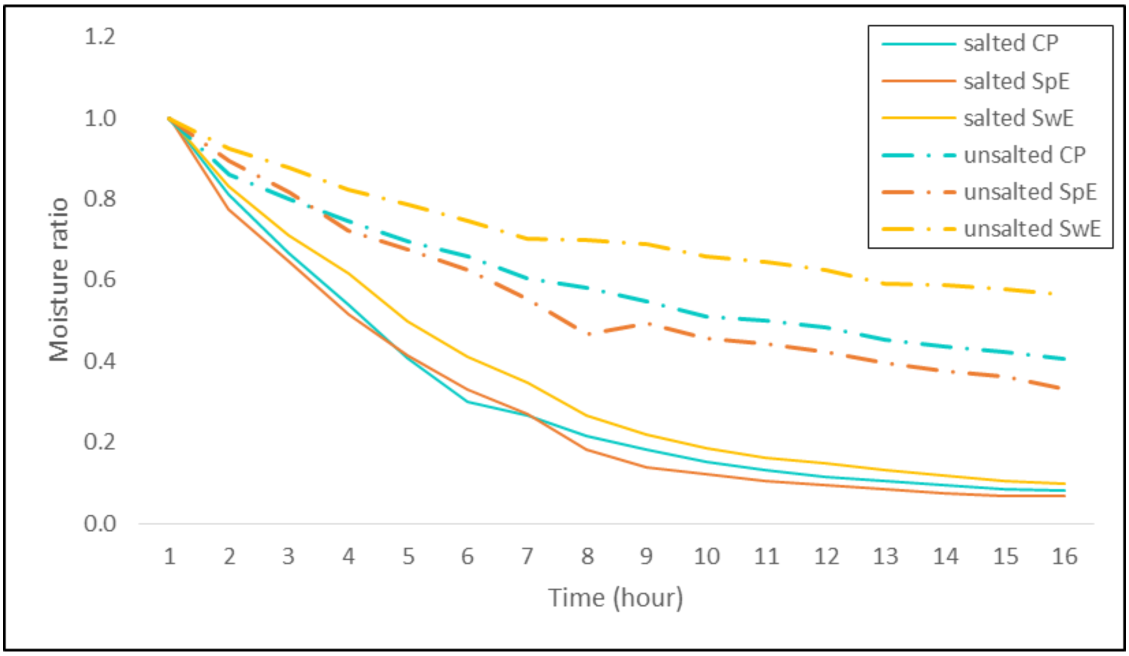

Figure 17: MR of CP, SpE, SwE (all in salted or unsalted variation) dried in electric oven

4.3. Rehydration ratio

The results of rehydration experiment of fish samples Climbing perch, Spiny eel, Swamp eel (all samples in salted and unsalted variation) dried in electric oven are shown in the Figure 18. It was found out the statistical significant differences between rehydration of fish samples with salt pretreatment and control fish samples without pretretment. The same result achieved Debnath *et al.* (2004) who found out, that salt pretreatment decrease effective diffusion coefficient of water absorption. Cunningham *et* *al.* (2008) performed the same experience with potato and had the same results too. But Muñoz *et al.* (2012) performed this experience with minced meat from ham and found out salt pretreatment had not significantly effect on rehydration.

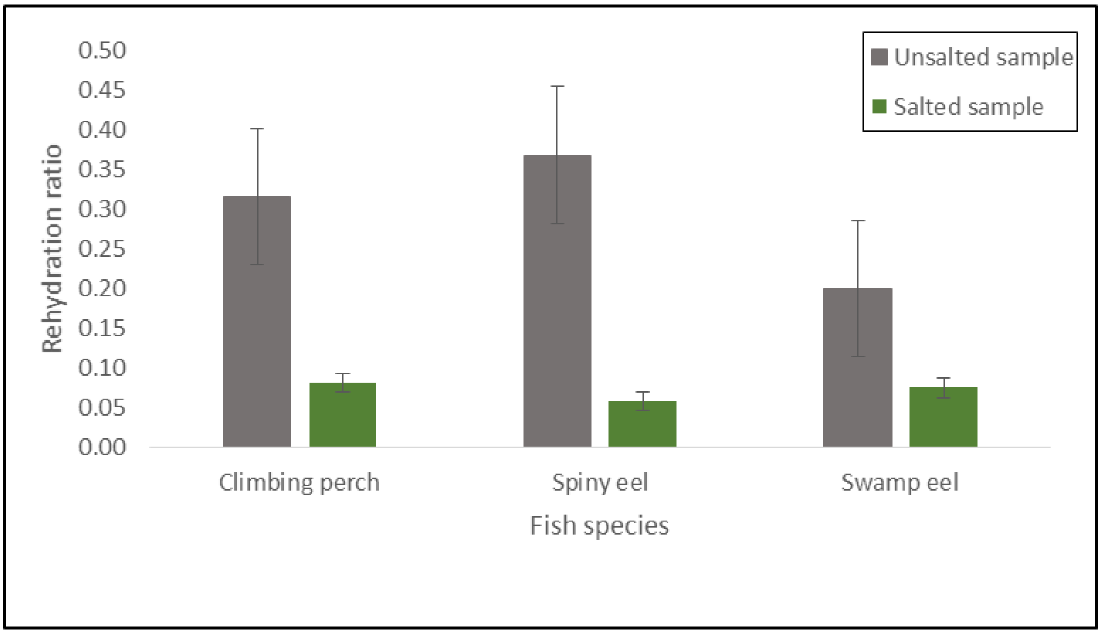

Figure 18: Rehydration ratio of CP, SpE, SwE (salted and unsalted) dried in EO

5. Conclusion

The drying behaviour of three selected fish species: Climbing perch (CP), Spiny eel (SpE) and Swamp eel (SwE) commonly available in Cambodia were investigated in this study. Standard electric oven (EO), solar dryer (SD) and solar hybrid dryer (SHD) were used for drying process. Saline solution (3.5%) was used as a pretreatment for all fish samples of CP, SpE, SwE. In case of drying in electric oven fish samples of CP, SpE and SwE without saline treatment were used as a control samples in addition to samples of fishes treated with salt.

The constant temperature in EO was 55°C and 24.4 % relative humidity. The average drying air temperature, drying air relative humidity and air velocity inside the drying chamber of SD were 40.38 ºC, 47.66 % and 0.25 $m \cdot s^{-1}$, respectively. In case of SHD the average drying air temperature, drying air relative humidity and drying air velocity were 38.70 ºC, 41.77 % and 0.15 $m \cdot s^{-1}$, respectively. Average global solar radiation was 417.48 $W \cdot m^{-2}$. According to the Anova test and Tukey test there were statistical significant differences ($p < 0.05$) between drying behaviour of fish samples dried in EO and fish samples dried in SD, as well as differences between drying behaviour of fish samples dried in EO and fish samples dried in SHD. The differences in drying behaviour between Climbing perch, Spiny eel and Swamp eel with respect to used drying technology, was statistically not significant (95% confidence level). In contrast during rehydration experiment were found statistical significant differences ($p < 0.05$) between salted and unsalted fish samples of CP, SpE and SwE dried in the (EO).

Dried fish meat is an important nutrient source in many developing countries, including Cambodia. This study brings new knowledge about drying behaviour of selected fish species. Even this thesis shows standard EO more efficient in terms of drying speed of dried product in comparison to SD, the solar dryer is more suitable for drying of products in rural areas in developing countries. Solar dryers in comparison to electric oven could be low cost and it is possible to use it off-grid system, which is very important especially when 1.3 billion people on the world have not access to regular electricity (85 % of them live in rural areas of sub –Saharan Africa and South Asia) (Pode *et al.,* 2015).

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