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Faculty of Tropical AgriSciences

Using a solar dryer for preparation of traditional Vietnamese beef jerky

Diploma thesis

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Statement

I declare that I have developed this diploma thesis on the topic "Using a solar dryer for preparation of traditional Vietnamese beef jerky" by myself and independently and I have quoted only from the sources listed in the bibliography. These data I have added by information which was the outcome of my own research.

In Prague 26th April 2017

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Jan Staš

Abstract

Meat is one of the most valuable livestock products, for many people serves as their first source of protein. Rising demand for meat in developing countries combined with poor equipment and knowledge about meat preservation highlight the importance of feasible alternatives for rural populations.

Drying or dehydration is one of the most popular methods for food preservation. Drying the product directly on the sun, which is still popular in rural areas in Vietnam, is associated with lots of difficulties as possibility of contamination by microorganisms, pests or molds. For that reason, this diploma thesis focuses on the use of solar dryer for preparation of traditional Vietnamese beef jerky as alternative to open sun-drying and as well as alternative to laboratory dryer (electric oven).

Beef and buffalo meat samples were prepared, and two different types of pre-treatment were applied; marinating the samples in Vietnamese traditional marinade and frying the samples in the oil on the pan before drying. Drying was conducted in Active Solar Dryer (ASD) and Laboratory Oven (LD). The aim was to find any correlation between the dryers and the speed of drying and if there was any correlation between the different types of pre-treatment applied. Behaviour of both meat types was also analysed. From these results it was observed, that both drying efficiencies (in ASD and LD) are similar. It was found that depending on the pre-treatment applied, the marinating might influence the drying process in a way in which it will make it slower in both, ASD and LD. The influence of the marinade on the drying process was not statistically significant. The same effect was found in the case of frying the samples before drying. With this pre-treatment, the slowdown of the drying process in LD was statistically significant ($p<0.05$). There was no significant difference in the behaviour of beef and buffalo meat.

Organoleptic properties of five samples were assessed by the 13-member degustation panel. The best scored sample was beef meat from local market (BM), followed by beef meat dried in ASD (BE) and buffalo meat dried in ASD (BU). Frying the samples before drying did not affect final organoleptic properties significantly.

Key words: Solar drying; meat drying; beef and buffalo jerky; renewable energy; organoleptic properties; CIE Lab.

Abstrakt

Maso je jeden z nejcennější živočišných produktů a pro mnoho lidí slouží jako hlavní zdroj živočišných bílkovin. Stále rostoucí poptávka po mase v rozvojových zemích v kombinaci se špatným vybavením a znalostmi o konzervaci masa zdůrazňuje význam možných alternativ zpracování masa pro venkovské obyvatelstvo.

Sušení neboli dehydratace je jednou z nejoblíbenějších metod konzervace potravin. Sušení produktu přímo na slunci je stále běžné ve venkovských oblastech Vietnamu, přestože je spojeno s mnoha problémy, jako například možnost kontaminace mikroorganismy, škůdci nebo plísněmi. Z tohoto důvodu se tato diplomová práce zaměřuje na použití solární sušárny pro přípravu tradičního vietnamského hovězího jerky jako alternativa k sušení přímo na slunci či jako alternativa k laboratorní sušárně (elektrická trouba).

Vzorky hovězího a buvolího masa byly před sušením ošetřeny dvěma způsoby; Marinování vzorků ve vietnamské tradiční marinádě a smažení vzorků v oleji na pánvi. Sušení bylo prováděno v Aktivní Solární Sušárně (ASD) a v Laboratorní Sušárně (LD). Cílem bylo zjistit, zda existuje vztah mezi použitými sušárnami a rychlostí sušení a zda existuje nějaká korelace mezi různými typy ošetření před sušením a rychlostí sušení. Rovněž bylo sledováno chování obou druhů mas. Z výsledků je zřejmé, že účinnost sušení v ASD je podobná jako u LD. Bylo zjištěno, že v závislosti na použitém ošetření, může marinování zpomalovat proces sušení jak v ASD, tak i v LD. Vliv marinády na sušení nebyl statisticky významný. Stejný účinek byl zjištěn v případě smažení vzorků před sušením. Při této předúpravě bylo zpomalení procesu sušení v LD statisticky významné ($p < 0,05$). Nebyl prokázán významný rozdíl v chování hovězího a buvolího masa během sušení.

Organoleptické vlastnosti pěti vzorků byly hodnoceny 13-členným degustačním týmem. Nejlépe hodnocené bylo hovězí maso z místního trhu (BM), následovalo hovězí maso sušené v ASD (BE) a buvolí maso sušené v ASD (BU). Smažení vzorků před sušením významně neovlivnilo konečné organoleptické vlastnosti

Klíčová slova: Solární sušení; sušení masa; sušené hovězí a buvolí maso; obnovitelná energie; organoleptické vlastnosti; CIE Lab.

Preface

Preservation of human food such as meat, vegetable, fruit, spices, and herbs by open-air drying on the sun was one of the first ways to extend shelf-life of product. Even though, drying meat on the sun is one of the oldest methods of food preservation, it is still a popular method in many developing countries, in particular where no cold chain is available. But, this method of drying has also a lot of disadvantages, for example, the potential risk of contamination of product by microorganisms, pests, molds, etc. In order to avoid this, there is opportunity to used solar dryers. This method of preservation is ideal for drying the meat. As meat is one of the most valuable products around the world; the meat consumption is increasing in the developing countries most of it thanks to a positive economic growth.

The main driver of this thesis is the lack of studies on the field of usage of solar dryers for preparation beef jerky in Vietnam as well as in whole Southeast Asia. Another driver is present urge to use renewable energy everywhere, where possible. Moreover, meat drying is an undemanding process, which majority of rural people can easily familiarize with. Food drying processes basically means preservation of food for indefinite periods by extracting the moisture, thereby inhibiting the growth of microorganism. Additional pre-treatments are given to the drying procedure to enhance drying and speed and to avoid growing of microbiological organisms by evaporating water from the product. All this is to assure a proper and healthy storage of food.

Table of content

List of Figures

List of Tables

1. Introduction

Solar radiation used for drying is one of the oldest applications of solar energy. It was used since the dawn of mankind mainly for food preservation but also for drying other useful materials as cloths, construction materials, etc. The first installation for drying by solar energy was found in South France and is dated at about 8000 BC. Solar heat was the only available energy source to mankind until the discovery and use of wood and biomass. Until today in remote small communities, not only in the so-called third world regions, but also in the western countries, people take advantage of solar radiation to dry and preserve small amounts of food (Belessiotis and Delyannis, 2011).

Drying by solar energy is a rather economical procedure for agricultural products, especially for medium to small amounts of products, to preserve excess of production. It is friendly to the environment. It is still used for domestic up to small commercial size drying of crops, agricultural products and foodstuff, such as fruits, vegetables, aromatic herbs, wood, etc., contributing thus significantly to the economy of small agricultural communities and farms.

1.1 Drying

There are two main sources of food; plants and animals. Although various researchers have classified foods in different ways, generally they are categorized as perishable (which spoils very fast) and non-perishable (relatively slower spoilage) (Rahman, 1999).

All variety of foods in our day to day life requires some form of preservation mainly to reduce or stop spoilage, to make it available throughout the year, to maintain desired levels of nutritional properties for the longest possible time span and to make value-added products. Amongst these, spoilage is the foremost reason for employing food preservation techniques. Spoilage or deterioration of food occurs during handling or due to mechanical, physical, chemical, or microbial damage. Out of these, chemical and microbial damages are most frequent causes (Rahman, 1999; Mujumdar, 2007). Microbial growth depends on the storage conditions and the moisture level in the product. Different micro-organisms have different growth rates depending on the conditions. There can also be several chemical and enzymatic changes during processing and storage of foods. Commonly employed methods for food preservation are: freezing, vacuum packing, canning, preserving in syrup, food irradiation, adding preservatives, and the most popular method, dehydration or drying. However, drying will never replace freezing and canning, because of their better ability to retaining the taste, appearance, and nutritive value of fresh food. Drying, or dehydration, of foods is one of the most common methods used for preserving food. Its discovery and spread allowed people to become less dependent on daily food supply, even despite the often-difficult environmental conditions (Rahman, 2007).

The dehydrated foods industry has a prominent place among today’s food industries all over the word, especially in developing countries (Vega-Gálvez, 2011). Different types of drying and their various operating variables affect food microstructures that are formed during the drying process, thus influencing the structure of the final product (Vega-Gálvez, 2011).

Selection of dryers for particular food product is itself a complex step as there are hundreds of dryers available and more than one dryer can suit a particular application. In developing countries food products are dried traditionally by open sun drying. Although this method is still common at several places for non-commercial use, there have been numerous efforts to develop advanced drying methods for food products on commercial scale (Kudra and Mujumdar, 2009).

1.1.1 Drying theory

There are quite a variety of methods when it comes to drying, depending on the specific requirements we could judge them based on their energy efficiency, time to dry, product quality, among others. (Mujumdar, 2008), the goal of the drying process is to decrease the weight through the evaporation of moisture from the meat, and this should follow one of the trends illustrated in the Figure below (see Fig. 1). Basically, weight will be decreasing in time.

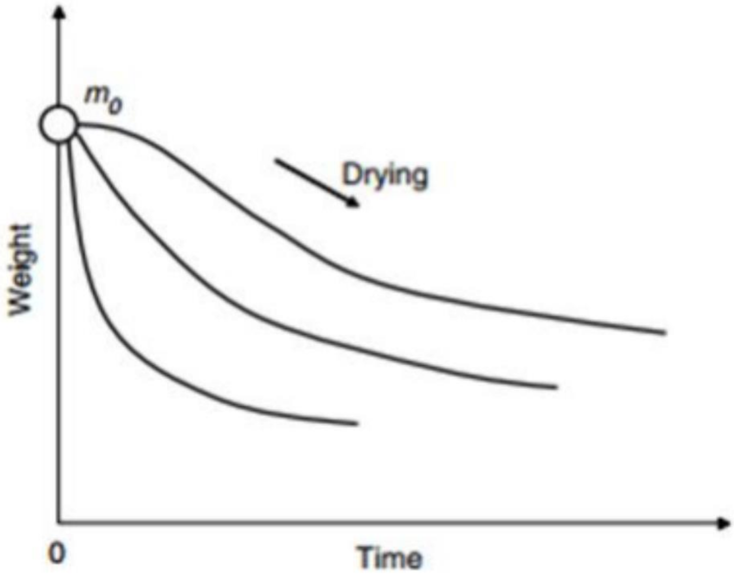

Figure 1. Weight loss curves as drying proceeds (Chen and Mujumdar, 2008)

The drying process not only contributes to microbial growth stability but also modifies the enzymatic reactions and the sensory characteristics of the meat (Grau et al., 2014), this will allow extending its shelf life. “Shelf-stable product” refers to those products that do not require refrigeration for freezing for safety and acceptable organoleptic characteristics (Wisconsin University, 2005).

The main goal of the drying process is to inhibit the growth of microorganism through the evaporation of moisture, is it important to know the minimum water activity required for different microorganisms to grow, thus aside from the drying behaviour it’s important to identify acceptable levels of water activity to assure proper conservation of products. Meat drying is a complex process with many important steps, starting from the slaughtering of the animal, carcass trimming, selection of the raw material, proper cutting and pre-treatment of the pieces to be dried and proper arrangement of drying facilities. In addition, the influence of unfavourable weather conditions must also be considered to avoid quality problems or production losses. The secret of correct meat drying lies in maintaining a balance between water evaporation on the meat surface and migration of water from the deeper layers. In the process of drying is necessary to evaporate moisture from the product and a flow of air is needed to carry away the evaporated moisture. There are two basic mechanisms involved in the drying process;

during the initial stages of drying, known as the constant-rate period, water is evaporated from the surface of the product and the temperature of the product remains constant. In the final stages of drying, known as the falling-rate period, the temperature of the product increases, causing water to move from the interior to the surface for evaporation (Bal et al., 2010).

Three major stages of drying can be observed in the drying curve:

- Transient early (warming -up) period, during which the product is heating up
- Constant rate period, in which moisture is comparatively easy to remove
- Falling rate period, in which moisture is bound or held within the solid matrix

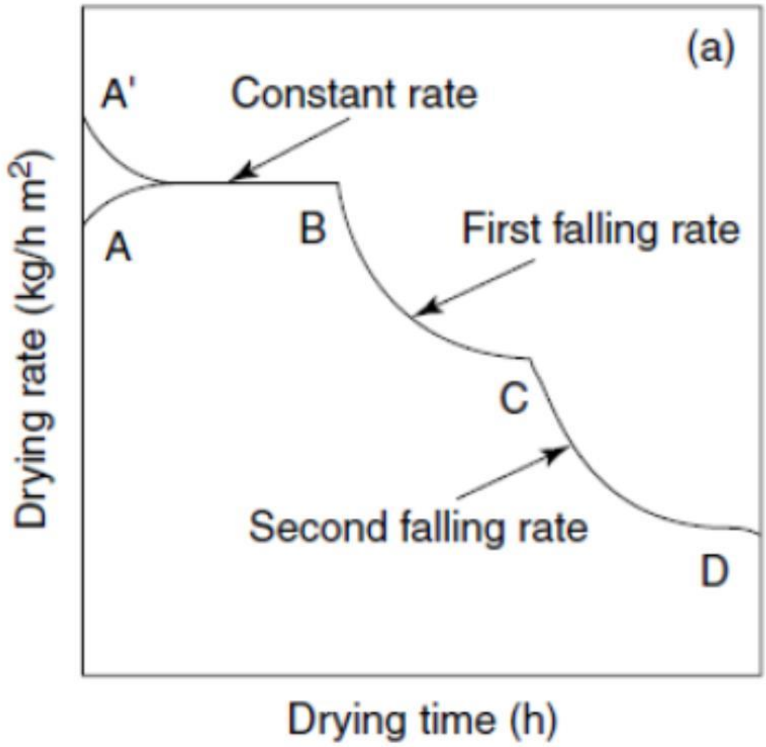

Figure 2. Typical drying rate curves (FAO, 2017).

The rate of drying is determined by the moisture content and the temperature of the product and the temperature, the (relative) humidity and the velocity of the air in contact with the product.

1.1.1 Classification of dryers

There are many schemes used to classify dryers (Mujumdar, 2007; Van't Land, 1991). Classification of dryers on the method used for removing water is perhaps the most useful since it allows one to identify some key features of each class of dryers:

- thermal drying
- osmotic dehydration
- mechanical dewatering

Osmotic dehydration and mechanical dewatering are quite out of scope of presented thesis. Thus, they were excluded from further classifications of drying systems.

1.1.2 Thermal drying

Thermal drying, which is one of the most widely used methods of drying foods, is a process where high temperatures are used to eliminate moisture from the material. The type or physicochemical state of the dried material and the drying process determine the mechanisms of moisture transfer. Thermal drying takes place in gaseous or void environment.

Thermal drying can be divided further into three types:

- 1. Air drying
- 2. Low air environment drying
- 3. Modified atmosphere drying

Convection pneumatic drying

Application of the convection pneumatic dryers is represented especially in food industry in plants for industrial processing of grains (wet milling processing of wheat and corn). Generally, such dryers can be used for drying of meal-like and fine-kernel materials. Simple construction and a relatively low consumption of energy have enabled successful application of such dryers in the above stated industrial branches. The construction of the convection dryer enables simultaneous pneumatic transport of wet material and its drying. The material is dried in matter of several seconds, therefore method is suitable for drying of foods sensitive to high temperatures (Prvulovic and Tolmac, 2007).

Sun Drying

The most basic method of drying is to spread the crop on a surface exposed to the sun (Heindl, 2000).

From an ancient time, solar drying was the only way, how to dry foods. In this process, drying material is laid on the ground or hanged in the air to be exposed to direct sun light. The advantage of solar drying is that it uses renewable energy source. Although sun drying is the cheapest and also least demanding way, how to dry foods, it has many disadvantages. For example, the temperature rises without regulation. Drying is therefore uneven, and caramelized and crusted pieces result. The direct exposure to the sun also destroys colour, vitamins and flavour, and there is chance of contamination with dust, dirt, insect infestation, and contact with other pests. They may also be drenched by rain or dew and, may need further drying if mold growth is to be avoided during storage. Sun-drying may take 2-14 days (De Guzman and Siemonsma, 1999).

In-store drying

In-store drying is also called low temperature drying or in-bin drying. Commonly it is used when grains or another crops are stored for longer time or until sold. Tropical climate weather conditions are less favourable for this type of drying, because of high ambient temperatures and relative humidity values (Rahman, 2007).

Spray Drying

Spray drying is a method of producing a dry powder from a liquid or slurry by rapidly drying with a hot gas. This is the preferred method of drying of many thermally-sensitive materials such as foods and pharmaceuticals. A consistent particle size distribution is a reason for spray drying some industrial products such as catalysts. Air is the heated drying medium; however, if the liquid is a flammable solvent such as ethanol or the product is oxygen-sensitive then nitrogen is used (Mujumdar, 2007).

Vacuum Drying

Vacuum drying of lumber has been considered for many years, but until recently has not been in commercial use. The main attraction of vacuum drying is that by lowering the boiling temperature of water in vacuum, free water can be vaporized and removed at temperatures considerably below 100°C almost as rapidly as it can with high-temperature drying above 100°C. Vacuum drying is essentially high-temperature drying at low temperatures (Simpson, 1987).

Freeze drying

Freeze-drying, lyophilisation, or cryodesiccation is a dehydration process typically used to preserve a perishable material or make the material more convenient for transport. Freeze-drying works by freezing the material and then reducing the surrounding pressure to allow the frozen water in the material to sublimate directly from the solid phase to the gas phase (Garrett, 2012)

Despite being used in a wide variety of products (such as pharmaceuticals and foodstuff), lyophilisation presents a great challenge for scientists in the field, especially its usage for long-term conservation of living systems (Ciurzinska and Lenart, 2011).

Heat pump drying

The heat pump dryer is a further extension of the conventional convection air dryer with an inbuilt refrigeration system (Figure 3). Dry heated air is supplied continuously to the product to pick up moisture. This humid air passes through the evaporator of the heat pump where it condenses, giving up its latent heat of vaporization to the refrigerant in the evaporator. This heat is used to reheat the dry air passing over the hot condenser of the refrigeration circuit and used to reheat the air within the dryer. The use of the heat pump dryer offers several advantages over conventional hot air dryers for drying food products, including higher energy efficiency, better product quality, the ability to operate independent of outside ambient weather conditions and zero environmental impact (Rahman,2007).

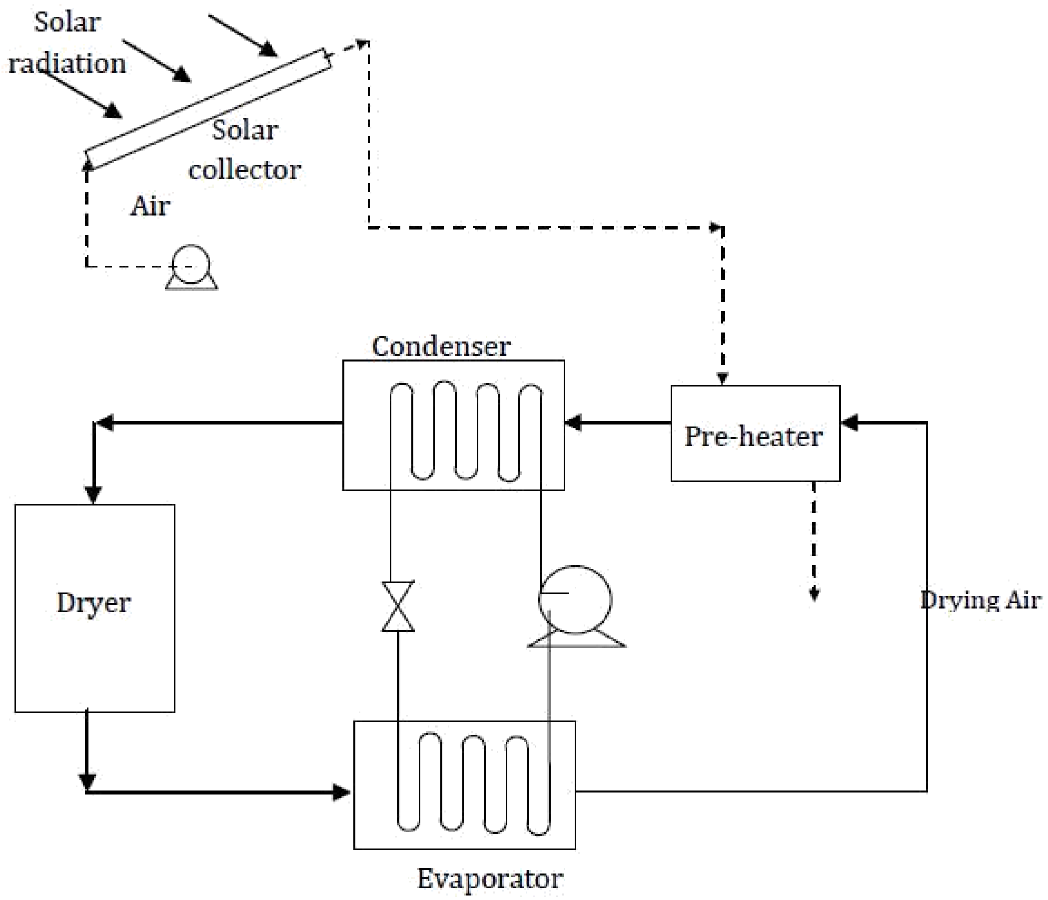

Figure 3: Solar assisted heat pump drying system (Jangam, 2011).

This is practically a new concept of drying foods using heat pump dryers, which uses modified atmospheres such as nitrogen and carbon dioxide. These atmospheres help maintain better quality and preservation of constituents of foods, prone to oxidation. Technologies to create the modified atmosphere drying are now evolving. The modified atmosphere drying has weaker adverse effects on the product, especially in terms of shrinking, colour change, types of molds, and peroxide values (Rahman 2007).

1.2 Solar energy drying

Solar dryers are equipment, generally of small capacity and based rather on empirical and semi-empirical data than in theoretical designs. The majority of the numerous solar dryer designs, which are available, are used mainly for drying of various crops either for family use or for small-scale industrial production. Solar radiation, in the form of solar thermal energy, is an alternative source of energy for drying especially to dry meat products, fruits, vegetables, agricultural grains, and other kinds of material, as wood, etc. This procedure is especially applicable in the so-called “sunny belt” worldwide, i.e. in regions where the intensity of solar radiation is high and sunshine duration long. It is estimated that in developing countries there exist significant post-harvest losses of agricultural products, due to lack of other preservation means, that can be saved by using solar dryers.

Solar drying is an extension of sun drying that uses radiation energy from the sun. Solar drying is a non-polluting process and uses renewable energy. Moreover, solar energy is an abundant source, that cannon be monopolized. However, solar drying has some disadvantages that limit its in large-scale production. It also needs large areas of space and high labour inputs and there is again possibility of insect infestation and microbial contamination. (Rahman, 2007)

1.2.1 Importance of solar dryers in developing countries

In comparison with developed countries has agriculture in developing countries an irreplaceable role in terms of the number of economically active population. The agricultural sector employs an average of 50% of the economically active population in developing countries (FAO, 2015). Moreover, agriculture in developing countries constituted in 2013 average 12% of GDP (World Bank, 2015). Agricultural production in developing countries faces several problems that cannot be discussed here due to their extent. In general, we can say that most of them are economic, technological, and political character. One of the main problem is the lack of adequate technology for the processing of food, whether plant or animal origin, inappropriate cultivation methods and fertilization, poor marketing, poor logistics and high post-harvest losses. It is estimated that the above problems in developing countries have resulted in 10-40% losses in food production (Murthy, 2009).

A partial solution of this situation may be the introduction of appropriate technologies for processing of agricultural products. Here, offers primarily the drying as one of the oldest methods of post-harvest processing that is used in agriculture. Even in developing countries, it is now possible to observe an increase of small and medium-sized enterprises oriented on drying as agricultural products processing. Drying of agricultural products in developing countries mainly provides these positives (Jon and Kiang, 2008):

- increases agricultural production through the introduction of alternative products on the market,
- generates job opportunities in urban and rural areas,
- reduces the losses of harvest fresh produce (fruits, vegetables, and others)
- improves nutrition of the producers themselves (farmers) due to possible reserves of dried products outside their harvest season,
- generates a new source of income for farmers,
- creates new value-added products.

Despite the technological level of the food industry, the vast majority of agricultural products in developing countries is processed by drying directly on the sun (Imre, 2007). The technique of drying of agricultural products on the sun has a disproportionately large loss (up to 30% of total production) and it is mainly due to the factors as damage of products by domestic animals, rodents and birds during drying, exposing to the direct impact of climate (rainfall, dew, wind, etc.), contamination of products by insects, bacteria or mold.

For many reasons, suitable alternative to traditional drying on the sun in developing countries could be solar dryers. Above all, we must realize, that more than 80% of all food in developing countries is produced by small producers or small-farmers (Murthy, 2009), who do not have needful capital, to invest it in relatively expensive sophisticated technologies for food processing. Solar dryers could be a possible option for farmers in developing countries, mainly, because of their advantages as low input and operating costs, simple construction, easy service without complicated electronic and mechanical features, more efficient compared with traditional drying methods and easy maintenance and replacement of spare parts.

Another and equal important fact, which contributes to the usage of solar dryers for agriculture products processing is changing human view in the field of usage energy in developing countries. In the last two decades, we can observe some effort on energy independence, environmental protection, and interest in the usage of renewable energy sources at the expense of fossil fuels (Imre, 2007).

1.2.2 Classification of solar-energy drying systems

All drying systems can be classified primarily according to their operating temperature ranges into two main groups of high temperature dryers and low temperature dryers. However, dryers are more commonly classified broadly according to their heating sources into fossil fuel dryers (more commonly known as conventional dryers) and solar-energy dryers. Strictly, all practically-realized design of high temperature dryers are fossil fuel powered, while the low temperature dryers are either fossil fuel or solar-energy based systems.

To classify the various types of solar dryers, it is necessary to simplify the complex construction and various modes of operation to the basic principles. Solar dryers can be classified based on the following criteria:

- Mode of air movement
- Exposure to insulation
- Direction of air flow
- Arrangement of the dryer
- Status of solar contribution

Another useful classification is based on (1) the method of transferring heat to the wet solids or (2) the handling characteristics and physical properties of the wet material. The first method of classification reveals differences in dryer design and operation, while the second method is most useful in the selection of a group of dryers for preliminary consideration in a given drying problem.

A classification chart of drying equipment on the basis of heat transfer is shown in Figure 4 (Ekechukwu, 1999; Sharma et al., 2009).

This chart classifies dryers as direct or indirect, with subclasses of continuous or batch wise operation. Solar-energy drying systems are classified primarily according to their heating modes and the way the solar heat is utilized (Belessiotis, 2011). In broad terms, they can be classified into two major groups, namely:

- passive solar-energy drying systems (conventionally termed natural-circulation solar drying systems) and,

- active solar-energy drying systems (most types of which are often termed hybrid solar dryers).

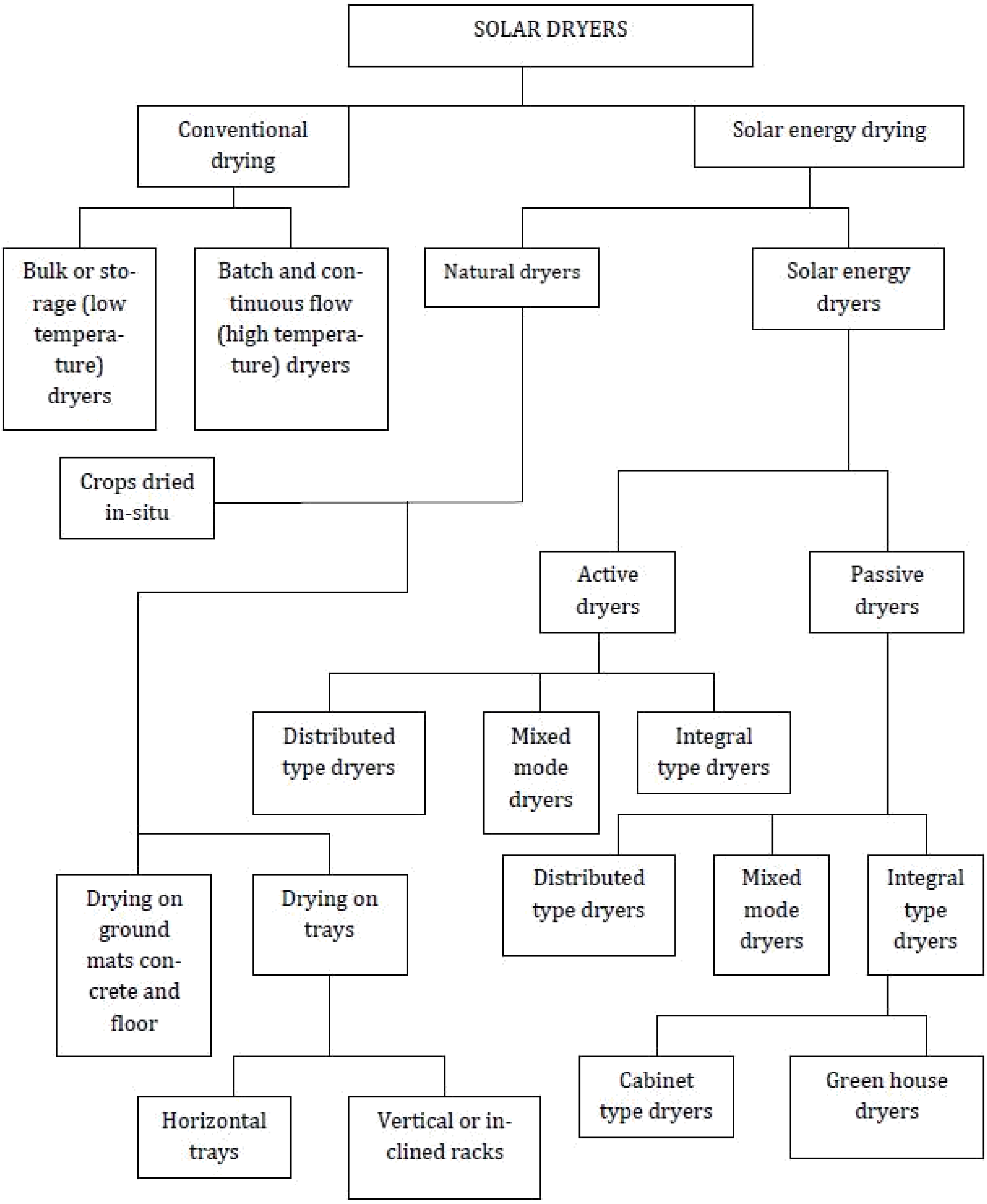

Figure 4: Classifications of dryers and drying models (Ekechukwu, 1999).

Three distinct sub-classes of either the active or passive solar drying systems can be identified namely:

- integral-type solar dryers;
- distributed-type solar dryers; and
- mixed-mode solar dryers.

The main features of typical designs of the various classes of solar-energy dryers are illustrated in Figure 5, showing three main groups for solar dryers based on the energy sources used (Leon et al., 2002). The design of solar dryers is adjusted to the quantity, character, and designation of the material to be dried as well as to the energy sources used and accordingly, various types of solar dryers have been developed and are in use to date.

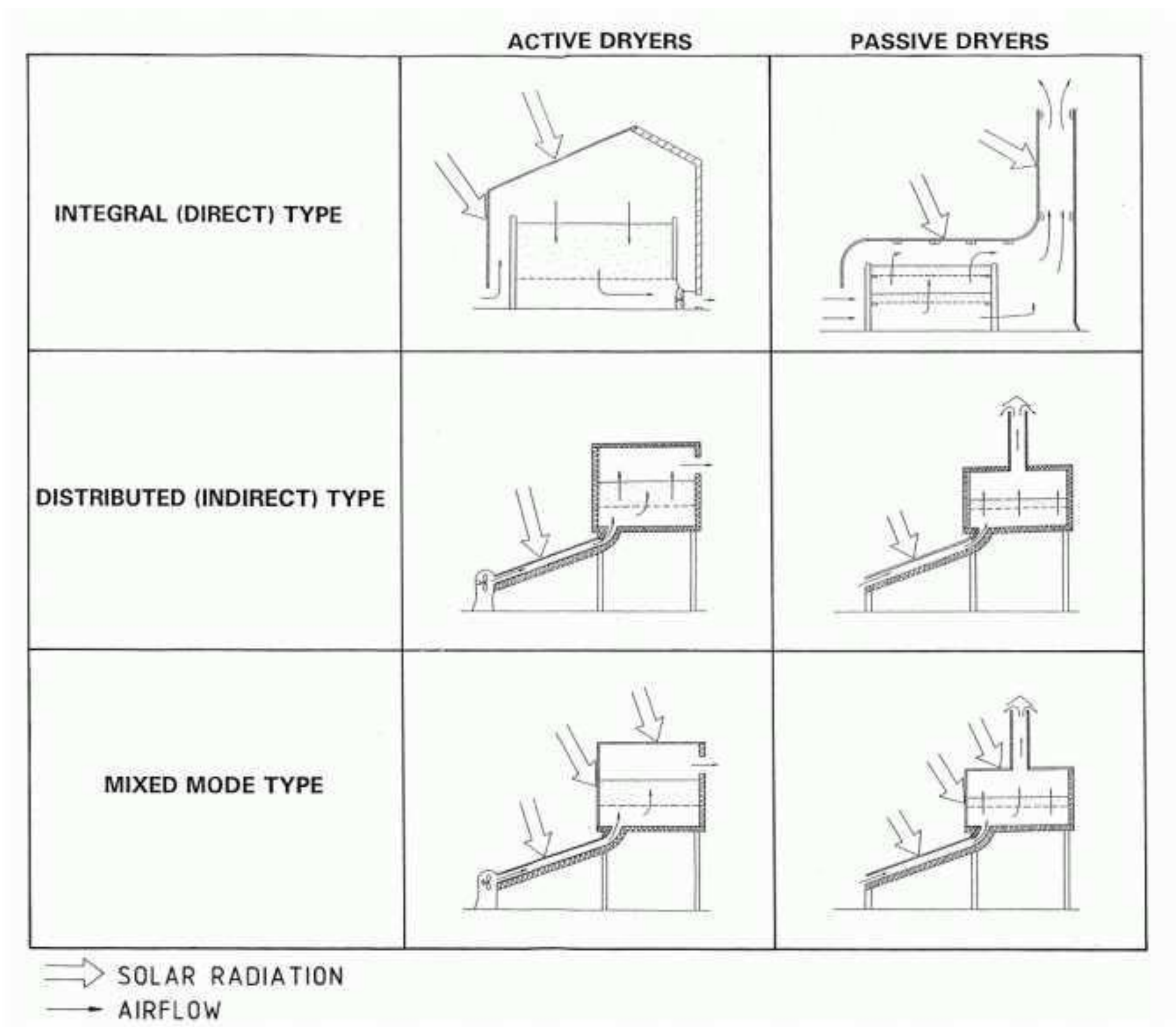

Figure 5: Typical solar energy dryer designs (Ekechukwu and Norton, 1999).

The mode of drying can be differentiated into direct and indirect, depending whether the product is directly exposed to solar radiation or dried in the shade. In direct mode, the product itself serves as absorber, i.e. the heat transfer is affected not only by convection but also by radiation according to the albedo of the product surface. Therefore, the surface area of the product being dried must be maximized by spreading the crop in thin layers. To obtain uniform final moisture content, the crop must be turned frequently.

It should be noted, that sunlight may affect certain essential components in the product e.g. chlorophyll is quickly decomposed. Due to the limitation of the bulk depth, such dryers need large ground surface areas. If grounds are scarce, indirect mode type of dryers are preferred for drying large quantities (Weiss, 2003).

1.2.2.1 Passive solar dryers

In a passive solar dryer, air is heated and circulated naturally by buoyancy force or because of wind pressure or in combination of both. Normal and reverse absorber cabinet dryer and greenhouse dryer operates in passive mode. Passive drying of crops is still in common practice in many Mediterranean, tropical and subtropical regions especially in Africa and Asia or in small agricultural communities. These are primitive, inexpensive in construction with locally available materials, easy to install and to operate especially at sites far off from electrical grid. The passive dryers are best suited for drying small batches of fruits and vegetables such as banana, pineapple, mango, potato, carrots etc. (Hughes et al., 2011).

They can be either direct (e.g. tent and box dryer) or indirect (e.g. cabinet dryer). Natural-circulation solar dryers depend for their operation entirely on solar-energy (Weiss, 2003)

Tent solar dryers are consist of a frame of wood poles covered with plastic sheet. This is the main reason, why are these dryers cheap and simple to construct. Important is, that black plastic should be used on the wall facing away from the sun. They are usually used for fruit, fish, coffee, or other products for which wastage is otherwise high. Even so, they have disadvantage of being easily damaged by strong wind.

The aim of solar cabinet dryers is mainly to improve product quality by reducing contamination by dust, insect infestation, and animal or human interference. It consists of a hot box with a transparent top and blackened interior surfaces. Ventilation holes in the base and upper parts of slide walls maintained a natural air circulation (Szulmayer, 1991).

Several other designs of passive solar cabinet dryer in configuration to that developed by Brace Research Institute have been built and tested for a variety of crops and locations. Ezekwe (1981) reported a modification of the typical design shown in Figure 6 equipped with a wooden plenum guiding the air inlet and a long plywood chimney to enhance natural circulation, accelerating the drying rate by about 5 times over open-sun drying.

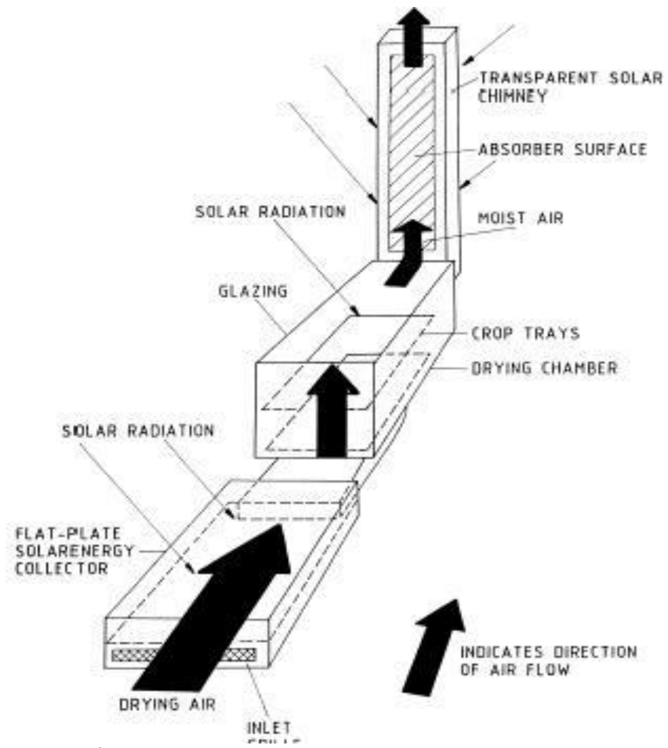

Figure 6. Features of a typical mixedmode natural-circulation solar-energy dryer (Ekechukwu and Norton, 1999).

A hybrid type passive solar-energy dryer would have the same typical structural features as the indirect-type and direct-type (i.e. a solar air heater, a separate drying chamber, and a chimney), and in addition has glazed walls inside the drying chamber so that the solar radiation impinges directly on the product as in the direct-type dryers.

1.2.2.2 Active solar dryers

Active solar dryers system are constructed including external means, like fans, ventilators or pumps, for moving the heated air, as a solar energy, from the collector area to the drying beds. By their application, all active solar dryers are forced convection dryers. A classical active solar dryer depends on solar energy only for the heat source, while for air circulation uses motorized fans or ventilators. These dryers are commonly used in large-scale commercial drying operations in combination with convectional fossil-fuel to have a better control over drying by inhibiting the effect of fluctuations of solar insolation on the drying air temperature. Active solar dryers are known to be suitable for drying higher moisture content foodstuffs such as papaya, kiwi fruits, brinjal, cabbage and cauliflower slices. A variety of active solar-energy dryers could be divided into either direct-type, indirect-type, or hybrid dryers. (Visavale, 2012)

Indirect-type active solar drying systems

These active dryers have a separate collector and drying unit. They are usually composed of four basic components viz., a solar air heater, drying chamber, a fan for air circulation and ductings (Visavale, 2012). Figure 7 shows a typical in-direct active solar dryer.

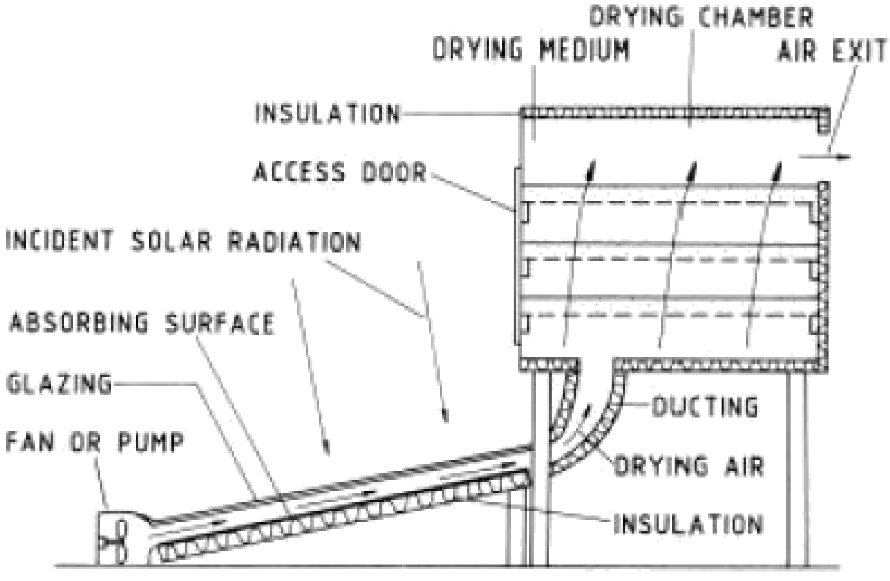

Figure 7. Features of a typical distributed-type active solar energy dryer (Ekechukwu and Norton, 1999).

The direct-type active solar drying systems are designed with integral solar energy collection unit. Generally, three distinct designs of direct-type active solar dryers can be classified viz., the absorption type, storage type and greenhouse dryers (Visavale, 2012).

The hybrid solar dryers combine the features of a solar energy with a conventional or some auxiliary source of energy and can be operated either in combination or in single mode with either source of energy. These dryers generally are medium to large installations operating in the range of 50-60%, and compensate the temperature fluctuations induced by the climatic uncertainties (Visavale, 2012).

1.2.3 Solar drying of meat

1.2.3.1 Importance of meat in human diet in developing countries

Meat is a concentrated nutrient source, previously considered essential to optimal human growth and development (Higgs, 2000). Although some epidemiological data has revealed a possible association between its consumption and increased risk of several forms of cancer, cardiovascular and metabolic diseases (Silva, 2016), meat consumption has been important in human being evolution, especially the brain and intellectual development.

The role of meat, especially red meat, as a protein source is unequivocal. However, meat protein content can vary substantially. According to the (INSRJ, 2006), the average protein content is 22%, however it can be as high as 34.5% (chicken breast) or as low as 12.3% (duck meat). Additionally, meat proteins have been distinguished by their essential amino acids content. Amino acids are proteins' building blocks. There are one hundred and ninety amino acids known although only twenty are necessary to synthesize proteins. Within this twenty, eight cannot be produced by the human body which makes them essential, thus they must be supplied by diet. Even if these non-essential amino acids can be produced by the human body, it is mandatory to have all the raw materials necessary for their production. Inadequate consumption of amino acids, the primary units of proteins, can lead to protein malnutrition. The nutritional value of each food can be determined by the quantity and the quality of the several amino acids present or absent. If a certain food supplies enough of seven of the eight essential amino acids, the lacking amino acid is defined as the “limiting amino acid.” In addition to its richness, meat protein distinguishes itself because of its richness in all the essential amino acids with no limiting amino acids (Williams, 2007).

Meat consumption is based largely on price, price, and also tradition of the country. Meat production is a complex procces depending not only on demand (which is mainly based on price and income) but on many social and economic factors such as official policy, price support mechanisms, and interrelations such as the interaction between beef and milk production, the availability of animal feedstuffs and competition for food between man and animals.

It is difficult to make accurate comparisons of meat consumption between countries because different methods are used to estimate consumption. The amount of meat consumed in different countries varies enormously with economic, social, and political influences, but as well on religious beliefs and geographical differences. For instance, there are still about 20 developing countries where per capita meat consumption is below 10 kg/year, compared with an average of 80 kg/year in developed countries. (FAO. 2013)

Meat is held in high esteem in most communities. It has prestige value, it is often regarded as the central food round which meals are planned, various types of meat are sometimes made the basis of festive and celebratory occasions, and from the popular as well as the scientific point of view, it is regarded as a food of high nutritive value. (Bender, 1992)

1.2.3.2. Dried meat and meat drying

The consumption of meat and meat products in developing countries is increasing. We must take on to consideration that, meat is a highly perishable product and soon becomes unfit to eat and possibly dangerous to health through microbial growth, chemical change, and breakdown by endogenous enzymes (Bender, 1992). According to this fact, there is need to use adequate way of preservation of meat. One of the most widely used techniques to preserve food is drying processes, this basically means preservation of food for indefinite periods by extracting the moisture, thereby inhibiting the growth of microorganism, additional pre-treatments are given to the drying procedure to enhance drying and speed and to avoid growing of microbiological organisms by evaporating water from the product. All this is to assure a proper and healthy storage of food. The water can be found in three different states, solid, liquid and gas. The phase in which it will be found it will depend on the temperature and pressure conditions.

There is no unique classification because existing of many traditional meat products involves a mixture or a sequence of processes. Dried meats are those meats in which the stability is essentially due to water reduction by sun-drying, air-drying. Intermediate moisture meats are meats, which are stabilized by combined techniques involving dehydration. These are mainly dehydrated meats after curing- salted and/or fermented, cooked, smoked (Collignan et al., 2008).

Traditional dried meats are not cooked before drying. They are prepared by cutting into strips, and sometimes are salted. The water content of these is around 10% (w.b.). Simple meat drying is more famous in Africa. In Latin America and Asia is meat pre-treated by brining or soaking in salt or sugar solution (Collignan et al., 2008).

Beef jerky

The most known dried meat is American beef jerky, which originates from meat dried by native Americans to suit their nomadic lifestyle. Later, cowboys adopted this type of food as they could store it in their saddlebags for long time. The word ‘jerky’ as such originates from the fact, that cowboys hand cut or pulled (jerked) meat from a side of beef. Beef jerky is produced from very lean muscle tissue from the hindleg such a topside meat or inside or outside rounds. No connective tissue or fat should be present in the meat and, as a result, a product very low in fat is obtained.

To produce beef jerky, extremely well-trimmed meat is sliced into slices 4–8 mm thick, weighed and subsequently mixed with a marinade containing salt, nitrite, ascorbate (erythorbate), sugar, spices (garlic, onion, chilli, and cayenne pepper) and quite commonly materials such as red wine, soy sauce or Worcestershire sauce as well. The meat is left to marinade for 12–14 hours under chilled conditions before being placed on grid racks or hung up. Several different methods of drying are followed. One of the method is to dry the meat at 60–65 ∞C and at a low RH until an Aw below 0.89 is obtained, with no smoking taking place. Drying of food takes place at a fast rate at temperatures of around 60–65 °C because temperatures above this range more or less cook muscle tissue, thus entrapping moisture (Jones et al., 2001).

Pastirma

Pastirma or (basturma) is a salted dried beef product made in Moslem countries. Hindquarter meat is cut into strips 40–50 cm long at a thickness (diameter) of between 4 and 5 cm. The meat is covered with salt which contains 0.02–0.03% potassium nitrate and is stored in piles for 1–2 days at room temperature. The cut strips of meat also commonly have been incised to facilitate the penetration of salt into meat. After 1–2 days, the pile of salted meat is turned over, salt is applied once again and left for another day. The salted meat is washed briefly and then heavily pressed for around 12–24 h.

After pressing, the meat is dried for up to 2 weeks before a paste called cemen is applied to the semidried meat with a thickness between 4 and 6 mm. The paste consists of around 35–40% garlic, spices such as hot paprika, kammon, mustard and other powdered materials as well as water, but the water content of the paste is only around 30%. Garlic is by far the most important part of the paste, not only because it imparts a strong flavour to the product, but also because it prevents growth of mould on the product (Jones et al., 2001).

Rou gan and shafu (PR China)

Dried meat products (sou gan) are produced in China in many different ways. Rou gan is the most common product and this product has been produced in the same way for many years. This product is visually not very attractive and has a crumbly structure. It is also dark in colour and occasionally sold in shredded form. Rou gan and similar products are heavily dried. To produce rou gan, lean meat from the loin or leg is cut into thin slices of around 2–3 mm thickness and then marinated in a mixture of sugar, salt and spices such as five-spice mix (watchau (Szechwan pepper), anise, clove, cinnamon and fennel), MSG and soy sauce. The sliced meat is marinated in this mixture for around 24–36 h at room temperature and then dried on racks at around 60 °C until around 45–50% of their original weight is lost.

The slices are then grilled over coal at around 150°C for a few minutes and subsequently dried by room temperature. These products are very dry in texture and sweet in taste as between 8% and 10% of sugar is present in the finished product. The level of salt is around 2.5%. A visually improved version of rou gan is shafu, which is sold in a sliced form. Shafu is juicier than rou gan. It is also strongly red in colour (but not as dark as rou gan), soft in texture and less sweet than rou gan (Feiner, 2006).

Kilishi

Traditional Kilishi is prepared using quality beef. It is prepared by skilfully cutting lean meat into thin sheets (1-2mm thick). These sheets of meat are sun dried on a raised wooden table covered in rush matting for about four hours. The sheets of meat are then immersed in a slurry of groundnut caked and seasonings including sugar, salt and paper (Igene, 1988). After immersion, the meat is returned to the rush matting to dry in the sun for a further five to twelve hours.

The product is finally roasted briefly over fire. Kilishi production is not standardised and there are many variations of the method described above. Ingredient formulations, infusion time and duration of the solar drying stages vary depending on the required taste and environmental conditions. There are also variations in drying methods and some producers do not employ the final roasting stage (Jones et al., 2001).

Biltong

African biltong is made from strips of salted meat. Beef is still the meat of choice, but game meats such as antelope are processed more often nowadays (Heinz and Hautzinger, 2007). The finest-quality biltong is garing-biltong, produced from the eye muscle from the loin and the most tender product is binne-biltong or oumase-biltong, which uses fillet meat. To make all types of biltong, lean muscle tissue is utilized as the possibility that rancidity develops during the months of drying is reduced when lean meat is used. In addition, meat from younger animals is preferred as this meat contains less intramuscular connective tissue than meat from older animals. During trimming as much connective tissue as possible is removed and lean pieces of meat are cut into strips of around 30–50 mm in width.

The salted pieces of meat are placed in tubs under chilled conditions and left standing for several days, with the pieces of meat occasionally being shifted around. Once removed from the tub and when equalization of salt is completed, the salted pieces of meat are then dried until around 50% of weight is lost. Because of such heavy drying, the level of salt increases within the product to around 6–7% (Jones et al., 2001).

Charque

Charque (or charqui) is the popular marinated and sun dried beef in Latin America especially in Brazil. Beef from fore and hindquarter is cut into large pieces of about 5 kg, and approximately 5 cm thick, then wet salting or brining. After that are meat pieces piled on a sloping concrete slab under a roof. Alternate layers of salt and meat are put up to reach a height of about 1 m. The pile is then covered with wooden planks and pressed with heavy weights. Every 8 hours is the pile restacked and this process takes 5 days. Then are the meats washed and sun dried for approximately 5 days. For consumption, the salt must be reduced by immersing the meat pieces in water (Heinz and Hautzinger, 2007; Collignan et al., 2008). Charqui is stable for periods of months under ambient temperature due to its low moisture and high salt content (5% and more) (Heinz and Hautzinger, 2007).

1.2.4. Traditional drying of meat in Vietnam

Historically variety of meats and meat products has been developed in Europe and America where a large amount of meat products have been consumed. In Asian countries, in contrast, grains and vegetables significantly contribute to the consumer's diets and a relatively small amount of meat or meat products have been consumed. Therefore, the meat and meat processing industry have not been well developed in the Asian region. This historical trend in food consumption has been changed in the recent years. During the last 50 years, per capita income of Asia (including Oceania and Pacific) increased 6.7 times from 1956 (513 US$) to 2006 (3425 US$). Along with the increase of income, the consumption of animal products (including milk and eggs) also increased 2.7 times from 1956 (28.7 kg/person/year) to 2006 (77.205 kg/person/year). Due to a rapid economic growth in Asian countries and a strong expansion of western culture, the relative portion of meat and meat products in the consumption pattern will be continuously grown (Nam et al., 2010).

During the 1990s, Vietnam undertook a rapid reform (Doi Moi) of its economic system. This reform was focused first on the agriculture sector, which experienced a marked increase in rice and other agricultural production (General Statistical Office, 2001). During this period of economic expansion, the food supply diversified. Many key products experienced marked decline in price, while real household income increased and the rate of inflation decreased considerably. Linked with this was an important reduction in poverty but remarkably minimal change in malnutrition (World Bank, 1999; Bhushan et al, 2001; Glewwe et al, 2001).

Vietnam appears to be undergoing a shift in the population's diet structure including a decrease in carbohydrates, an increase in protein sources (ie, pork, poultry, and beef), and an increase in fruits and vegetables in harmony with the increase of food production (FAO-VN, 1999).

Vietnam is one of the developing countries with considerable changes in meat consumption patterns. Annual GDP has achieved a comparatively high growth rate of approximate 6% over the last years. Income per capita has increased rapidly over the last two decades (GSO, 2013). There are nearly 94 million people in Vietnam who make up about 27 million households (GSO, 2015). In terms of expenditure, meat is one of the most important food groups consumed when families spent 20.9% their food expenditure for meat.

As we can see at Figure 8, the structure of diet shifted to less starchy staples while proteins and lipids (meat, fish, other protein-rich higher fat foods) increased significantly.

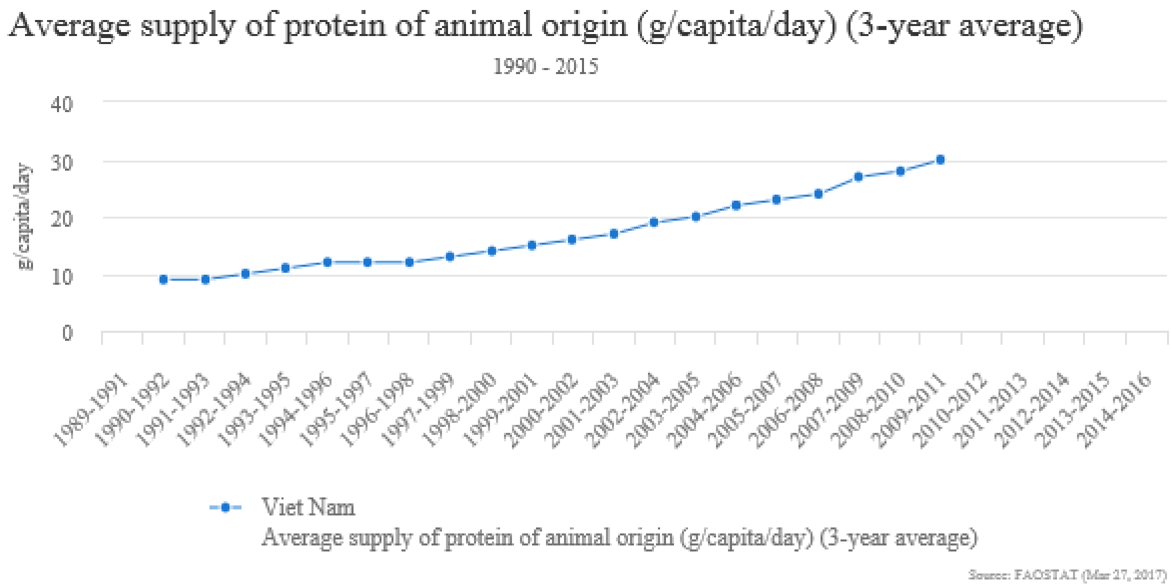

Figure 8. Average supply of protein of animal origin in Vietnam. (FAOSTAT, 2017)

In next Figure (see fig. 9) we can observe, how the number of slaughtered beef and buffalo animals in Vietnam rapidly increased in recent years.

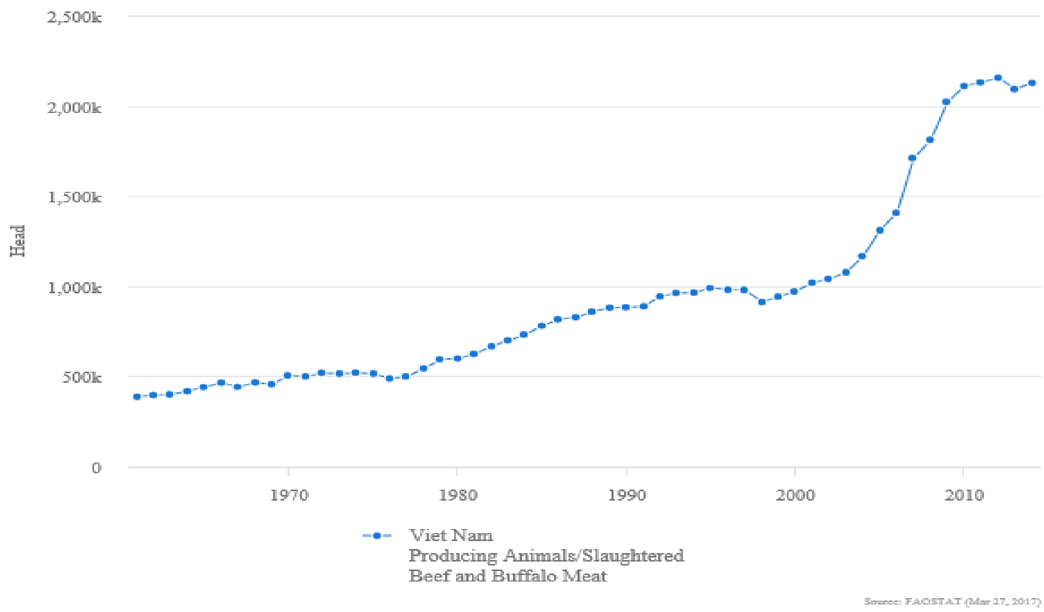

Figure 9. Number of beef and buffalo animal slaughtered in Vietnam (FAOSTAT, 2017)

2. Objectives

2.1. Main objective

To investigate the influence of drying method on drying behaviour and final product quality with respect to used drying pre-treatments of beef and alternative buffalo meat.

2.2 Specific objectives

i. Investigation of two different drying methods: a) solar dryer b) laboratory dryer

ii. Evaluation of drying behaviour of different meat (beef, buffalo) with respect to used drying technology and its comparison.

iii. Comparison of influence of different processing/pre-treatments of meat on final sensory properties.

3. Materials and Methods

3.1. Meat Samples

Fresh boneless beef and buffalo meat from *biceps femoris* was purchased from the local slaughterhouse (Hue, Vietnam). All visible fat and connective tissue were trimmed off as far as possible. The muscle was cut into smaller pieces, rinsed, and washed with clean water to remove blood. Both have been vacuum-packaged and were stored at -18°C for 24 hours for later use. The frozen meat samples were thawed at 4°C overnight and were cut into samples of size 0.5 × 8 × 2.5 cm. Sample size 0.5 cm was cut through the fibre. Together 48 (24 × beef, 24 × buffalo) samples were used.

The fresh beef was reddish and bright, soft, fine, firm and elastic. Natural odour and intramuscular marbling was present. The raw buffalo meat was dark reddish and less bright, moderately soft, fine, firm and elastic. Natural meaty odour was present in raw buffalo meat.

3.2. Drying pre-treatments

Curing

Vietnamese traditional marinade (Chau, 2016) consisted of 40 gr fresh lemon grass, 30 gr brown sugar, 22 gr oyster sauce (Maggi), 15 gr vegetable oil, 21 gr fresh garlic, 20 gr sate (Magic Ngon), 3 gr iodized soup base (VISAchef), 1 gr five spices powder (Kim Nga), 1 gr chilli powder and 1 gr turmeric powder (see Figure 10) was used. Lemon grass and garlic were chopped into small pieces and then mixed with all other ingredients. Immediately after cutting the meat, half of the samples (12 × beef (Be), 12 × buffalo (Bu)) were marinated in the Vietnamese traditional marinade (Ma). All samples were than stored in the refrigerator overnight (10 hours).

Frying

After 10 hours in refrigerator, half of both, marinated samples (6 × Be, 6 × Bu) and unmarinated samples (6 × Be, 6 × Bu) were fried in the vegetable oil on the preheated pan for one minute from each side. Second half of samples were not fried.

Figure 10. Ingredients for Vietnamese Traditional Marinade

All samples with abbreviation, which were used for drying are summarized in Table 1.

Table 1. Designation of the samples used for experiment.

Pre-treatment	Beef	Buffalo
Marinated + fried	BeMaPa	BuMaPa
Marinated not fried	BeMaNo	BuMaNo
Not marinated + fried	BeNoPa	BuNoPa
Not marinated not fried	BeNoNo	BuNoNo

Solar dryer					
Beef					
A1	A2	A3	B1	B2	B3
C1	C2	C3	D1	D2	D3
Buffalo					
E1	E2	E3	F1	F2	F3
G1	G2	G3	H1	H2	H3
Laboratory dryer					
Beef					
I1	I2	I3	J1	J2	J3
K1	K2	K3	L1	L2	L3
Buffalo					
M1	M2	M3	N1	N2	N3
O1	O2	O3	P1	P2	P3

3.3. Drying experiment

The drying of fresh and fried meat slices was carried out in the active solar dryer (see Figure 11), which were designed at the Faculty of Tropical AgriSciences at Czech University of Life Sciences Prague (CULS) and constructed at Hue University of Agriculture and Forestry (HUAF), Vietnam. This solar dryer is classified as a forced convection direct type and is based on the familiar construction of the suspended plate air heating solar collector. The fans in the active solar drier (ASD) were connected directly to a PV panel by parallel connection.

Figure 11. Active solar dryer, which were used in experiment.

Solar drying of meat was compared with drying in a laboratory dryer (LD, standard dehydrator) with constant temperature 55°C. Drying was conducted in August at HUAF. The specific climatic and drying conditions of both days of solar drying experiment are presented in Table 2. Drying experiments took 2 days – 6.5 hours each day. First day started at 9:30 AM and stopped at 4:00 PM. Second day started at 8:00 AM and stopped at 2:30 PM. During the night, the samples were collected and placed in a room in vacuum-packed plastic bags.

Table 2. Climatic and drying conditions – averages of whole day with Standard Derivation (SD)

Outside	First Day ± SD	Second Day ± SD
Temperature (°C)	45.74 ± 6.02	36.61 ± 4.75
Relative Humidity (%)	35.11 ± 10.59	61.31 ± 14.76
Global Solar Radiation($W \cdot m^{-2}$)	653.79 ± 421.53	329.53 ± 284.40
Inside	**First Day ± SD**	**Second Day ± SD**
Temperature (°C)	48.37 ± 6.84	38.82 ± 7.55
Relative Humidity (%)	32.42 ± 9.96	50.53 ± 14.26
Air velocity ($m \cdot s^{-1}$)	0.77 ± 0.41	0.24 ± 0.32

Following operational parameters were measured every 30 minutes during solar drying experiments:

- drying air temperature (°C) and drying air relative humidity (RH) (%) – Temperature - Humidity Logger S3121 (Comet System, Czech Republic)
- drying air velocity ($m \cdot s^{-1}$) - at the inlet part of the drier- Anemometer TA 888 (Greisinger, Germany)
- weight loss of samples of meat slices (gr) – Pioneer PA512 (Ohaus)
- ambient air temperature (°C) and ambient air RH (%) – Mini data logger 174H (Testo)
- global solar radiation ($W \cdot m^{-2}$) - pyranometer SL200 (KIMO instruments)

At the end of each drying test in the SD and LD the control samples were collected and dry matter content of each sample was estimated by the oven method at 105°C for 24 h. Equation (3.1) was used to estimate dry matter content on dry basis and equation (3.2) to estimate dry matter content on a wet basis (Belessiotis and Delyannis, 2011). The mean values were used for further calculations:

$$MCdb = water\ (kg) / dry\ meat\ (kg) \tag{3.1}$$

$$MCwb = water\ (kg) / water\ (kg) + dry\ meat\ (kg) \tag{3.2}$$

To predict the drying curves of meat, processed by both solar and laboratory drying, the measured moisture content is transformed into the moisture ratio (MR) as described in eq. (3.3), and simplified in eq. (3.4) (Rayaguru and Routray, 2012).

$$MR = M(t) - Me\ /\ Mi - Me \tag{3.3}$$

$$MR = Mt\ /\ Mi \tag{3.4}$$

Note: MR is the moisture ratio (decimal); M(t) is the moisture content at any time (% d.b.); Mi is the initial moisture content (% d.b.); Me is the equilibrium moisture content (% d.b.); t is the time (min);

3.4. Organoleptic properties and sensory analysis

Together 13 panellists were selected and trained. Each panellist evaluated the meat samples submitted on a paper tray designated by digit code. For evaluation was used the profile method and it has been used 100 mm unstructured graphic scale. Evaluated parameters see in Table 3.

Table 3. Parameters and orientation in sensory analysis

Parameter/Orientation	0	100
General look	Like	Dislike
Colour Intensity	Light	Dark
Colour Likableness	Like	Dislike
Odour intensity	Slightly intensive	Extremely intensive
Odour Likableness	Like	Dislike
Marinade Odour	Slightly intensive	Extremely intensive
Texture - Hardness	Very soft	Very hard
Texture - Masticability	Excellent	Very bad
Texture - Juiciness	Juicy	Dry
Texture - General	Excellent	Very bad
Taste - Likableness	Like	Dislike
Taste - Meat	Slightly intensive	Extremely intensive
Taste - Fatty	Slightly intensive	Extremely intensive
Overall acceptability	Like	Dislike

Five different meat samples were investigated during sensory analysis panel. Four samples were all cured in TM and then dried in ASD in two days (6.5 hours each day) – beef fried on the pan before drying, beef not fried on the pan before drying, buffalo fried on the pan before drying and buffalo not fried on the pan before drying. Fifth sample were dried beef meat obtained from local market (Hue, Vietnam).

Figure 12. One of the panellist

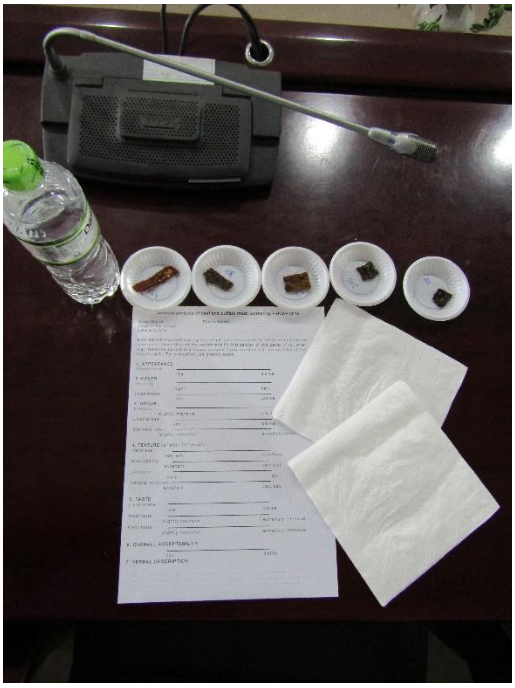

Figure 13. Samples and 100mm scale

The surface colour values of the jerky samples were measured with a spectrophotometer CM-2600d (MINOLTA) in the CIE L* a* b* colour space.

To evaluate the effect of different pre-treatments on the overall combined colour of dried meat, the index ΔE as given by the following equation (3.5), (Chua et al., 2000; Kashaninejad and Tabil, 2004) was calculated by taking the colour of the control sample (C) as the reference value.

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad \textbf{(3.5)}$$

3.5 Statistical analysis

Data were analysed with the STATISTICA software version 12.0 for analysis of variance of main (fixed) effects, as well as all interactions among fixed effects. As a standard test was chosen multifactorial ANOVA test and Tukey test was used as a post hoc test.

4. Results and Discussion

4.1. Physical characteristics of raw meat

Results of physical characteristics of raw meat are shown in Table 4. Warner-Bratzler shear force for buffalo meat was higher and statistically ($p < 0.05$) differ from beef. A higher WB shear force for buffalo meat in comparison with beef meat was already published by (Robertson et al., 2006). Buffalo meat was darker (lower value L = 31.07 ± 3.26, $p < 0.05$) and contained less redness (a = 14.83 ± 1.76) and less yellowness (b = 8.15 ± 0.97). These data are in accordance with a lighter colour found in beef compared to buffalo (Robertson et al., 2006) and compared to other meat (Koch et al., 1995; Rincker et al., 2006; Farouk et al., 2007). Dry matter content was almost the same for both samples of buffalo and beef, which agrees with the results reported in previous studies (Malek et al., 2009)

Table 4. Results of physical characteristics of raw meat.

Characteristic		Buffalo	Beef
Dry matter content (%)		24.42 ± 3.75	23.47 ± 2.12
Warner - Bratzler Shear force (N)		41.28 ± 15.92	28.95 ± 21.75
Colour	L	31.07 ± 3.26	34.06 ± 2.16
	a	14.83 ± 1.76	16.58 ± 2.05
	b	8.15 ± 0.97	8.71 ± 1.46

4.2. Evaluation of drying behaviour of beef and buffalo meat

As its clear from Table 2, climatic conditions were different during each day of drying. The values of mean ambient temperature, relative humidity and solar radiation during experiments were 41.03 ± 5.39 °C, 48.21 ± 12.67 % and 491.66 ± 352.97 $W.m^{-2}$, respectively. Further the values of mean drying air temperature, drying air relative humidity and mean drying air velocity during solar drying experiments were 43.60 ± 7.20 °C, 41.48 ± 12.11 % and 0.51 ± 0.37 $m.\ s^{-1}$, respectively. The ambient temperature, ambient RH and solar radiation curves during the typical solar drying experiment are presented in Figure 14, and the daily mean values of the drying chamber temperature, drying chamber RH and drying air velocity are presented in Figure 15.

From these figures, it is evident that high solar radiation corresponds to high drying temperature and low relative humidity of the drying air. The maximum solar radiation on the first day was 1199.00 $W.m^{-2}$, the second day 1093.40 $W.m^{-2}$. Ambient temperature varied during the whole experimental run between 30.72°C and 54.8°C, and ambient RH between 22.21 % and 82.35 %. Corresponding daily mean values of the drying air temperature and RH in the drying chamber of the ASD varied from 30.5 °C to 71.29 °C and 19.92 % to 71.2 %.

Obtained drying temperatures in the ASD were close to those recommended for the preparation of beef jerky (Faith et al., 1998; Allen et al., 2007). The daily mean values of drying air velocity varied from 0.00 to 1.56 $m.\ s^{-1}$. The relatively large difference between the maximum and minimum drying air velocities was due to the direct connection of the PV module (PV panel) with fans. The fans in the ASD were connected directly to a PV panel by parallel connection. No regulatory systems were required as the system regulates the air flow itself due to the position of the sun during the day. However, this disposition makes the airflow rate highly sensitive to actual insolation.

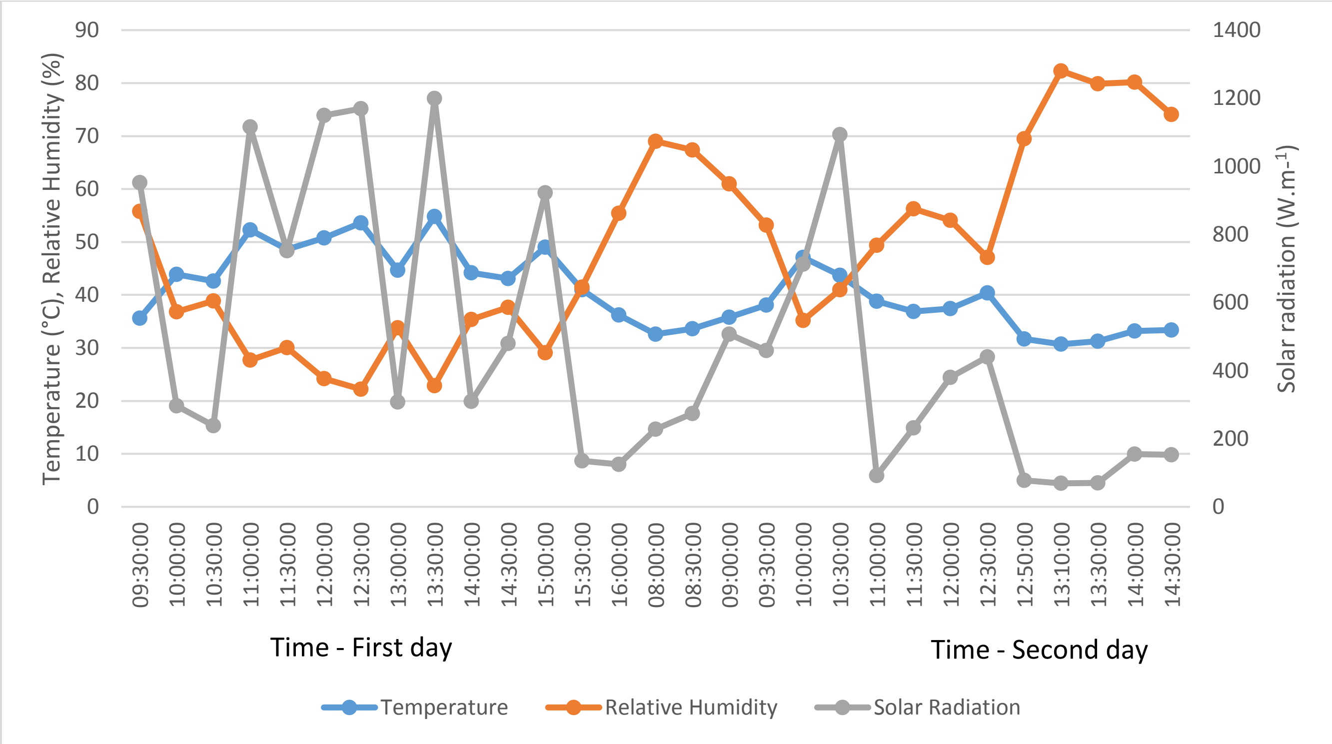

Figure 14. Ambient temperature, ambient relative humidity, and solar radiation.

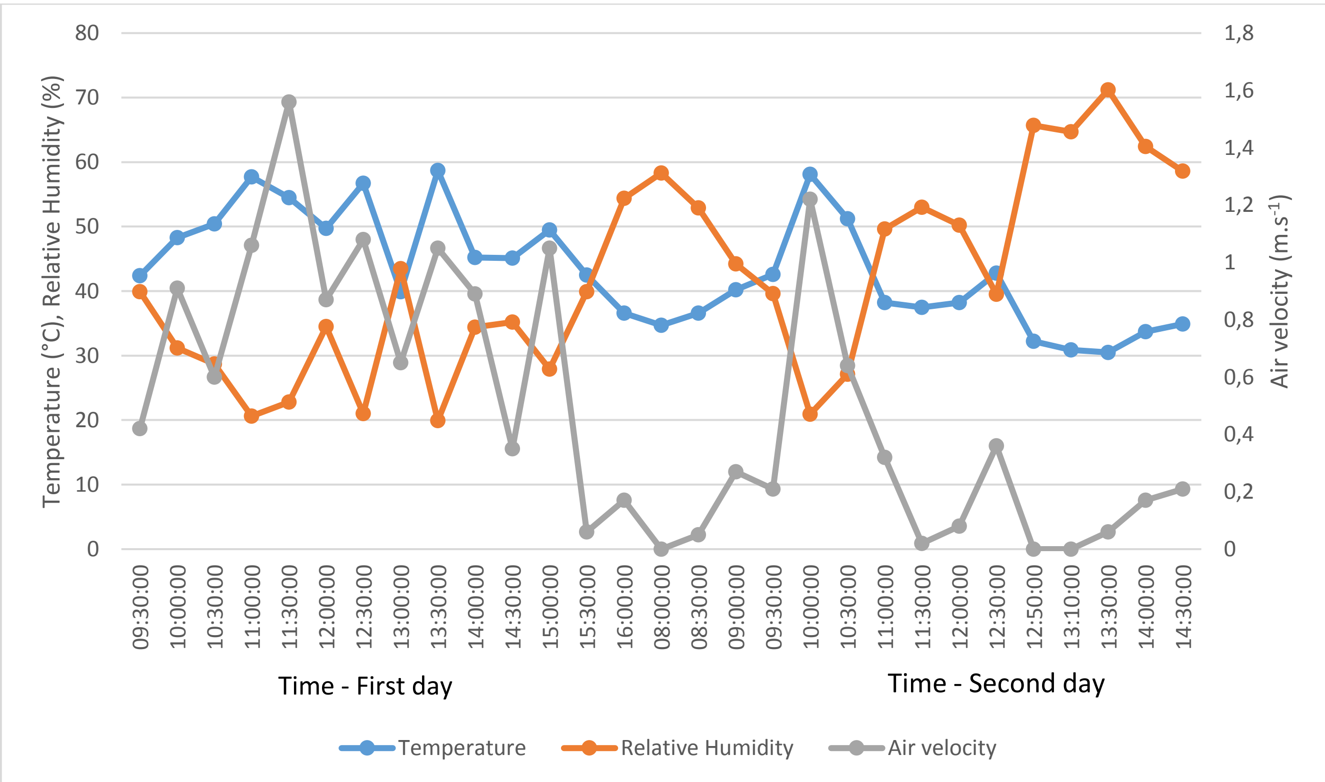

Figure 15. Drying chamber Temperature, drying chamber Relative Humidity and drying Air velocity.

The drying curves (MR with time) of the beef and buffalo samples with both pre-treatments (marinated, fried on the pan) dried in the ASD and LD are presented in Figures 16;17;18;19. The MR decreased exponentially with the time in both meat samples and all the used selected pre-treatments which is in agreement with the results reported in previous studies (Perea-Flores et al., 2012). Values of beef and buffalo MRs were analysed using t-test. There was no statistically significant difference (95% confidence level) between beef and buffalo meat MR dried in the ASD or between buffalo and beef meat dried in LO. From the statistical point of view, it is possible to conclude that the drying behaviour of buffalo and beef meat is the same, even though beef generally contains more lipids, which could affect the drying process (Faith et al., 1998).

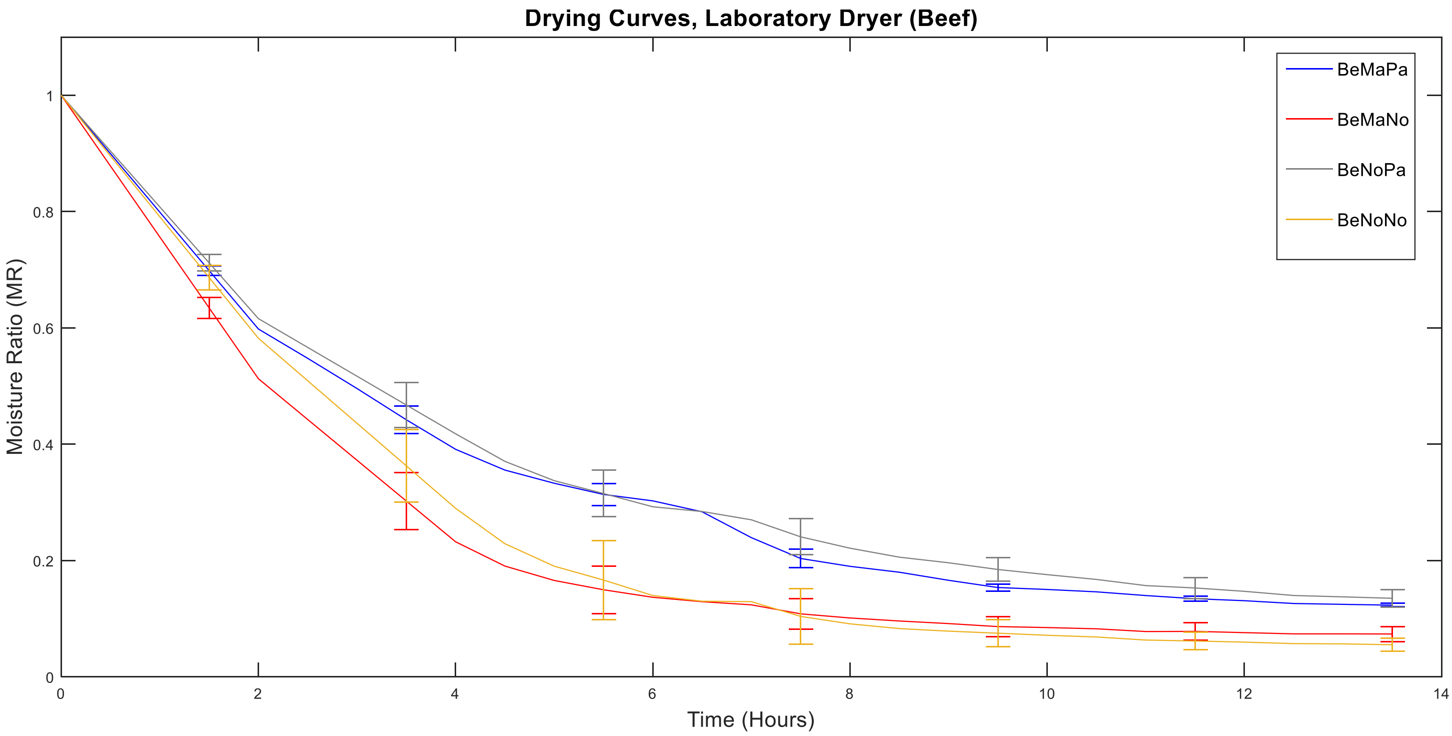

Figure 16. Drying curves of beef samples in laboratory dryer. (BeMaPa – beef samples, marinated and fried on the pan before drying; BeMaNo – beef samples, marinated and not fried on the pan before drying; BeNoPa – beef samples, not marinated and fried on the pan before drying; BeNoNo – beef samples, not marinated and not fried on the pan before drying).

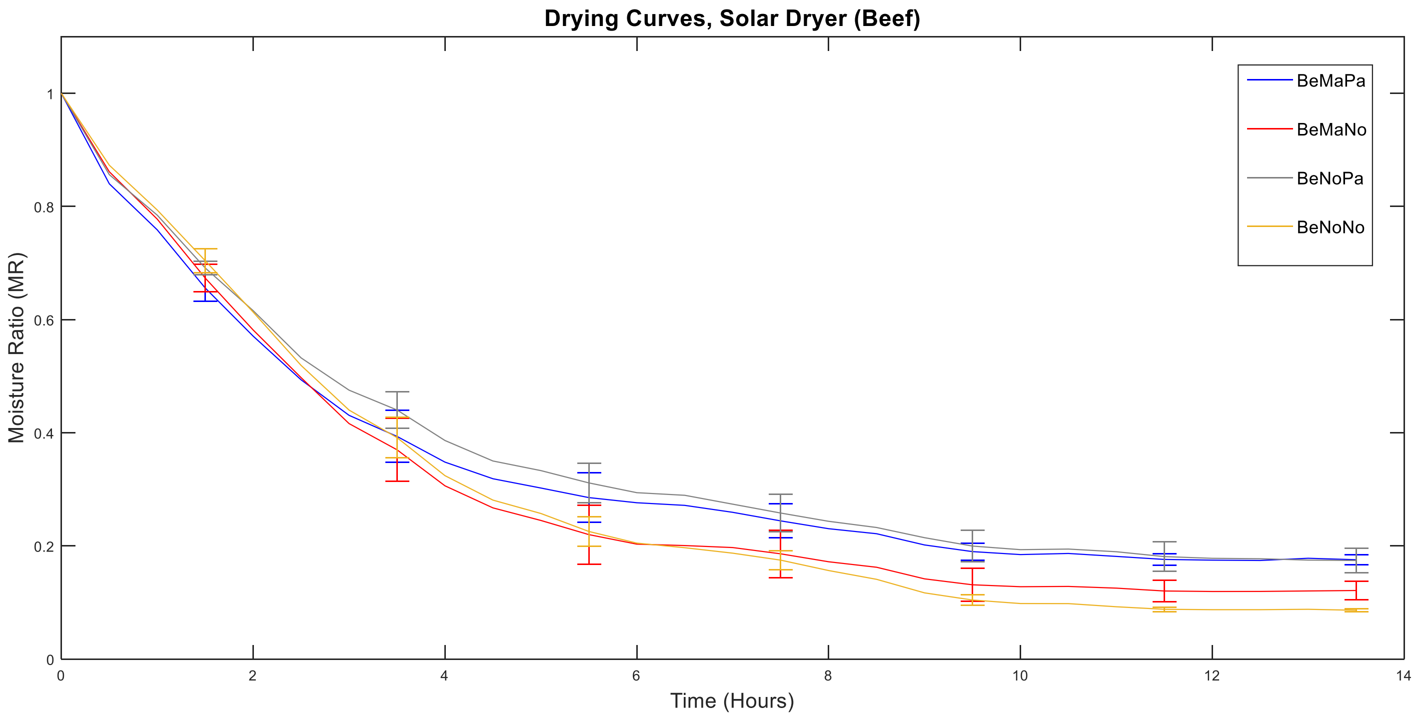

Figure 17. Drying curves of beef samples in solar dryer. (BeMaPa – beef samples, marinated and fried on the pan before drying; BeMaNo – beef samples, marinated and not fried on the pan before drying; BeNoPa – beef samples, not marinated and fried on the pan before drying; BeNoNo – beef samples, not marinated and not fried on the pan before drying).

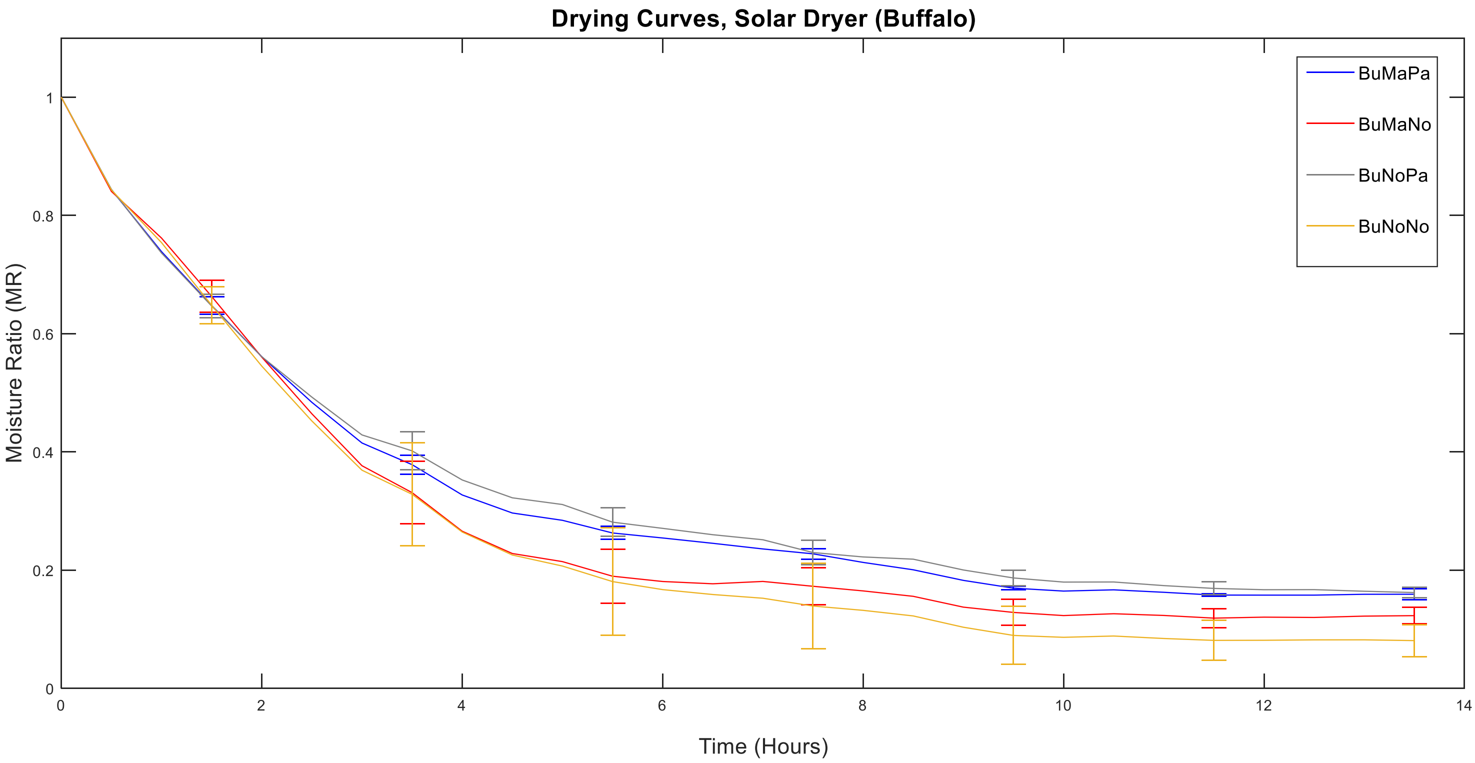

Figure 18. Drying curves of buffalo samples in solar dryer. (BuMaPa – buffalo samples, marinated and fried on the pan before drying; BuMaNo – buffalo samples, marinated and not fried on the pan before

drying; BuNoPa – buffalo samples, not marinated and fried on the pan before drying; BuNoNo – buffalo samples, not marinated and not fried on the pan before drying).

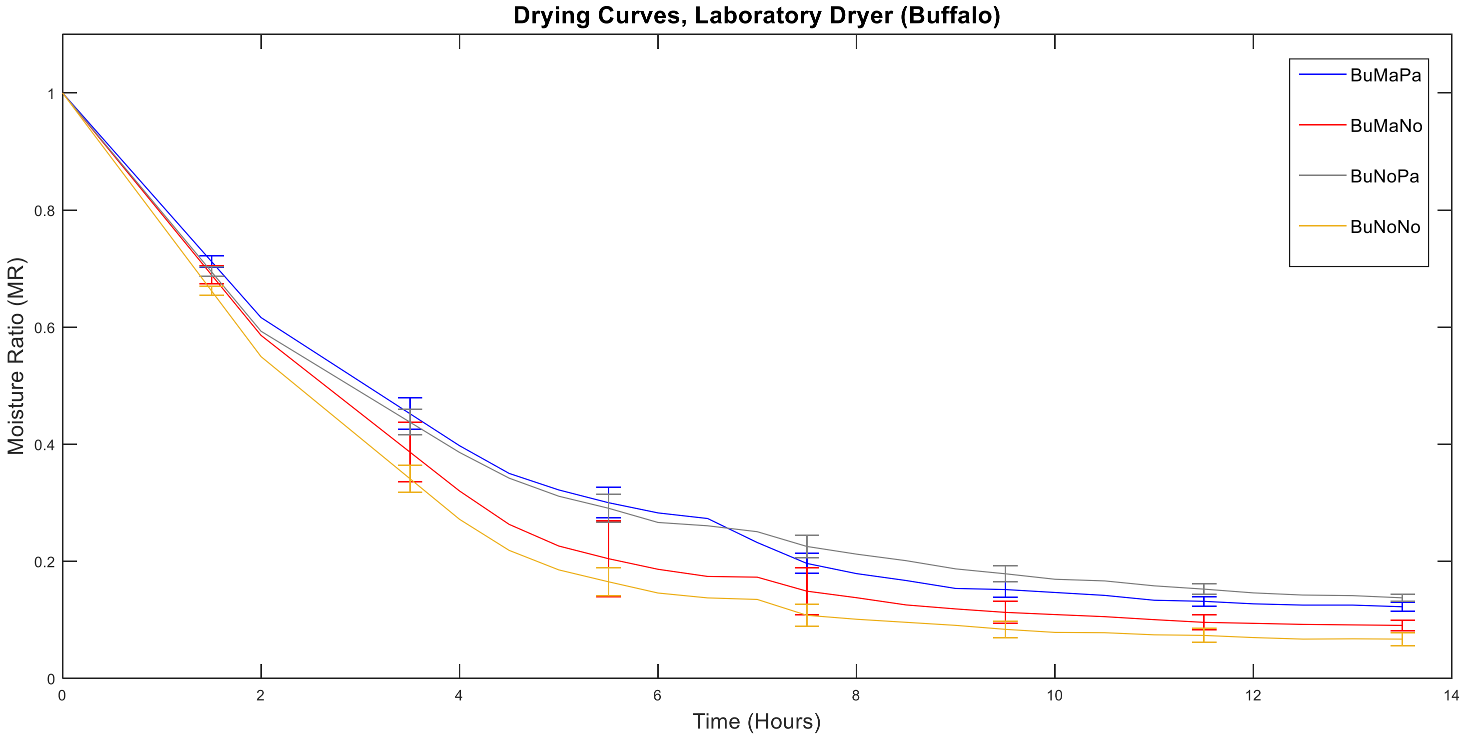

Figure 19. Drying curves of buffalo samples in laboratory dryer. (BuMaPa – buffalo samples, marinated and fried on the pan before drying; BuMaNo – buffalo samples, marinated and not fried on the pan before drying; BuNoPa – buffalo samples, not marinated and fried on the pan before drying; BuNoNo – buffalo samples, not marinated and not fried on the pan before drying).

Once the statistical analysis was carried out, it could be observed that the difference reflected on the graph is statistically significant only for the case of drying in laboratory dryer. This could be explained since at higher temperature and constant circumstances in the laboratory dryer, there are then ideal conditions for drying, which is resulting in higher differences between samples. The table can be seen below (see Table 5).

Table 5. ANOVA Factorial Statistical Test, Different Pre-treatments, Laboratory Oven

Pretratment	BeMaPa	BeMaNo	BeNoPa	BeNoNo
BeMaPa		**0.045600**	0.975321	0.203571
BeMaNo	**0.045600**		**0.037728**	0.991082
BeNoPa	0.975321	**0.037728**		0.081328
BeNoNo	0.203571	0.991082	0.081328	

BeMaPa – beef samples, marinated and fried on the pan before drying; BeMaNo – beef samples, marinated and not fried on the pan before drying; BeNoPa – beef samples, not marinated and fried on the pan before drying; BeNoNo – beef samples, not marinated and not fried on the pan before drying.

4.2. Influence of drying pre-treatments on drying kinetics

Curing the samples before drying in the Vietnamese traditional marinade slow down the drying, but the difference is not statistically ($p < 0.05$) significant.

From the results, it is clear that the drying rate was higher in the case of untreated control sample as compared with the marinated samples. This fact was confirmed by a multiple comparison procedure, which was used to analyse the influence of drying pre-treatments on the MR of dried buffalo meat. Data were tested with the Tukey test as the pairwise multiple comparison procedure with 95% confidence level.

These findings correspond to the results of similar studies where the effects of different methods of pre-treatments used before drying affected the final organoleptic properties, bacterial contamination, and drying behaviour (Albright et al., 2003; Bower et al., 2003; Calicioglu et al., 2003; Nummer et al., 2004; DiPersio et al., 2007).

Frying the samples in the oil on the pan before drying negatively affect the speed of drying in both, beef, and buffalo meat and in both dryers. As we can see in Figures 16;17;18;19 samples without frying treatment (BeMaNo, BeNoNo, BuMaNo, BuNoNo) were dried faster than fried samples in both dryers. It confirms, that oil slow down the length of drying. Similar effect was observed on the moisture movement during the drying of seedless grapes (Pangavhane et al., 1999) and on bell pepper (Tunde-Akintunde et al., 2011). This finding also correspond to the results of similar study, where the dipping the beef meat in the oil affected drying by making it slow probably due to the coating of the surface by wax-like oil (Claramount, 2016).

4.2. Influence of different dryer on drying kinetics

From Figures 16;17;18;19 it is also evident that the drying rate in the ASD was higher as compared to the LD mainly in the initial period of drying. This is due to higher maximum drying temperatures of first day in the solar drier as compared to the LD. Focusing on the overall progress of the drying curves of both meat samples and all pre-treatments we may observe higher drying rates at the initial stages of drying and decreasing drying rates at the latter stages of drying when the process entered the falling rate period. This is typical of all foods, including meats. In case of meat it could be caused by denatured proteins being subjected to heat during drying and therefore a gel matrix is formed, resulting in difficult movement of water from the interior part of the meat (Nathakaranakule et al., 2007). From the statistical point of view, it is possible to conclude that the drying behaviour of meat is the same in ASD and LD.

4.4. Sensory analysis and organoleptic properties

The results of the sensory panel are shown in Figure 20. This sensory panel aimed to investigate if different pre-treatments (curing and frying on the pan) and different kind of meat (beef and buffalo) can influence the results of sensory profile analysis. Comparison with dried beef meat obtained from local market (BM) were also analysed. Almost in all observed parameters the best results showed the BM. It could be explained as panellist can recognize the sensory properties of the sample, which originate from their local market. If we categorize the samples according to meat type, the beef meat showed much better result than buffalo meat.

Assessors could not distinguish differences in intensity of fatty taste, even if beef meat contained more fat, but they assessed the buffalo samples as juicier than the beef samples, which disagree with Ruiz-Carrascal et al. (2000), who pointed out that intramuscular fat plays a decisive role in most features of dry-cured products directly linked to their sensory characteristics, such as marbling and juiciness.

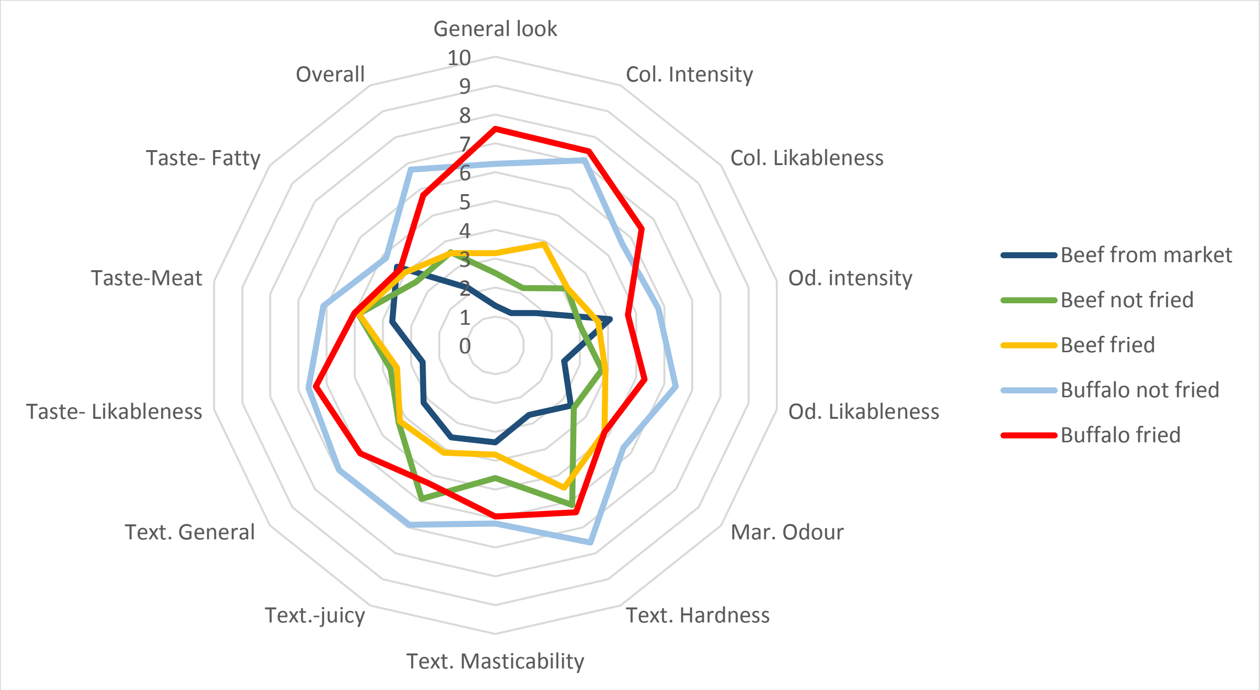

Figure 20. Spider diagram of sensory profiling of the dried samples in ASD (n=13).

5. Conclusion

Meat consumption is rapidly increasing not just in Vietnam, but in all countries. Meat plays important role in human diet, especially in countries, where one-component diet is common. Solar drying could be ideal method for meat preservation, that will suit in climatic conditions of central Vietnam.

Having no previous studies over the using of solar dryers for preparation traditional Vietnamese beef jerky, focusing the aim of the thesis on comparing solar dryer with laboratory dryer was a really innovating approach. With the help of two pre-treatments, different types of meat and the proper acquisition of the drying curves in combination with an accurate statistical analysis it has allowed not only to conclude interesting findings on the topic, but also has allowed us to provide a discussion for future researchers which are interested in the usage of solar dryer for drying meat.

For these reasons our conclusions were:

- It can be concluded, that the efficiency of drying in ASD is similar as in LD. It means, that ASD could substitute conventional drying in electric ovens and it could be suitable innovation for rural people, who still dry the meat on directly on the sun.

- Beef and buffalo meat showed similar behaviour during drying in both, ASD and LD. It was confirmed by having no statistically significant difference ($p>0.05$) between these two different types of meat.

- In contrast, statistically significant differences in drying behaviour were observed between samples without any treatment and samples, which were marinated. It can be concluded, that curing the samples in traditional marinade slow down the drying.

- It can be concluded, that frying the samples in the oil on the pan before drying negatively affected speed of drying in both, beef, and buffalo meat and also in both dryers. It is probably due to the coating the meat surface by wax-like oil which not allow water to evaporate faster.

- The best scored sample in sensory analysis was beef meat from local market (BM), followed by beef meat dried in ASD (BE) and buffalo meat dried in ASD (BU). Frying the samples before drying did not affect final organoleptic properties significantly

6. References

Allen K, Cornforth D, Whittier D, Vasavada M, Nummer B. 2007. Evaluation of high humidity and wet marinade methods for pasteurization of jerky. Journal of Food Science 72, C351-C355.

Albright SN, Kendall PA. Avens, J.S., Sofos, J.N., 2003. Pretreatment effect on inactivation of Escherichia coli O157:H7 inoculated beef jerky. LWT - Food Science and Technology 36, 381-389.

Akintunde TY, Akintunde BO and Fagbeja A. 2011.Effect of Blanching Methods on Drying Kinetics of Bell Pepper. African Journal of Food, Agriculture, Nutrition and Development. ISSN 1684 5374. Volume 11 N° 7.

Bal LM, Kar A, Satya S, Naik SN. 2010. Drying kinetics and effective moisture diffusivity of bamboo shoot slices undergoing microwave drying. International Journal of Food Science and Technology 45, 2321-2328.

Belessiotis V, Delyannis E. 2011. Solar drying. Solar Energy 85: 1665-1691.

Bender A. 1992. Meat and meat products in human nutrition in developing countries. FAO, Rome.

Bhushan I, Bloom E, Nguyen MT & Nguyen HH. 2001. Human Capital for the Poor in Vietnam. Manila: Asian Development Bank.

Bower CK, Schilke KF, Daeschel MA. 2003. Antimicrobial properties of raisins in beef jerky preservation. Journal of Food Science 68, 1484-1489.

Calicioglu M, Sofos JN, Samelis J, Kendal, PA, Smith GC. 2003. Effect of acid adaptation on inactivation of Salmonella during drying and storage of beef jerky treated with marinades. International Journal of Food Microbiology 89, 51.

Ruiz-Carrascal J, Ventanas J, Cava R, Andrés AI, García C. 2000. Texture and appearance of dry cured ham as affected by fat content and fatty acid composition. Food Research International 33, 9195.

Chadwick J. 1995. The Busy Persons Guide to Preserving Food: Easy Step-by-Step Instructions for Freezing, Drying, and Canning. Food preservation 3:224-232.

Chen XD, Mujumdar AS. 2008. Food drying fundamental. Drying Technologies in Food Processing: 1-52.

Chua KJ, Mujumdar AS, Chou SK, Hawlader MNA, Ho JC. 2000. Convective drying of banana, guava and potato pieces: Effect of cyclical variations of air temperature on drying kinetics and color change. Drying Technology 18, 907-936.

Claramount DA. 2016. Analysis of Influence of Essential Oil Blanching on Drying Kinetics of Dehydrated Meat. Diploma thesis.

Ciurzyńska A, Lenart A. 2011. Freeze drying: Application in Food Processing and Biotechnology. Pol. J. Food Nutr. Sci. 61: 171-174.

Collignan A, Santchurn, S, Zakhia-Rozis, N. 2008. Dehydratation of Muscle Food. In: Hui YH, Clary C, Farid MM, Fasina OO, Noomhorn A, Welti-Chanes J. (Eds.), Food Drying Science and Technology. DEStech Publications, USA.

De Guzman CC, Siemonsma JS. 1999. Plant Resources of South-East Asia. Leiden: Backhuys Publishers, 400p.

DiPersio PA, Kendall PA, Yoon Y, Sofos JN. 2007. Influence of modified blanching treatments on inactivation of Salmonella during drying and storage of carrot slices. Food Microbiology 24, 500-507.

Ekechukwu OV, Norton B. 1999. Review of solar-energy drying systems I: an overview of drying principles and theory. Energy Conversion and Management 40: 593–613.

Ezekwe CI. 1981. Crop drying with solar air heaters in tropical Nigeria, ISES, Solar World Forum: 997-1005.

Faith NG, Le Coutour NS, Alvarenga MB, Calicioglu M, Buege DR, Luchansky JB. 1998. Viability of Escherichia coli O157: H7 in ground and formed beef jerky prepared at levels of 5 and 20% fat and dried at 52, 57, 63, or 68 degrees C in a home-style dehydrator. Int J Food Microbiol. 41:213–21.

Farouk MM, Beggan M, Hurst S, Stuart A, Dobbie PM, Bekhit AED. 2007. Meat quality attributes of chilled venison and beef. Journal of Food Quality 30, 1023-1039.

Feiner G. 2006. Meat Products Handbook Practical Science and Technology. CRC Press.

Food and Agriculture Organization.2017. Country profile. Available at: http://www.fao.org/faostat/en/#country/237. Accessed 2017-01-14.

Food and Agriculture Organization. 2015. FAOSTAT database. Available at http://faostat.fao.org/default.aspx: Accessed 2017-04-14.

Food and Agriculture Organization of the United Nations, Vietnam Office. (FAO–VN) 1999. ENS–Nutrition Country Profile, Vietnam, 1999.

Glewwe P, Koch S, Nguyen BL. 2001. Child nutrition, economic growth, and the provision of health care services in Vietnam in the 1990s. Unpublished paper.

Grau R, Andres A, Barat JM. 2014. Principles of Drying, in Handbook of Fermented and Poultry (eds F. Toldrá, Y. H. Hui, I. Astiasarán, J. G. Sebranek and R. Talon), John Wiley & Sons, Ltd, Chichester, UK.

General Statistic Office of Vietnam, 2017. Available at: http://www.gso.gov.vn/Default_en.aspx?tabid=766: Accessed 2017-04-02

Heindl A. 2000. Solar drying of medicinal and aromatic plants. Zeitschrift fur Arznei- & Gewurzpflanzen 5: 80-88.

Heinz G, Hautzinger P. 2007. Meat Processing Technology. For Small to Medium-Scale Producers. Food and Agriculture Organization of the United Nations.

Higgs JD. 2000. The changing nature of red meat: 20 years of improving nutritional quality. Trends in Food Science & Technology 11, 85-95.

Hughes BR, Oates M. 2011. Performance investigation of a passive solar-assisted kiln in the United Kingdom, Solar Energy 85: 1488-1498.

Igene JO. 1988. Lipid, fatty acid composition and storage stability of kilishi, a sun dried meat product. Tropical Science 28, 153-161.

Imre L. 2007. Solar drying. Mujumdar AS editor. In Handbook of Industrial Drying. Florida:CRC Press, 1280p.

Imre L. 2007. Solar drying. Mujumdar AS editor. In Handbook of Industrial Drying. Florida:CRC Press, 307–361.

Jon CK, Kiang, CS. 2007. Food Dehydration and Developing Countries. Food Drying Science and Technology: 67.

Jones MJ, Tanya VN, Mbofiing MC, Fonkem DN, Silverside DE. 2001. A Microbiological and Nutritional Evaluation of the West African dried meat product, Kilishi. The Journal of Food Technology in Africa: 126-129.

Kashaninejad M, Tabil LG. 2004. Drying characteristics of purslane (Portulaca oleraceae L.). Drying Technology 22, 2183-2200.

Koch RM, Jung, HG, Crouse JD, Varel VH, Cundiff, LV. 1995. Growth, digestive capability, carcass and meat characteristics of Bison Bison, Bos- Taurus, and Bos x Bison. J. Anim. Sci. 73, 1271-1281.

Kudra T, Mujumdar AS. 2009. Advanced Drying Technologies. US: CRC Press, 483p.

Kuo JC, Ockerman, HW. 1985. Effect of salt, sugar and storage time on microbiological, chemical and sensory properties of chinese style dried pork. Journal of Food Science 50, 1384-1387.

Leon MA, Kumar S, Bhattacharya SC. 2002. A comprehensive procedure for performance evaluation of solar food dryers. Renewable and Sustainable Energy Reviews 6: 367-393.

Malek MA, Hossain MM, Islam R, Akhter S.2009. Methods of drying beef and buffalo meat on meat quality. The Bangladesh Veterinarian 26(1): 31 – 38.

Mujumdar AS. 2007. Handbook of industrial drying. US: CRC Press, 710p.

Murthy MVR. 2006. A review of new technologies, models and experimental investigations of solar driers. Renewable and Sustainable Energy Reviews 13: 835–844.

Nam KH, Jo Ch, Lee M. 2010. Meat products and consumption culture in the East. Meat Science.

Nathakaranakule A, Kraiwanichkul W, Soponronnarit S. 2007. Comparative study of different combined superheated-steam drying techniques for chicken meat. Journal of Food Engineering 80, 1023-1030.

Nummer BA, Harrison JA, Harrison MA., Kendall P, Sofos JN, Andress EL.2004. Effects of preparation methods on the microbiological safety of home-dried meat jerky. Journal of Food Protection 67, 2337-2341.

Pangavhane DR, Sawhney RL and PN Sarsavadia Effect of various dipping pretreatments on drying kinetics of Thompson seedless grapes. J. Food Eng.1999; 39: 211 – 216.

Passos ML, Ribeiro CP. 2009. Innovation in Food Engineering: New Techniques and Products. US: CRC Press, 747p.

Perea-Flores MJ, Garibay-Febles V, Chanona-Perez JJ, Calderon-Dominguez G, Mendez-Mendez JV, Palacios-Gonzalez E, Gutierrez-Lopez GF. 2012. Mathematical modelling of castor oil seeds (Ricinus communis) drying kinetics in fluidized bed at high temperatures. Ind. Crop. Prod. 38, 64-71.

Prvulovic S, Tolmac D. 2007. Convection drying in the food industry. International Commission of Agricultural Engineering: 1682-1130.

Rahman MS. 1999. Handbook of Food Preservation. New York: CRC Press, 1088p.

Rayaguru K, Routray W. 2012. Mathematical modelling of thin layer drying kinetics of stone apple slices. International Food Research Journal 19, 1503-1510.

Rincker PJ, Bechtel PJ, Finstadt G, Van Buuren RGC, Killefer J, McKeith FK. 2006. Similarities and differences in composition and selected sensory attributes of reindeer, caribou and beef. J. Muscle Foods 17, 65-78.

Robertson J, Bouton PE, Harris PV, Ratcliff D. 2006. A Comparison of Some Properties of Beef and Buffalo (Bubalus bubalis) Meat. Journal of Food Science 48(3): 686 – 690.

Sharma A, Chen CR, Lan NV. 2009. Solar-energy drying systems: A review, Renewable and Sustainable Energy Reviews 13: 1185-1210.

Silva FA, Kawanishi K, Varki A. 2016. Human risk of diseases associated with red meat intake. Molecular Aspects of Medicine, 18-24.

Simpson WT. 1987. Vacuum drying northern red oak. Forest products journal 37: 35-38.

Szulmayer W. 1991. From Sun-Drying to Solar Dehydration I and II. Food Technology in Australia: 440-501.

Van't Land CM. 1991. Industrial Drying Equipment: Selection and Application. New York: Marcel Dekker, 362p.

Visavale GL. 2012. Principles, Classification and Selection of Solar Dryers. Solar drying: Fundamentals, Applications and Innovations: 1-50.

Williams P. 2007. Nutritional composition of red meat. s4 The Role of Nutrition and Dietetics, 64: 113–119.

Wisconsin University (WISC) 2005, Principles of Food Preservation of Shelf-stable Dried Meat Products. Available at: http://meathaccp.wisc.edu/validation/assets/Principles%20for%20preservation.pdf Accessed on 2017-02-11

Weiss W, Buchinger J.2003. Solar drying: establishment of a production, sales and consulting infrastructure for solar thermal plants in Zimbabwe. Available at http://www.aeeintec.at/0uploads/dateien553.pdf: Accessed 2017-02-06.

World bank. 2017. World Bank Data. Available at: http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS/countries/1W-XL-ZF-4E-7EXJ-XQ?display=graph: Accessed 2017-02-10

World Bank 1999. Vietnam: Attacking Poverty. Washington, DC: World Bank Data. Available at: http://documents.worldbank.org/curated/en/929551468780565502/Viet-Nam-Development-report-2000-attacking-poverty-country-economic-memorandum. Accessed 2017-04-14.

ANNEX A.

Photo documentation of Experiments.

a. Marinating the samples

b. Samples after marinating.

c. Frying samples in the oil on the pan

d. Drying of samples in ASD.

e. Samples after drying in LD.

f. Samples after drying in ASD.