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Effect of Drying Pretreatments on Air and Solar Drying of Jerky Prepared from Eland *(Taurotragus oryx)* Meat.

DISSERTATION THESIS

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Declaration

I, Ing. Iva Kučerová, declare that this thesis, submitted in partial fulfillment of the requirements for the degree of Ph.D., in the Faculty of Tropical AgriSciences of the Czech University of Life Sciences Prague, I have elaborated independently, only with expert guidance of my thesis supervisor doc. Ing. Jan Banout, Ph.D.

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Abstract

Mathematical modeling of thin-layer solar drying and organoleptic properties of eland jerky was investigated in this study. Eland jerky was compared to the traditional beef jerky, inasmuch as both were treated with traditional jerky marinade (TM), TM with fresh pineapple juice (TMP), TM with honey (TMH), TM with Coca Cola (TMCCL) and compared to an untreated control (C). The influence of the marinades on the drying process was statistically significant. Based on the coefficient of determination, the root mean square errors and the chi-squares, the Two-term model was found to be the most suitable model for describing the solar drying kinetics of eland jerky. The mean effective moisture diffusivities of solar dried eland meat for the C and selected pre-treatments TM and TMH samples were 2.07 x 10^{-10}, 1.45 x 10^{-10} and 1.43 x 10^{-10} $m^2.s^{-1}$, respectively. The activation energy values for solar dried eland jerky were 23.75, 26.22 and 26.97 $kJ.mol^{-1}$ for C, TM and TMH, respectively. Organoleptic properties of dried eland meat were assessed by the 22 member degustation panel. The best scored pre-treatment was TMP, which has a significant effect on texture, color and taste. The effect of the different pre-treatments on the overall combined color (ΔE) was calculated. Generally for both meat dried in both driers TMH marinade was evaluated as the one with the highest total difference ΔE contrariwise meat dipped in TMP pre-treatment has the lowest total difference ΔE.

Key words: solar drier, drying kinetics, eland jerky, effective moisture diffusivity, organoleptic properties, CIE Lab

Abstrakt

Tato práce se zabývá matematickým modelováním sušícího procesu antilopího masa a jeho organoleptickými vlastnostmi. Sušené antilopí maso bylo následně porovnáváno s tradičním sušeným hovězím masem, známým jako jerky. Vzorky antilopího i hovězího masa byly marinovány v tradiční jerky marinádě (TM), v marinádě TM s čerstvou ananasovou šťávou (TMP), TM s medem (TMH) a TM s Coca Colou, k porovnání sloužil vzorek masa bez jakékoliv úpravy (C). Vliv jednotlivých marinád na sušící proces byl vyhodnocen jako statisticky průkazný. Two term model byl na základě koeficientu určení, střední kvadratické odchylky a chí-kvadrátu vybrán jako nejvhodnější model popisující kinetiku sušícího procesu antilopího masa v solární sušárně. Průměrné hodnoty difuzivity vlhkosti sušeného antilopího masa byly vypočítány pro vybrané vzorky C, TM, TMH následovně: 2.07 x 10^{-10}, 1.45 x 10^{-10} and 1.43 x 10^{-10} $m^2.s^{-1}$, kdy hodnoty aktivační energie pro vybrané vzorky C, TM a TMH byly následující 23.75, 26.22 and 26.97 $kJ.mol^{-1}$. Organoleptické vlastnosti sušeného antilopího masa byly hodnoceny v rámci degustačního panelu 22 hodnotiteli. Nejlépe byl hodnocený vzorek TMP, který měl statisticky průkazný vliv na texturu, barvu a chuť. Rovněž byl vyhodnocen vliv jednotlivých marinád na celkovou změnu barvy (ΔE). Největší vliv na celkovou změnu barvy měla marináda TMH oproti marinádě TMP, která byla vyhodnocena jako marináda s nejmenším vlivem na výslednou barvu po usušení. Stejné výsledky byly zaznamenány u hovězího i antilopího a to sušené v solární i v laboratorní sušárně.

Klíčová slova: solární sušárna, kinetika sušení, sušené antilopí maso, matematické modelování, 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 presumably one of the first systematic technological activities undertaken by human beings (Imre, 1997). 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. The fact that dried meat is no longer comparable to fresh meat in terms of appearance and sensory and processing properties, has to be weighed against the significant extension of the shelf-life. Under certain circumstances, in particular in the absence of refrigeration, these disadvantages have to be accepted, particularly where the alternative might be loss of the valuable meat by spoilage. Most nutritional properties of meat, in particular the protein content, remain unchanged through drying (Heinz and Hautzinger, 2007). Pioneer American settlers described the dried meat as "jerky", derived from the Spanish word ''charqui'' (Nummer *et al.*, 2004). Dried meats are traditional in different parts of the world and they are known as ''cecina'' in Spain, ''biltong'' in South Africa and ''bresaola'' in Italy (Hierro *et al.*, 2004). Nowadays, jerky is more of a convenient snack food with a great variety of products where safe preservation, flavor, and texture are important. A sale increase of this type of snack food in USA from 631.6 million dollars in 1994 to almost 2.7 billion dollars in 2004 and at the same time it is estimated that 39% American families regularly buy meat snack foods (Konieczny *et al.*, 2007). The popularity and importance of dried meat is not unique just in USA. For instance, in developing countries the consumption of dried meat corresponding to total meat consumption, which has been continuously increasing from a modest average annual per capita consumption of 10 kg in the 1960s to 26 kg in 2000 and will reach 37 kg around the year 2030 according to FAO projections. This forecast suggests that in a few decades, developing countries consumption of meat will move towards that of developed countries where meat consumption remains stagnant at a high level (Heinz and Hautzinger, 2007).

The simplest method to make jerky is to cut meat into strips and dry it. More typically, spices or marinades are used to flavor the meat, and curing or smoking might be used in combination with drying to make jerky (Nummer *et al.*, 2004). According to the U.S. Department of Agriculture a jerky is classified as a heat-treated and shelf-stable ready-to-eat meat product. A moisture-to-protein ratio (M/Pr) of jerky is ≤ 0.75:1 and can be made from sliced (i.e. whole-muscle jerky) or ground (i.e. re-structured or formed jerky) portions of usually lean beef, pork, fish, chicken, turkey, and/or venison (USDA, 2004).

Even that a jerky can be made from different animal species more than 70% of jerky is produced from beef meat. But nowadays consumers are increasingly becoming concerned about healthy and safe products and the demand for these products is escalating. Relating to some studies a game meat and venison meets most of the criteria demanded by a discerning consumer (Hoffman and Wiklund, 2006). In general a game meat has very low lipid concentrations in muscles. Moreover, these lipids are primarily structural lipids with little contribution from triglycerides having a very desirable fatty acid profile. The average fat content of most game species has been recorded to be less than 3 % (Hoffman and Wiklund, 2006). One of the perspective venison and/or game animals is eland (*Taurotragus oryx*). The domestication of eland in Africa for farm production was recommended by FAO (Scherf, 2000). Nowadays the biggest herds of farmed eland might be found in South Africa, however the total number of farms is less than five (Hoffman and Wiklund, 2006). The oldest eland farming in temperate zones is in Askanija Nova (Ukraine) where they start with the domestication in 1892 (Treus and Kravchenko, 1968). Since 2001 there is one experimental herd of domesticated elands on the school farm of the Czech University of Life Sciences Prague (CULS Prague) in Lány (Czech Republic) (Kotrba and Ščevlíková, 2002). The eland is the largest kind of antelope comparable to the domestic ox not only in size but also in its placid nature. Its meat is comparable to beef. Further, the eland meat has a lower content of intramuscular fat and total fat content is on average around 2.4 % (La Chevallerie *et al.*, 1971). This fact is important from the meat drying point of view, hence higher fat contents in meat decreasing the drying rate. Faith *et al.* (1998) reported, that there is a positive correlation between fat content in dried meat and presence of pathogens where higher fat content meaning higher possibility of pathogen evolution. From the healthiness point of view the fatty acid composition of meat, particularly the ratio of polyunsaturated fatty acids to saturated fatty acids (P:S), is more important for health reasons than the total fat content. Wood *et al.* (2004) mentioned a recommended P: S value of no less than 0:4, and further noted that the normal P: S ratio of meat is around 0: 1. According to Hoffman and Wiklund (2006) the fatty acid profiles of the game species, including eland all had P: S ratios above 0:4. Finally a game meat was not at associated with BSE. Above mentioned facts makes eland meat perspective source of human nutrition as well as alternative product to traditional beef even in dried form.

Today there is a lack of any detailed research and information in scientific literature on drying behavior and drying pretreatments of jerky prepared from eland meat. Further, in case of eland meat drying it is also reasonable to investigate the solar drying processes mainly because the dried meat is one of very potential and important part of the diet for people in rural areas of developing countries where the connection to the electricity grid is either unavailable. Advantages of solar driers that enable them to compete with traditional open-to-sun drying techniques and/or conventional driers powered by energy from fossil fuels have been previously reported in the literature by many researchers (Karathanos and Belessiotis, 1997a; Bala *et al.*, 2003; Hossain and Bala, 2007). Thus, an investigation of the influence of different drying pretreatments on solar drying behavior during eland meat processing may be useful, justifiable and finally will bring new information about important preservation techniques relating to jerky production.

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1 INTRODUCTION

1.1 Role of meat in human diet

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). The livestock production is growing rapidly, which is interpreted to be the result of the increasing demand for animal products. Since 1960, global meat production has more than trebled. This is attributed partly to the rise in population, as well as to the increase in affluence in many countries. Delgado *et al.* (1999) suggested that global production and consumption of meat will continue to rise, from 233 million metric tons (Mt) in the year 2000 to 300 million Mt in 2020. The types of meat commonly consumed in different countries are dependent on eating habits and the ability to rear the animals successfully, which is influenced by local climate, geography, and economy. Sheep and goat meat are more popular in developing countries, while native llama, buffalo, and antelope are important parts of the local ecosystems in many areas, especially Bolivia, Peru, Ecuador, Asia, and Africa. Beef, lamb, pork, and chicken are the major meats (Higgs and Pratt, 2003).

Red meat and poultry contribute about a sixth of all protein consumed by humans and, if fish, milk and eggs are included, animal products supply a third. Not only is meat a very concentrated source of protein, but this has a high biological value because its composition matches closely that of our own proteins. It contains all the amino acids essential for human health. Meat is also an important source of the B vitamins, particularly B1 (thiamine), niacin (nicotinic acid), B2 (riboflavin), B6 and B12 (cyan cobalamin), and vitamin A (retinol). It is a major source of iron, copper, zinc and selenium. Iron in meat has high bioavailability, the main reservoir being as a component of the haem protein myoglobin. Iron deficiency is the most common nutritional deficiency in the world (Neale, 1992). Even that meat is a concentrated nutrient source, previously considered essential to optimal human growth and development (Higgs, 2000), frequently is as well associated with a ‘‘negative’’ health image due to its ‘‘high’’ fat content and in the case of red meat is seen as a cancer-promoting food. Therefore a low meat intake, especially red meat is recommended to avoid the risk of cancer, obesity and metabolic syndrome (Biesalski, 2005).

Table 1.1 Nutritional composition of several meat cuts (INSRJ, 2006).

Meat cut	Energy value (kcal)	Protein (g)	Fat (g)	Saturated fat (g)	Vitamin B12 (mcg)	Na (mg)	P (mg)	Fe (mg)	Zn (mg)
Chicken breast, skinless, raw	108	24.1	1.2	0.3	0.37	60	220	0.5	0.8
Chicken breast, raw	176	24.1	8.9	2.1	0.37	72	200	1	0.8
Chicken, average, raw	110	22.9	2	0.5	0.72	77	204	0.9	1
Beef, stak cuts, raw	122	20.9	4.3	1.8	2	60	169	1.4	3.6
Beef, loin, raw	114	21	3.3	1.4	2	60	145	1.5	3.6
Beef, calf, loin, raw	148	19.9	7.6	3.2	1.2	24	195	0.9	3
Pork, loin, raw	131	22.2	4.7	1.6	1	53	221	0.6	1.6
Pork, chop, raw	355	17.3	31.8	10.9	1	61	189	1.3	1.7
Pork, leg, raw	152	21	7.5	2.6	1	86	167	0.7	2.7
Turkey, breast, skinless, raw	105	23.4	1.3	0.3	1	63	210	0.7	0.6
Turkey, average, skinless, raw	137	20.5	6.1	2	2	49	210	2	1.6
Duck meat, average, skinless, raw	133	19.3	6.2	1.6	3	92	202	2.4	1.9
Mutton, chop or meat, raw	124	19.7	5	2.2	2	64	220	1.7	3.8

From the historic point of view, humans appear to be adapted to an omnivorous diet, based on the shape of their teeth and their unspecialized gut, and it is likely that quite early in human evolution meat began to play a part in our diet. Originally this would have been scavenged from the kills of more effective predators, such as the large cats, until hunting techniques developed. The domestication of animals and the development of animal husbandry ensured a more reliable source of meat and coincidentally reduced the number of species from which it was obtained to about two dozen or so, of which half are now significant sources of meat. These include not only mammals such as cattle, sheep, goats, pigs, buffaloes, camels, yaks, llamas, deer and rabbits but also birds, especially domestic fowls and turkeys, geese and ducks, reptiles such as alligators, fish and various invertebrates. Currently there is also considerable interest in using various new species for meat production (Kyle, 1994) including several antelopes, the American bison and the ostrich (Warriss, 2000). In industrialized countries, there have been slow but continuous changes over the years in the relative amounts of different types of meat consumed (beef, pork, lamb, poultry) depending partly on price and influenced by fashion, advertising, etc. In more recent years health aspects, more correctly, perceived health aspects, have become a factor (Bender, 1992).

1.1.1 Role of game meat

There is substantial evidence from both the archaeological and ethnographic literature to show that consumption of wild animal tissues played a predominant role in the diet of early humans (Marean and Assefa, 1999; Milton, 1999; Stanford and Bunn, 1999) as well as in historically studied hunter-gatherers (Cordain *et al.*, 2000).

Around the world, meat from all game animals is referred to as venison. It is, however, advisable that South Africa should distinguish game meat from venison, as game animals produced for meat in Australia, New Zeeland, Europe and America are increasingly being replaced by domesticated and farmed animals, whereas African game meat originates from wild, free-running animals (Hoffman and Wiklund, 2006).

There is potential in currently unexploited indigenous animals as sources of meat. Wild animals supplement domestic meat supplies in many parts of the world and there would appear to be considerable potential in developing these animals as managed meat producers. They are already adapted to local environments and so have advantages over imported stock and they appear to be resistant to many diseases that affect domestic livestock. Developments of this kind have already taken place in many countries, illustrating this potential e.g. the farming of red deer in Scotland, hybrid deer in New Zealand (Ainger, 1991), bison and water buffalo in other areas. Giraffe, elephant, hippopotamus, antelope, rhinoceros and possum can be added to the list; game reserves could be exploited as managed sources of meat (Bender, 1992).

Consumer demands high quality, convenient, innovative, regular and safe meat products with natural flavor and taste and an extended shelf-life and the demand for these products is escalating. Moreover, less salty, less acidified and less chemical preserved products are required (Aymerich *et al.*, 2008). Relating to some studies a game meat and venison meets most of the criteria demanded by a discerning consumer (Hoffman and Wiklund, 2006). In general a game meat has very low lipid concentrations in muscles. Moreover, these lipids are primarily structural lipids with little contribution from triglycerides having a very desirable fatty acid profile. The average fat content of most game species has been recorded to be less than 3 % (Hoffman and Wiklund, 2006). One of the perspective venison and/or game animals is eland (*Taurotragus oryx*) (Hoffman and Cawthorn, 2013).

1.1.2 Eland (*Taurotragus oryx*)

One of the perspective venison and/or game animals is eland (*Taurotragus oryx*), see Figure 1.1. The domestication of eland in Africa for farm production was recommended by FAO (Scherf, 2000). Nowadays the biggest herds of farmed eland might be found in South Africa, however the total number of farms is less than five (Hoffman and Wiklund, 2006). The oldest eland farming in temperate zones is in Askanija Nova (Ukraine) where they start with the domestication in 1892 (Treus and Kravchenko, 1968). Since 2001 there is one experimental herd of domesticated elands on the school farm of the Czech University of Life Sciences Prague (CULS Prague) in Lány (Czech Republic) (Kotrba and Ščevlíková, 2002).

Figure 1.1 Eland (*Taurotragus oryx*) (Klimes, 2015)

The eland is the second largest African antelope. Males are larger than females (Underwood, 1981). Shoulder height averages 163 cm for males and 142 cm for females. Body mass averages 500–600 kg for males and 340–445 kg for females (Estes, 1991). Pelage color varies from dark gray brown to reddish brown (Hillman, 1974) with 2–15 transverse white stripes, which are more distinct anteriorly (Halternorth and Diller, 1980). Both sexes have a dewlap (Kingdon, 1997) and spiraled horns, but the horns of males are shorter and thicker (Estes, 1991). Eland live throughout ca. one-third of Africa.

The northern limit of their range cuts northeast through Angola and southern Zaire and then north to include Tanzania, Kenya, and southern Somalia. Populations occurring in the southern tip of the continent, including parts of South Africa, Botswana, and Namibia, are primarily reintroduced, whereas northern populations are native (Skinner and Smithers, 1990; Estes, 1993)

The eland reproduces yearly (Jeffery, 1979) Sexual maturity in females is approximately. 2.5 years of age and in males are approximately. 4 years of age (Hall, 1975; Hosking and Withers, 1996). Although eland can reproduce at any time of the year, they have peak breeding and calving seasons. Peak calving months are between August and November (Posselt, 1963; Jeffery, 1979), and calving usually peaks during the wet season, when is enough of food.

The eland is comparable to the domestic ox not only in size but also in its placid nature(La Chevallerie *et al.*, 1971). Compared to Hereford cattle, the eland has a high metabolic rate for their size (Taylor and Lyman, 1967). Milk is high in fat, and fat content ranges from 11% to 17.3% 5 days postpartum (Posselt, 1963). Its meat is comparable to beef. Further, the eland meat has a lower content of intramuscular fat and total fat content is on average around 2.4 % (La Chevallerie *et al.*, 1971). This fact is important from the meat drying point of view, hence higher fat contents in meat decreasing the drying rate. Faith *et al.* (1998) reported, that there is a positive correlation between fat content in dried meat and presence of pathogens where higher fat content meaning higher possibility of pathogen evolution. From the healthiness point of view the fatty acid composition of meat, particularly the ratio of polyunsaturated fatty acids to saturated fatty acids (P:S), is more important for health reasons than the total fat content. Wood *et al.* (2004) mentioned as recommended P: S value of no less than 0:4, and further noted that the normal P: S ratio of meat is around 0:1. According to Hoffman and Wiklund (2006) the fatty acid profiles of the game species, including eland all had P: S ratios above 0:4. Finally a game meat was not at associated with BSE. Above mentioned facts makes eland meat perspective source of human nutrition as well as alternative product to traditional beef even in dried form.

1.1.3 Specific condition in tropics

Agricultural progress in most developing countries has mainly involved an increase in the production of staple crops and the introduction of industrial crops. New varieties, improved farming techniques, greater use of fertilizers, irrigation and chemical control of pests have resulted in considerable increases in production, sufficient, in the absence of climatic disasters, to meet domestic needs in many countries and even, in some instances, to provide a surplus for export. On the other hand developments in livestock production have lagged far behind. Although there has been an increase over the years in the amount of meat available in developing countries the quantities are small (Bender, 1992). Meat consumption per capita in developing countries is considerably lower than that in the developed world. In 2012, average consumption in developing countries was 32.7kg/head per year and 79kg/head per year in developed countries (FAO, 2012). However, in developing countries livestock is not only valued for their contribution to human food, they have additional roles to play through the provision of draught power and manure, and in contributing to the livelihoods of rural people. Demand for meat in developing countries is rising rapidly as the result of population growth and also the trend for people to move from villages to the cities (Gill, 1999).

Meat consumption is based largely on availability, price and tradition. Meat production is a very complex operation depending not only on demand (which is usually based on price and income) but on many social and economic influences. The amount of meat consumed in different countries varies enormously with social, economic and political influences, religious beliefs and geographical differences. Because provides a relatively rich source of well absorbed iron and also improves the absorption of iron from other foods, its amino acid composition complements that of many plant foods, and it is a concentrated source of B vitamins, including vitamin B12, which is almost absent from plant foods, there is pressure to increase the availability of meat products (Bender, 1992). In other hand in developing countries much more dietary energy (80%) comes from carbohydrates than in developed countries (55%). The difference in energy from carbohydrates is made up by increased fat (meat) consumption. The diets of developing countries are therefore a lot less energy-dense with much higher levels of fiber. Energy-dense diets that are low in fiber tend to be associated with various chronic diseases amongst which are coronary heart disease, cerebrovascular disease and various cancers (Warriss, 2000).

Meat is a rich nutrient matrix that provides a suitable environment for proliferation of meat spoilage microorganisms and common food-borne pathogens, therefore adequate preservation technologies must be applied in order to preserve its safety and quality (Aymerich *et al.*, 2008). But this presents one of the biggest problems in many areas of developing countries due to electricity shortages. Lack of cooling systems and other preservation techniques results in considerable losses and can affect public health (Bender, 1992). For this reason drying is only possible technique. The consumption of dried meat corresponding to total meat consumption, which has been continuously increasing from a modest average annual per capita consumption of 10 kg in the 1960s to 26 kg in 2000 and will reach 37 kg around the year 2030 according to FAO projections. This forecast suggests that in a few decades, developing countries consumption of meat will move towards that of developed countries where meat consumption remain stagnant at a high level (Heinz and Hautzinger, 2007).

1.2 Meat drying

The perishable nature of the meat and the demands of growing world population have led to the development of a large meat processing industry, which is considerable economic importance today (Collignan *et al.*, 2008). Processed meat represents 30% of total meat production in the US, while cured, dried, smoked and cooked products account for 15% of this production (Pearson and Gillett, 1999). In Europe, the dried meat (mainly dried pork) represents 10% of total pork production, where beef production is very marginal with 0,06% of the total production (OFIVAL, 2004). However, no data are currently available on the production of dried meat products and their status on the world market. This could partially be explained by the fact that many of traditional products, especially from developing countries have not yet been properly identified and characterized, and these products are generally produced to meet very localized domestic demands (Collignan *et al.*, 2008).

Meat drying is not a clearly defined technology. Drying may be made for the single purpose of dehydrating fresh meat for extension of storage, but it may also be one of various processing steps during the manufacture of specific meat products. The manufacture of fermented meat products, such as raw hams or dry sausages, is an example, where drying is one processing component amongst several others. To have an extended shelf life, fermented products need to lose moisture during their fermentation, they are dehydrated or “dried” to a certain extend. Besides, such more complex drying techniques, the simple dehydration or drying of lean meat under natural conditions have been practiced for centuries (Heinz and Hautzinger, 2007). Meat dehydration was used in ancient times when primitive humans preserved game meat by sun-drying. Ancient Egyptians preserved meat products by salting and sun-drying, and first more elaborate dry cured ham appeared a few centuries BC (Collignan *et al.*, 2008). It is still a popular method in many developing countries, in particular where no cold chain is available. It is predominantly carried out for meat preservation, based on the experience that dehydrated meat will not spoil easily (Heinz and Hautzinger, 2007). See Figure 1.2 and Figure 1.3 where two methods of sun drying are shown.

Figure 1.2 Sun drying by suspension practiced in a rural setting (Heinz and Hautzinger, 2007).

Figure 1.3 Sun drying by exposing flat meat pieces on drying trays (Heinz and Hautzinger, 2007).

Dried meats are temperature stable products with moisture content around the equilibrium moisture content of the meat mixture at ambient temperature and humidity. The products can be consumed as they are without rehydration, having a desirable texture without brittleness or over dryness (Chang *et al.*, 1996). Meat drying is a simple but efficient food preservation activity. In the drying process, the ultimate water activity (aw) approaches 0.60 to 0.90, which is equivalent to a relative humidity (RH) of 60-90% at ambient temperature (Leistner, 1987). Due to the low water content, microbial spoilage of the muscle proteins can be safely prevented and can be stored under ambient temperature for many months (Heinz and Hautzinger, 2007).

According to Heinz and Hautzinger (2007), is advisable to use lean meat only, because deterioration of adhering fatty tissue through rancidity cannot be stopped. From this point of view beef and buffalo meat as well as goat and certain game meats (deer, antelopes) are best suited. The same applies to meat of livestock used in some regions for meat production, such as camels or yaks. The suitability of mutton is ranked slightly lower. Pork is less suitable, as it contains higher amounts of intermuscular and mostly invisible intramuscular fat, which is prone to oxidation and hence turns quickly rancid.

1.2.1 Dried meat products

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). Table 1.2 shows popular salted dried meat products in developing countries.

Table 1.2 Salted dried meats in developing countries.

Meat product and type	Origin	a_w	Salt content % (wb)	References
Kilishi	Sahel African countries	0.65	8.8	(Egbunike and Okubanjo, 1999)
Biltong	South Africa	0.77	5	(Prior, 1984)
Unam inung	Nigeria		2-2.9	(Solomon *et al.*, 1994)
Kaddid	Morocco	0.54	10	(Bennani *et al.*, 1995)
Kundi	Nigeria	0.82	0.5	(Alonge, 1987)
Carne do sol	Brazil	0.94	5-6	(FAO, 1985)
Charque (Charqui)	Brazil	0.87-0.9	12-15	(FAO, 1985)
Pastirma (Basturma)	East Mediterranean	0.85-0.9	5	(Leistner and Gould, 2002)
Tasajo	Cuba	0.75	22	(Radic, 1990)
Chinese dried pork	Taiwan, China	0.4-0.66	3.6-4.6	(Leistner, 1985)

1.2.1.1 Air dried meats

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 pretreated by brining or soaking in salt or sugar solution (Collignan *et al.*, 2008).

Kilishi is widely consumed in Sahel African countries and is highly valued in both rural and urban areas of Niger. Traditionally it is made from the rump or shoulder of beef, goat, sheep or camel meat (Igene, 1988; Igene *et al.*, 1990). Meat is cut into strips (3-4 mm thick, 0.5- 1m long) and are dried in the sun on raised beds of millet straw on tables for 4-7h. Strips are periodically turned and after drying are coated with sauce and grilled over wood fire for 5-10min. The brown to black color and the brittleness are the criteria used for whether the meat is sufficiently dry (Kalilou and Zakhia, 1999).

Figure 1.4 Kilishi drying (Okafor, 2010).

The processing of quitab (in Sahel African countries) (Laurent, 1981) and sharmoot (typical in Chad and Sudan) (Varnam and Sutherland, 1995) is similar to that kilishi but those dried meats are not subsequently coated or grilled. The sharmoot is often ground into a powder and both are rehydrated and incorporated into local (Collignan *et al.*, 2008). In the Philippines, a shelf-stable dried meat is made from fresh uncooked lean beef meat, sliced into 3-4mm thickness, salted and sun dried on bamboo slatted trays to 10-12% moisture. To eat is fried in oil (Arganosa and Ockerman, 1987).

1.2.1.2 Intermediate moisture meat

Intermediate moisture meat processing, based on the hurdle technology concept (Leistner, 1985), involves the combination of dehydration and other stabilization techniques. These meats are generally either dry salted or wet salted (immersion in brine solution, eventually other additives) before drying. Complementary techniques such as smoking, frying, cooking or fermentation should be applied too (Collignan *et al.*, 2008).

Salted dried meats

Biltong is a well-known salted, dried meat originating from Southern Africa made from beef or antelope meat (Heinz and Hautzinger, 2007). It is usually made from long strips of beef muscle, which is commonly cured by dry salt, although sugar and spices (pepper, coriander, anise, garlic and other) are often added for improving flavor and taste. Nitrite or nitrate may be used to stabilize the color of biltong. South African regulations allow the addition of 0.1% potassium sorbate to prevent mold growth (Chang *et al.*, 1996; Heinz and Hautzinger, 2007). Salted strips are then transferred to a suitable container for further curing for several hours (maximum 12hr). The meat pieces are then dipped into a mixture of hot water and vinegar to prevent mold growth, but it also adds flavor to the product. After is sun dried for one day and then the rest of drying is in the shade. The biltong is ready when the inside is soft, moist and red in color, with a hard brown outer layer. The usual shelf-life is several months without refrigeration and packaging. In airtight packages the product can be stored for more than one year. Biltong is not heated during processing or before its consumption (Heinz and Hautzinger, 2007).

Figure 1.5 Biltong (Heinz and Hautzinger, 2007)

Unam inung is ready-to-eat (RTE) cured pork product popular in Nigeria. The meat is prepared by heavily salting of slices, which are sun dried and packed in a dry clay pot.

Sometimes are as well smoked. For consumption is necessary to remove the desired quantity from the pot, wash and boil it (Solomon *et al.*, 1994).

Charque (or charqui) is the popular cured and sun dried beef in Brazil and Latin America. 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).

Figure 1.6 Production of charque (Heinz and Hautzinger, 2007)

Carne-do-sol is made from beef or goat meat. It has typically dark brown surface color. Processing procedures are similar as of charque, however, there is only one step of dry-salting and mostly is dehydrated in covered and well ventilated areas. Because it has a salt content approximately 5% and water activity 0.95, it should be stored at 10°C. Before consumption of meat is necessary to desalting in water and then cooking (FAO, 1985; Collignan *et al.*, 2008).

Chinese dried pork is famous in Southeast Asia. It´s made from thinly sliced hams or loins, cured (with sugar, salt and soy sauce) and sun dried until it reaches 45-70% of its original weight. Before consumption is cooked (Kuo and Ockerman, 1985).

Basturma (or pastirma) is an intermediate meat (IM) meat product of Eastern Mediterranean countries (Turkey, Greece), in some parts of the former Soviet Union (Armenia) made from beef. In some areas of the Middle East camel meat or mutton is also used (Heinz and Hautzinger, 2007; Collignan *et al.*, 2008). It is preferably produced from September to November, since flies are not prevalent during this season. The air temperature is not as high as in the summer, and the relative humidity is moderate due to scanty rainfall (Chang *et al.*, 1996). The production process for pastirma takes several weeks. The meat is mostly taken from the hindquarters and is cut into 50 to 60 cm long strips with a diameter of not more than 5 cm. The strips are rubbed and covered with salt and nitrate. The salted meat strips are arranged in piles about 1 m high, repeatedly repiled and kept for two days. Thereafter the meat strips are washed and air-dried for two to three days in summer and for 15 to 20 days in winter. After drying the strips are piled up again and pressed with heavy weights for 12 hours. After another drying period of two to three days the meat pieces are again pressed for 12 hours. Finally the meat is again air-dried for 5 to 10 days. After the salting and drying process, the entire surface of the meat is covered with a 3 to 5 mm thick layer of a paste called cemen (paste made from garlic, mustard seeds etc.). The meat strips covered with cemen are stored in piles for one day, and thereafter dried for 5 to 12 days in a room with good air ventilation. The final product has an average water activity (aw) of 0.88. Pastirma is consumed raw as the biltong is (Feiner, 2006; Heinz and Hautzinger, 2007).

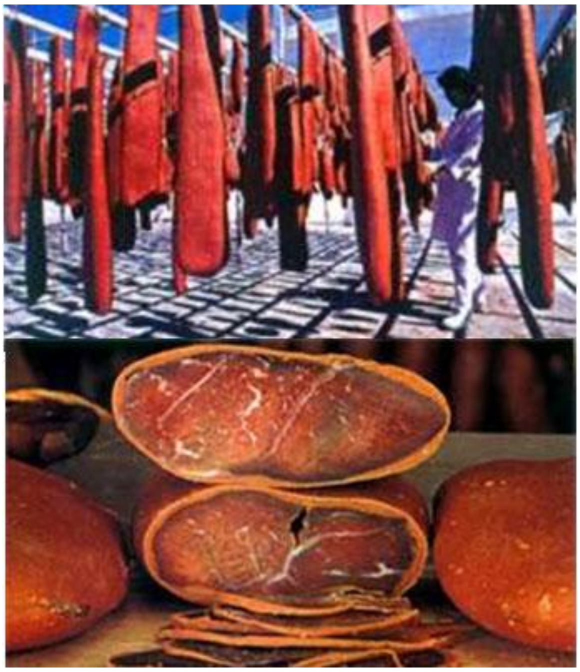

Figure 1.7 Pastirma. Air drying of large flat pieces of beef (above). Finished product (below) (Heinz and Hautzinger, 2007).

Jerky used to be the "iron food ration" in North America. Jerky is dehydrated lean meat, which contains salt and spices. There is no common processing technology, but many different approaches from the household level to industrial level to produce jerky. The lean meat, usually from beef, but buffalo (bison), deer, antelope or turkey meat may also be used. The meat is cut into strips not more than 0.5 cm thick, 1-2 cm wide and 15-20 cm long. Some people prefer cutting the meat across the grain, others parallel to the muscle fibers. All fat and other adhering white tissues should be removed. In modern processing, slightly frozen, but still relatively soft meat may be used to facilitate the cutting process. The "pioneer" jerky was seasoned only with salt and black pepper and then sun-dried. For faster and more advanced processing several seasoning and drying methods are now popular. It could be marinated, or cured or cooked before drying. Drying is done on the sun, by solar dried, by hot air oven drying or by industrial hot air driers. Sun drying is traditional method, but is not practiced anymore. Solar drying is suitable but not frequently practiced. Hot air oven method is for household users (Heinz and Hautzinger, 2007). In these days is jerky a popular product in the United States with a number of companies specializing in its production. Modern processing in temperature and humidity controlled smokehouses produces jerky in 10-24 h (Chang *et al.*, 1996).

Pemnican is a product originally made by American Indians. It was made from lean buffalo meat or venison. Processing is carried out by either sun-drying or smoking at low temperatures followed by pounding the dried meat into a shredded mass. It then had dried fruit pounded into the dried meat and was embedded in melted fat. It was sewn in rawhide bags and used by Indians on the warpath or in times of scarcity and later by mountain men and Arctic and Antarctic explorers. Although interest in pemmican was revived during World War II, it is no longer produced (Chang *et al.*, 1996).

Another dried meat product can be found. For example: owanta in Ethiopia, klioh in North Africa, odka in Somalia (Collignan *et al.*, 2008). In Indonesia there prepares dendeng giling. It´s a mixture of minced beef, salt, garlic, coriander and sodium nitrite, which is then sun dried (Darmadji *et al.*, 1990).

Smoked dried meats

Prior to smoking, meat may be salted and sometimes cooked. The most known meats in Africa are balangu and tsire in Niger and Nigeria, kitoza in Madagascar and banda in Sahel African countries. Banda is prepared by cutting meat into pieces, cooking in saline water and spreading them on dry grass. The grass is set on fire until charred. Kundi is produced by smoking fresh beef, camel or horse meat in Nigeria and is possible to store it without refrigeration. Could be also parboiled before smoking (Alonge, 1987). Kitoza is processed by cutting beef or pork meat into strips, salted and smoked over wooden fire for 2-3 days (Collignan *et al.*, 2008).

1.2.2 Quality of dried product

In case of drying, continuous evaporation and weight losses cause changes of the shape of the meat through shrinkage. The meat pieces become smaller, thinner and to some degree wrinkled and darker in color. The texture also changes from soft to firm to hard. The fact that dried meat is no longer comparable to fresh meat in terms of appearance and sensory and processing properties, has to be weighed against the significant extension of the shelf-life. Under certain circumstances, in particular in the absence of refrigeration, these disadvantages have to be accepted, particularly where the alternative might be loss of the valuable meat by spoilage. Most nutritional properties of meat, in particular the protein content, remain unchanged through drying (Heinz and Hautzinger, 2007).

Drying of fresh, untreated meat of the shape described (strips or flat) takes at least two days, in many cases three to four days. After this period the dried meat is ready for consumption and can be packaged, stored and/or transported. According to Heinz and Hautzinger (2007) at this stage the product should meet the following quality criteria:

- The appearance of the dried meat should be as uniform as possible. The absence of large wrinkles and notches indicates the desired steady and uniform dehydration of meat.
- The color of the surface, as well as of the cross-cut should be uniform and dark red. A darker peripheral layer and bright red color in the center indicates excessively fast drying. Because of the remaining higher water content in the center, these meat parts may still be susceptible to microbiological growth.
- The texture of properly dried meat must be hard, similar to frozen meat. A softer texture can be recognized by pressing the meat between fingers. These pieces should be kept for one more day in the drier for finishing.
- Taste and flavor are very important criteria for the acceptance of dried meat by the consumer. Dried meat should possess a mild salty taste which is characteristic of naturally dried meat with no added spices. Off-odors must not occur. However, a slightly rancid flavor, which occurs because of chemical changes during drying and storage, is commonly found in dried meat and is acceptable. Dried meat with a high fat content should not be stored for a long period, but used as soon as possible in order to avoid intensive rancidity.

Food safety is a top priority for authorities and consumers worldwide. Food safety objectives and hazard analysis and critical control point are being introduced worldwide. Adequate preservation technologies must be applied (Aymerich *et al.*, 2008). Solar drying is an option.

1.3 Solar drying

Drying by exposure to the Sun is one of the oldest methods using solar energy, for food preservation, as vegetables, fruits, fish, meat, etc. Already from the prehistoric times, mankind used the solar radiation as the only available thermal energy source to dry and preserve all necessary food stuffs for winter time, to dry soil bricks for their homes and animal skins for dressing (Belessiotis and Delyannis, 2011). The first known drying installation has been found in the South of France and is dated from about 8000 BC. It was a stone paved surface and used for drying of crops. Breeze or natural moderate wind velocities were combined with solar radiation to accelerate drying (Kroll and Kast, 1989).

Open sun drying is still widely practiced in the tropics and subtropics. In the traditional methods of drying, the agricultural products are placed on beaten earth, mat, concrete and floor and even on roads in the sun and these are vulnerable to contaminations by dirt and dust, insect infestation, and loss by birds and animals (Janjai and Bala, 2011). Such drying under hostile climate conditions leads to severe losses in the quantity and quality of the dried product (Pangavhane *et al.*, 2002). For example: total postharvest losses of 20- 50% have been estimated for developing countries (Kordylas, 2005), and nearly 10 - 40% of the crops harvested never reach the intended consumers due to post harvest losses along the supply chain (Esper and Muhlbauer, 1998).

Solar drying relies, as does sun drying, on the sun as its source of energy. Solar drying differs from sun drying in that a structure, often a very simple construction, is used to enhance the effect of the insolation. In many cases solar drying is a sensible alternative to sun drying (Brenndorfer *et al.*, 1985). Advantages of solar driers have been previously reported in the literature by many researchers (Karathanos and Belessiotis, 1997b; Bala *et al.*, 2003; Hossain and Bala, 2007) especially because of lower investments comparing to sophisticated drying techniques using fossil fuels and because of the fact that most developing countries are situated in climatic zones where the insolation is considerably higher than the world average of 3.82 kW h m^2 a day (Imre, 2007). In many rural locations in Africa and most developing countries, grid-connected electricity and supplies of other non-renewable sources of energy are either unavailable, unreliable or, for many farmers, too expensive. Thus, in such areas, crop drying systems that employ motorized fans and/or electrical heating are inappropriate. The large initial and running costs of fossil fuel powered driers present such barriers that they are rarely adopted by small scale farmers (Ekechukwu and Norton, 1999). Further, more than 80% of food in developing countries is being produced by small farmers and design of most solar driers can fulfill their needs (Murthy, 2009). Compared with sun drying, solar driers can generate higher air temperatures and consequential lower relative humidity which are both conductive to improved drying rates and lower final moisture contents of the dried items (Brenndorfer *et al.*, 1985). Improvement of product quality and reduction of losses can only be achieved by the introduction of suitable drying technologies. However, increase of purchasing power of the farmers of the driers and the reflection of the quality in the price of quality dried products are the important prerequisites for acceptance of the driers by the farmers and the introduction of improved drying technologies. As long as there is no or only slight difference in the price for high and low quality products, the additional expenses for new preservation techniques will never be paid back and the new drying technologies will not be accepted by the farmers (Janjai and Bala, 2011).

1.3.1 Drying fundamentals

The two processes occur simultaneously during the thermal process of drying a wet solid:

- heat transfer to change the temperature of the wet solid and to evaporate its surface moisture
- the mass transfer of moisture to the surface of the solid and its subsequent evaporation from the surface to the surrounding atmosphere

Surrounding medium is drying medium (in case of solar drying heated air). Consideration of the actual quantities of air required to remove the moisture liberated by evaporation is based on psychrometry and the use of humidity charts (Mujumdar, 2006).

Drying of food materials is complicated by the fact that physical, chemical and biochemical transformations may occur during drying, some of which may be desirable and others undesirable. Physical changes such can result in changes in mechanisms of mass transfer and rates of heat transfer within the material, often in an unpredictable manner (Mujumdar, 1997).

1.3.1.1 Thermodynamic properties

Psychrometry

Hot air is used both to supply the heat for evaporation and to carry away the evaporated moisture from the product. Drying with heated air implies humidification and cooling of the air. Pakowski *et al.* (1991) presented a comprehensive summary of the engineering properties of humid air. Both thermodynamic (e.g. adiabatic saturation temperature, humid heat, humid enthalpy) as well as transport properties (e.g. thermal conductivity, moisture diffusivity, permeability, inter-phase heat/mass transfer coefficients) are essential for solar drying. Table 1.3 provides a listing of brief definition of various terms encountered in psychrometry and drying (Mujumdar, 1997).

Table 1.3 Definition of commonly encountered terms in psychrometry and drying (Mujumdar, 1997).

Term/symbol	Meaning
Adiabatic saturation temperature, T_{as}	Equilibrium gas temperature reached by unsaturated gas and vaporizing liquid under adiabatic conditions (Note: for the air-water system only it is equal to the wet bulb temperature (T_{wb}).)
Bound moisture	Liquid physically and/or chemically bound to solid matrix so as to exert a vapor pressure lower than that of pure liquid at the same temperature.
Constant rate drying period	Under constant drying conditions, drying period when evaporation rate per unit drying area is constant (when surface moisture is removed).
Dew point	Temperature at which a given unsaturated ai-vapor mixture becomes saturated.
Dry bulb temperature	Temperature measured by a (dry) thermometer immersed in vapor-gas mixture.
Equilibrium moisture content, X^*	At a given temperature and pressure, the moisture content of moist solid in equilibrium with the gas-vapor mixture (zero for non-hygroscopic solids).
Critical moisture content, X_c	Moisture content at which the constant drying rate first begins to drop (under constant drying conditions).
Falling rate period	Drying period (under constant drying conditions) during which the rate falls continuously with time.

Table 1.3 (Continued)

Term/symbol	Meaning
Free moisture, X_f; $X_f = X - X^*$	Moisture content in excess of the equilibrium moisture content (hence free to be removed) at given air humidity and temperature.
Humid heat	Heat required to raise the temperature of units mass of dry air and its associated vapor through 1 degree (kJ kg^{-1})
Humidity, absolute	Mass of water vapor per unit mass of dry gas (kg kg^{-1}).
Humidity, relative	Ratio of partial pressure of water vapor in gas-vapor mixture to equilibrium vapor pressure at the same temperature.
Unbound moisture	Moisture in solid which exerts vapor pressure equal to that of pure liquid at the same temperature
Water activity, a_w	Ratio of vapor pressure exerted by water in solid to that of pure water at the same temperature.
Wet bulb temperature, T_{wb}	Liquid temperature attained when large amounts of air-vapor mixture are contacted with the surface. In purely convective drying, the drying surface reaches T_{wb} during the constant-rate period.

Psychrometric chart for the air-water system shows the relationship between the temperature (abscissa) and absolute humidity (ordinate, in g water per kg dry air) of humid air at 1 atmosphere total pressure over the range 0° to 180°C. Lines representing percent humidity and adiabatic saturation are drawn according to the thermodynamics definitions of these terms (Mujumdar, 1997).

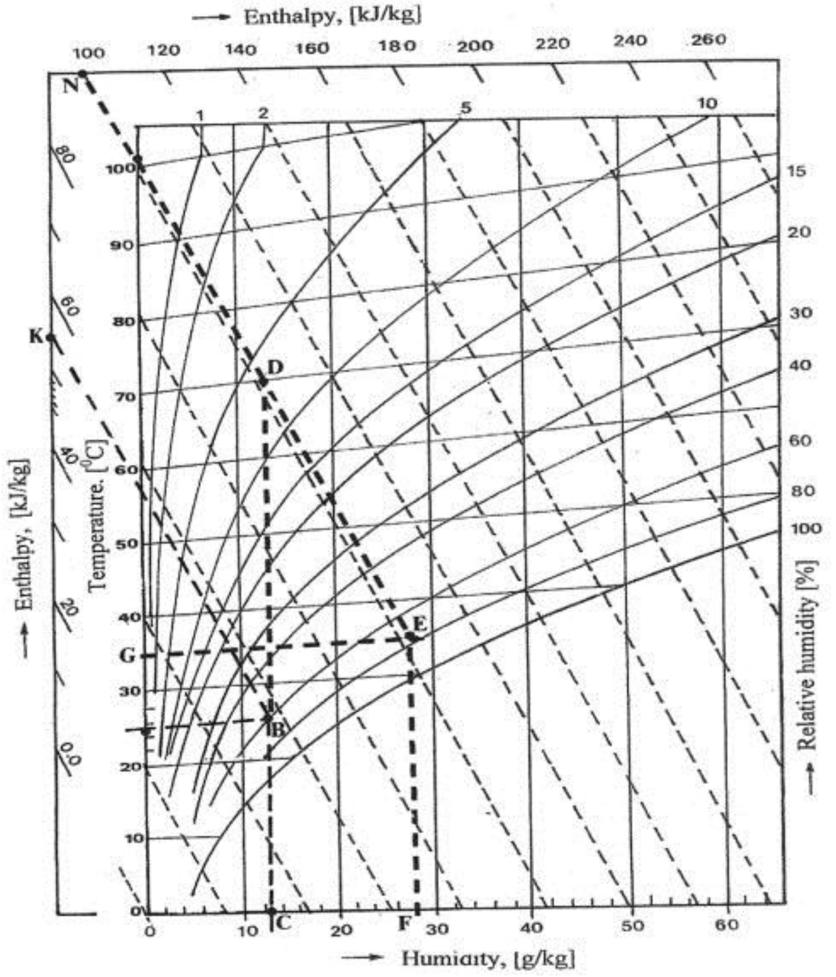

Figure 1.8 Psychrometric chart (Belessiotis and Delyannis, 2011).

Table 1.4 summarizes the essential thermodynamic relationships for humid air. Equation for the adiabatic saturation- and wet- bulb temperature lines on the psychrometric chart are as follows (Geankopolis, 1983):

$$\frac{Y-Y_{as}}{T-T_{as}} = -\frac{c_s}{\lambda_{as}} = -\frac{1.005+1.88Y}{\lambda_{as}} \tag{1.1}$$

and

$$\frac{Y-Y_{as}}{T-T_{as}} = -\frac{h/M_{air}k_y}{\lambda_{wb}} \tag{1.2}$$

where: ratio $(h/M_{air}k_y)$, termed the psychrometric ratio, lies between 0.96 and 1.005 for air-water vapor mixtures, thus is nearly equal to the value of humid heat c_s. If the effect of humidity is neglected, the adiabatic saturation- and wet-bulb temperatures (T_{as} and T_{wb}, respectively) are almost equal for the air-water system. The adiabatic saturation temperature is a gas temperature and a thermodynamic entity. Plots of Y_{as} versus T_{wb} on psychrometric chart are straight lines and represent the path followed by the air in adiabatic drier. In contrast the wet-bulb temperature is a heat and mass transfer rate-based parameter and refers to the temperature of the liquid phase. Under constant drying conditions, the surface of the drying material attains the wet-bulb temperature if heat transfer is by pure convection. The wet-bulb temperature is independent of surface geometry as result of the analogy between heat and mass transfer (Mujumdar, 1997).

Table 1.4 Psychrometric equations for air-water vapor system (Geankopolis, 1983).

Parameter	Equation
Absolute humidity: kg H_2O per kg dry air	$Y = \frac{18.02}{29.97}\frac{p}{p_a - p}$
Saturation humidity	$Y = \frac{18.02}{29.97}\frac{p_w}{p_a - p_w}$
Percent humidity	$Y_p = 100\frac{Y}{Y_s}$
Relative humidity	$\psi = 100\frac{p}{p_w}$
Humid heat: kJ kg^{-1} dry air	$c_s = 1.005 + 1.88Y$
Total enthalpy: kJ kg^{-1} dry air	$H = (1.005 + 1.88Y)(T - T_r) + Y\lambda_r$ T_r= Reference temperature, K
Latent heat vaporization λ, kJ kg^{-1}	$\lambda = a_1(a_2T)^{a_3}$ $a_1 = 267.155, a_2 = 374.2, a_3 = 0.38$ T in °C

Equilibrium moisture content

The equilibrium moisture content refers to the moisture content when the vapor pressure exerted by the moisture of product equals vapor pressure of the nearby ambient air. This means that moisture desorption from the product is in dynamic equilibrium with the absorption of the environmental air moisture contain. Relative humidity at this point is known as the “equilibrium relative humidity”, and is characterized by the curves of moisture content plots against equilibrium humidity known as moisture equilibrium isotherms. These describe sorption phenomena but only few found universal acceptance (Belessiotis and Delyannis, 2011).

1.3.1.2 Drying kinetics

Consider the drying of a wet solid under fixed conditions. In the most case, after an initial period of adjustment, the dry-basis moisture content *X*, decreases with time *t,* following the start of evaporation. This is followed by a non-linear decrease in X with t until, after a very long time, the solid reaches its equilibrium moisture content, *X** and drying stops. In term of free moisture content, defined as (Mujumdar, 1997):

$$X_f = (X - X^*) \qquad (1.3)$$

the drying rate drop to zero at $X_f = 0$.

By convention, the drying rate *N*, is defined as (Mujumdar, 1997):

$$N = -\frac{M_S}{A}\frac{\mathrm{d}X}{\mathrm{d}t} \quad \text{or} -\frac{M_S}{A}\frac{\mathrm{d}X_f}{\mathrm{d}t} \qquad (1.4)$$

under constant drying conditions.

where: *N*= the rate of evaporation of water (kg.m^{-2}.h^{-1})

A= the evaporation area (this may be different from the heat transfer area)

M_s= the mass of bone dry solid

If *N* is plotted versus *X* (or X_f) the resulting diagram is the drying rate curve, always obtained under constant drying conditions (Mujumdar, 1997).

Drying rate curve (Figure 1.9) displays an initial constant rate period where *N*= *Nc* = constant. At the so-called critical moisture content *Xc*, *N* begins to fall with further decrease in *X*. The mechanism underlying this phenomenon depends both on the material and the drying conditions. Many foods and agricultural products do not display a constant rate at all since internal heat and mass transfer rates determine the rate at which water becomes available at the exposed evaporation surface. As long as there is a film of free water present on the surface, the drying tare will remain in the constant period (Mujumdar, 1997). The rate N begins to drop at $X = Xc$ since water cannot migrate to the surface at the rate *Nc*, because of internal transport limitations.

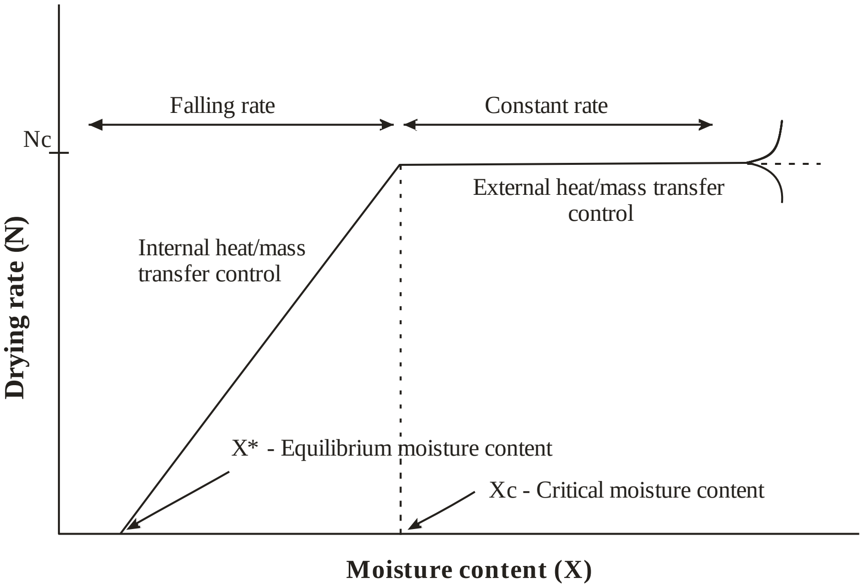

Figure 1.9 A textbook drying rate curve under constant drying conditions (Mujumdar, 1997).

Material may display more than one critical moisture content at which the drying rate curve shows a sharp change of shape. This is generally associated with changes in the underlying mechanisms of drying due to structural or chemical changes.

Nc is possible calculate using empirical or analytical techniques to estimate the external heat/mass transfer rates (Keey, 1978):

$$N_c = \sum q / \lambda_s \tag{1.5}$$

where: Σq= sum of heat fluxes due to convection, conduction and/or radiation

λs= latent heat vaporization at the solid temperature.

The drying rate in the falling rate period(s) is a function of X (or Xc) and must be determined experimentally for a given material in a given dryer. If N versus X is known, than drying time tf, required to reduce the solid moisture content from $X1$ to $X2$ is (Mujumdar, 1997):

$$t_f = \int_{X_1}^{X_2} \frac{M_S}{A} \frac{\mathrm{d}X}{N} \qquad (1.6)$$

Different analytical expression are obtained for the drying times, t_f, depending on the functional form of N or the model used to describe the falling rate e.g. diffusion of liquid or vapor, capillarity, evaporation-condensation (Mujumdar, 1997).

1.3.2 Classification of solar driers

Solar driers used in agriculture for food and crop drying are used for industrial drying processes. They can be proved to be a very useful device from the energy conservation point of view. It not only saves energy, but also saves a lot of time, occupies less area, improves quality of the product, makes the process more efficient, and also protects the environment. Solar driers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required (VijayaVenkataRaman *et al.*, 2012).

Different types of solar dryers have been designed, developed, and tested in the different regions of the tropics and subtropics (Bala and Janjai, 2012). In solar drying, solar-energy is used as either the sole source of the required heat or as a supplemental source. The air flow can be generated by either natural or forced-convection. The heating procedure could involve the passage of preheated air through the product or by directly exposing the product to solar radiation or a combination of both (Ekechukwu and Norton, 1999). Selection of a solar drier for drying a particular agricultural product is affected by the drying characteristics of the product, quality requirements and economic situation of the producer (Purohit *et al.*, 2006).

Solar driers can be classified into two broad categories:

- passive solar drying systems (conventionally termed natural- circulation)

- active solar drying systems (most types of which are often called hybrid solar driers)

According to Ekechukwu and Norton (1999) there are three distinct sub-classes of either the active or passive solar drying systems. They vary mainly in the design arrangement of system components and mode of utilization of solar heat. These sub-classes are:

- integral-type solar driers
- distributed- type solar driers
- mixed-mode solar driers

There are several types of driers developed to serve the various purposes of drying food products as per local need and available technology.

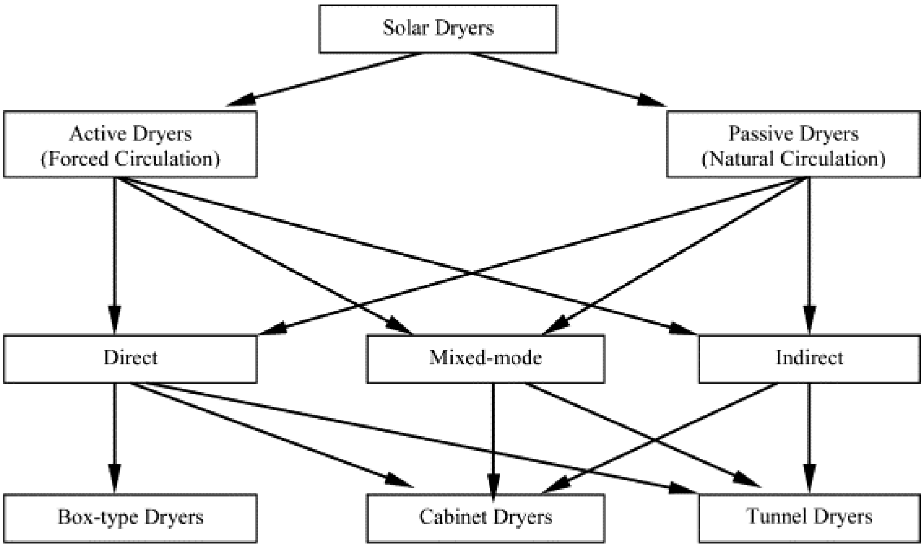

Figure 1.10 Classification of solar driers (Augustus Leon *et al.*, 2002).

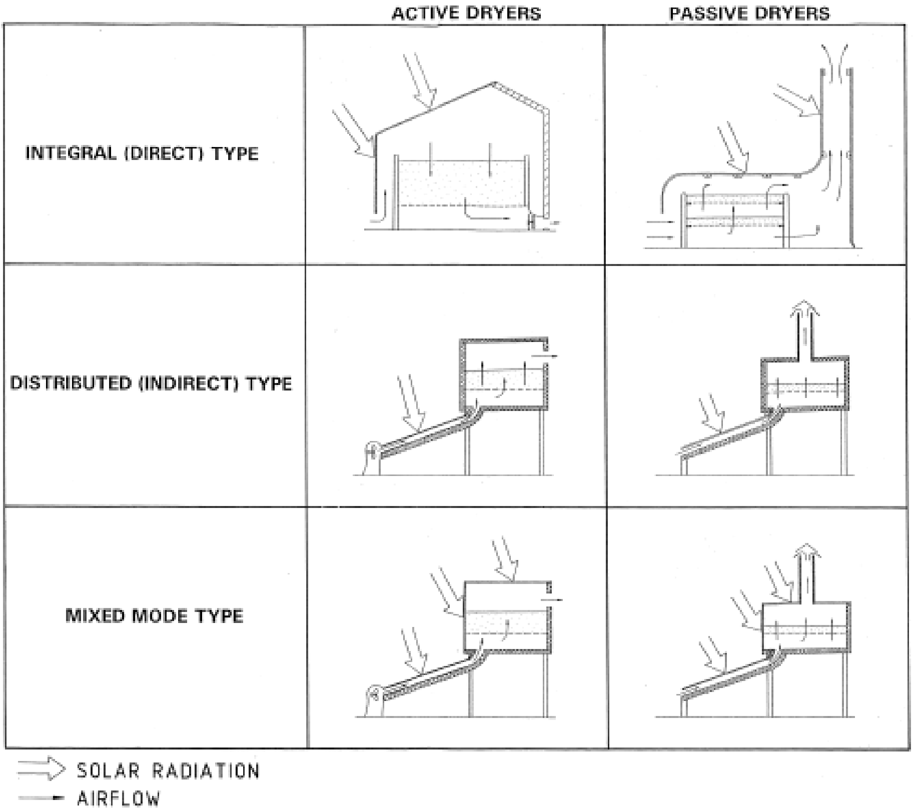

Figure 1.11 Typical solar energy drier designs (Ekechukwu and Norton, 1999).

Different solar drier examples see in the pictures- Annex A.

1.3.2.1 Passive solar driers

Open-to-sun drying

As was already published by Ekechukwu and Norton (1999) there are two traditional ways how to dry the product in tropical countries:

- drying "in situ" means that plant bearing the crop is not removed from the field
- the crop is dried on the ground, mat, cemented floor or placed on either horizontal or vertical shelves exposed to the sun and natural air flow

These techniques still remain in common use. Because the power requirements (i.e. from the solar radiation and the air´s enthalpy) are readily available in the ambient environment, and as little or no capital cost is required and running costs low, these are frequently the only commercially viable methods in which to dry agricultural produce in developing countries. These techniques even have important limitations as high crop losses ensue from inadequate drying, fungal and insect infestation, birds and rodent encroachment and weathering effects. The process in intermittent, being affected by cloudiness and unexpected rain. Output is low and can be of very poor quality (Ekechukwu and Norton, 1999)

Natural- circulation solar-energy driers

These solar driers depend for their operation entirely on energy from the Sun. In such systems, solar-heated air is circulated through the crop by buoyancy forces or as a result of wind pressure, acting either singly or in combination. These driers are often termed as "passive". The others and newer, which they use fans to convey the air through the crop, are called "active" solar driers. Natural- circulation solar driers appear the most attractive option for use in remote rural locations. They have a lot advantages. They don´t need large areas of land in compared to traditional open-sun drying. The quality of the dried crop is relatively high. The drying period is shortened compared with open air drying. The crop is protected from rain and construction and labor are commercially viable (Ekechukwu and Norton, 1999).

They can be subdivided, according to the criteria already stated, into these types (Imre, 1997):

- integral-type natural-circulation solar-energy driers
- distributed-type natural-circulation solar-energy driers
- mixed-mode natural-circulation solar-energy driers

Distributed –type natural circulation solar energy driers

These are often termed indirect passive solar driers. Here, the crop is located in trays or shelves inside an opaque drying chamber and heated by circulating air, warmed during its flow through a solar collector (Norton and Probert, 1984)

A typical distributed natural-circulation solar-energy drier would be comprised of the following basic units:

- an air-heating solar-energy collector

- appropriately insulated ducting
- a drying chamber
- a chimney

Integral-type natural-circulation solar-energy driers

In integral-type natural-circulation solar-energy driers (often termed direct solar driers), the crop is placed in a drying chamber with transparent walls that allow the insolation necessary for the drying process to be transmitted (Ekechukwu and Norton, 1999). Direct exposure to sunlight enhances the proper color ripening of greenish fruits by allowing, during dehydration, the decomposition of the residual chlorophyll in the tissue (Brenndorfer *et al.*, 1985; Ekechukwu, 1987).

For certain varieties of grapes and dates, exposure to sunlight is considered essential for the development of the required color in the dried product, and for Arabica coffee, a period of exposure to sunlight is considered inviolable for the development of full flavor in the roasted bean (Brenndorfer *et al.*, 1985; Ekechukwu, 1987).

Passive solar cabinet driers

These are usually relatively small units used to preserve „household“ quantities of fruit, vegetables, fish and meat.

Natural-circulation greenhouse driers

Often called tent dryers, these are essentially modified greenhouses.

Mixed-mode natural-circulation solar-energy driers

These driers combine the features of the integral (direct) type and the distributed (indirect) type natural-circulation solar-energy driers. Here the combined action of solar radiation incident directly on the product to be dried and pre-heated in a solar air heater furnishes the necessary heat required for the drying process.

A typical mixed-mode natural-circulation solar-energy drier would have the same structural features as the distributed-type (i.e. a solar air heater, a separate drying chamber and a chimney), but in addition, the walls of the drying chamber are glazed so that the solar radiation impinges directly on the product as in the integral-type driers (Ekechukwu and Norton, 1999).

1.3.2.2 Active solar driers

Active solar drying systems depend only partly on solar-energy. They employ solar energy and/or electrical or fossil-fuel based heating systems and motorized fans and/or pumps for air circulation. A typical active solar drier depends solely on solar-energy as the heat source, but employs motorized fans and/or pumps for forced circulation of the drying air (Ekechukwu and Norton, 1999).

Active solar driers that incorporate dehydrators for supplemental heating are commonly known as „hybrid solar driers“. A variety of active solar-energy driers exist which could be classified into either:

- integral-type
- distributed-type
- mixed-mode driers

1.3.3 Mathematical models of the solar drying

To describe solar drying processes accurately research work is more and more focused on studying mathematical models of the solar drying of different product. Drying processes are modeled with two main models:

i. Distributed models

Distributed models consider simultaneous heat and mass transfer. They take into consideration both the internal and external heat and mass transfer, and predict the temperature and the moisture gradient in the product better. Generally, these models depend on the Luikov equations that come from Fick’s second law of diffusion or their modified forms (Erbay and Icier, 2010).

ii. Lumped parameter models

Lumped parameter models assume a uniform temperature distribution that equals to the drying air temperature in the product and they don´t pay attention to the temperature gradient in the product (Erbay and Icier, 2010).

The assumptions resembling the uniform temperature distribution and temperature equivalent of the ambient air and product cause errors. This error occurs only at the beginning of the process and it may be reduced to acceptable values with reducing the thickness of the product (Henderson and Pabis, 1961). With this necessity, thin layer drying gains importance and thin layer equations are derived (Erbay and Icier, 2010).

For solar drying simulation models, thin-layer drying equations in terms of single value drying parameters are commonly used to predict changes in moisture content of the food product (Tripathy and Kumar, 2009). Thin-layer drying models fall into three categories, namely theoretical, semi-theoretical and empirical. The theoretical approach involves either a diffusion equation or simultaneous heat and mass transfer equations. The semi-theoretical approach involves approximate theoretical equations. Empirical equations are easily applied to drying simulations as they depend on experimental data (Midilli and Kucuk, 2003). Theoretical models are the most widely used. They are derived from Fick's second law of diffusion. Semi-theoretical models are as the theoretical models generally derived from Fick's second law and modifications of its simplified forms (another semi-theoretical models are derived by analogues with Newton's law of cooling). They are easier and need fewer assumptions due to using of some experimental data. On the other hand, they are valid only within the process conditions applied. Similar characteristics with the semi-theoretical models have the empirical models as well. They strongly depend on the experimental conditions and give limited information about the drying behaviors of the product (Erbay and Icier, 2010). On the other hand, they are easily applied to drying simulation, as they depend on experimental data (Midilli *et al.*, 2002).

The models derived from Newton´s Law of cooling:

1. Lewis (Newton) model
2. Page model
3. Modified Page models

The models derived from Fick's second law of diffusion:

1. Henderson and Pabis (Single term) model
2. Logarithmic (Asymptotic) model
3. Midilli model
4. Modified Midilli model
5. Demir et al. model

6. Two-Term model
7. .Two-Term Exponential model
8. .Modified Two-Term Exponential models
9. .Modified Henderson and Pabis (Three Term Exponential) model

Empirical models

1. . Thompson model
2. .Wang and Singh model
3. . Kaleemullah model

The most used evaluation criteria, which have the most complexity in the literature for thin-layer drying models, are coefficient of determination, reduced chi-square, root mean square error, mean relative percentage error, standard error of estimate, mean bias error, and reduced sum square error, respectively (Kucuk *et al.*, 2014).

The mathematical models applied to the solar drying curves of different agriculture product as cereals, tuber crops, fruits, vegetables, spices, dairy products and fish were previously reported in the literature (Nilnont *et al.*; Bahnasawy and Shenana, 2004; Jain and Pathare, 2007; Zomorodian and Dadashzadeh, 2009; Demir and Sacilik, 2010; Tunde-Akintunde Toyosi, 2010; Zomorodian and Moradi, 2010; Tunde-Akintunde, 2011; Meas *et al.*, 2012; Fudholi *et al.*, 2014). Although there are lots of studies conducted on the above-mentioned agricultural products, there is a lack of data on the solar drying of meat and particularly eland and/or game meat (Erbay and Icier, 2010).

2 OBJECTIVE

2.1 Main objective

The main objective of this work is to investigate the influence of drying pretreatments based (modified marinades) on the drying behavior and sensory properties of eland (*Taurotragus oryx*) jerky processed by hot-air drying.

2.2 Specific objectives

i) Investigation of two different drying methods: a) conventional laboratory dehydrator and b) solar drier.

ii) Evaluation of drying behavior of eland jerky with respect to used drying technology and its comparison to traditionally used beef jerky.

iii) Comparison of variously modified marinades on final sensory properties such as color, flavor, taste and texture of jerky from eland and its comparison with beef.

3 MATERIAL AND METHODS

3.1 Meat samples

Fresh beef (steer, *Bos taurus*, Fleckvieh Breed, 16 months old) from *biceps femoris* was purchased from the Institute of Animal Sciences (Prague- Uhříněves, Czech Republic). Fresh eland (steer, *Taurotragus oryx*, 16 months old) meat from *biceps femoris* was purchased from the school farm of the Czech University of Life Sciences Prague (Lány, Czech Republic). Both have been vacuum-packaged and were stored at -18°C for 4 days for later use. The frozen meat samples were thawed at 4°C overnight, and were cut with a food slicer (Concept KP 3530, FS-82T) into samples of size 0.5x 8x 2.5 cm. Sample size 0.5 cm was cut through the fibre. Meat slices were vacuum-packaged (MAGIC VAC Champion, Elaem Nuova) in bags and stored at -18°C for 1 month.

Figure 3.1 Preparation of meat samples.

3.2 Physicochemical characteristics of raw meat

For the physicochemical analysis were meat samples 24 hours after slaughter packed into LDPE bags and stored at temperatures ranging from 4 to 7 °C for 7 days. Afterwards, both eland and beef was analyzed on pH, dry matter content, Warner- Bratzler shear force, pigment concentration, weight loss during cooking, water holding capacity (WHC), colorimetry, fat content.

PH value was measured 24hours after slaughter using the pH meter Testo 205 (Lenzkirch, Germany). Measurement was repeated three times.

The dry matter content of meat was analyzed by drying at 103 ±2 °C of meat with sea sand- reference method ČSN ISO 1442:1997 in three replications.

Shear force was measured using Instron Model 5544, software Series IX (Instron Co., USA) equipped the device according to Warner- Bratzler. Samples of muscles were cleared and cut into pieces of 15 x 20 x 60 (mm). Measurement was repeated four times.

Haem pigments content was measured by the method according to Hornsey (1956). Solution of acetone and HCl was used for pigment extraction. Concentration of pigments was determined using spectrophotometer UV-2900 PC (Tsingtao Unicom-Optics Instruments CO., Ltd., China) and expressed as total haem pigments content (Pipek, 1986; AMSA, 1991). The concentration of each sample was measured in two replications.

Sample of meat was placed in a glass tube and it was weighted, covered with aluminum and placed in a water bath of temperature 80°C for 30 min. Water loss was measured gravimetrically (Pipek, 1986). Weight loss during cooking was measured for each sample two times.

Water holding capacity was determined using Grau and Hamm´s filter paper press method modified by Brendl (1970). Meat and total fluid areas were measured with a digital planimeter Planix 7 (Tamaya Technics Inc., Japan) (Hofmann, 1982; Pipek, 1986). Water holding capacity was for each sample measured twelve times.

Reflectance was measured with spectrophotometer Minolta CM206d (Minolta Co. Ltd., Japan). Muscle samples were cleared and cut crosswise. Reflectance was measured immediately on fresh cut samples (AMSA, 1991) and each sample was measured with three replications. After drying were pretreated and control samples measured again in twenty replications.

Fat content was obtained gravimetrically after extraction of dried samples with petrol ether for 4 hours according to the Soxhlet method in three replications.

3.3 Drying pretreatments

After one month of storage, the samples were thawed, were treated in marinades (see Figure 3.2) and subsequently dried in two driers. Following drying pretreatments were used in this study:

i) Tradition jerky marinade (TM)
ii) TM with pineapple juice (TMP)
iii) TM with honey (TMH)
iv) TM with Coca Cola (TMCCL)
v) Control samples- without marinade (C)

Tradition jerky marinade (Andress and Harrison, 1999; Yoon *et al.*, 2005) consisted of 60 ml soy sauce (Kikkoman Foods), 15 ml Worcestershire sauce (Vitana, Czech Republic), 0.6 g black pepper, 1.25 g garlic powder, 1.5 g onion powder and 4.35 g old hickory-smoked salt. Meat samples were dipped for 10 min at ambient temperature (24°C) into:

TM: tradition jerky marinade.

TMP: TM and freshly prepared pineapple juice (50% fresh pineapple juice/ 50% TM).

TMH: TM and bee honey solution (50% bee honey solution/ 50% TM), bee honey solution (50% bee honey/ 50% distilled water).

TMCCL: TM and Coca Cola (50% Coca Cola/ 50% TM), Coca Cola (The Coca-Cola Company). Ingredients of Coca Cola original: sugar, caramel color E150d, caffeine, phosphoric acid, carbonated water, flavor.

Figure 3.2 Marinating meat samples.

3.4 Drying experiment

The drying of fresh meat slices was carried out in the double- pass solar drier (DPSD) (Figure 3.3 and Figure 3.4) designed at the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague (Banout *et al.*, 2011). The DPSD is classified as a forced convection indirect type and is based on the familiar construction of the suspended plate air heating solar collector. The dimensions of the drier were as follows: length 5m, width 2m and height 0.30 m as shown in the Figure 3.4. The supporting structure was made from square steel rods. One side is equipped with doors enabling access into the drying chamber. The casing was made from a custom- made sandwich material consisting of four layers. Moving from inside out, these were an aluminum sheet metal (corrosion resistant and odor absorption free), a 2 mm layer of cork (insulation barrier from high heat that could harm the insulation), a 20mm styrofoam (insulation) and galvanized metal sheet (protection from outside influences). The absorber was made of galvanized metal sheet painted matt black to ensure good absorption of solar radiation. The absorber was provided with axial metal fins that increase the absorber surface. A polycarbonate panel sheet constituted the glazing on the collector part of the drier. This was made of a UV light stable material with good shatter resistance and transmissivity. At the beginning of the drier were five DC fans, which provided the necessary air flow through the absorption and drying chamber. The fans were connected directly to a photovoltaic (PV) panel by a parallel connection. No regulatory systems are required as the system regaulates the airflow itself due to the position of the sun during the day. The drying chamber was fitted with 3 trays, made from a steel frame and high-density polyethylene (HDPE). This form of plastic is temperature resistant and does not represent any intoxication danger for the product.

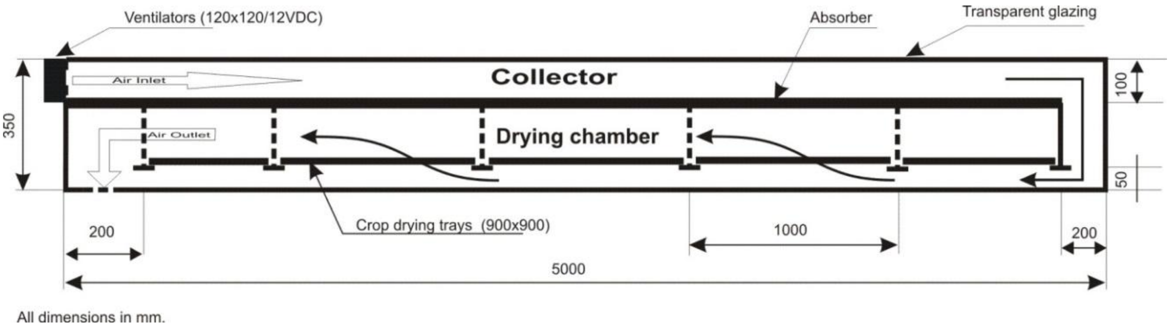

Figure 3.3 Cross-section view of Double-pass solar drier (Banout *et al.*, 2011).

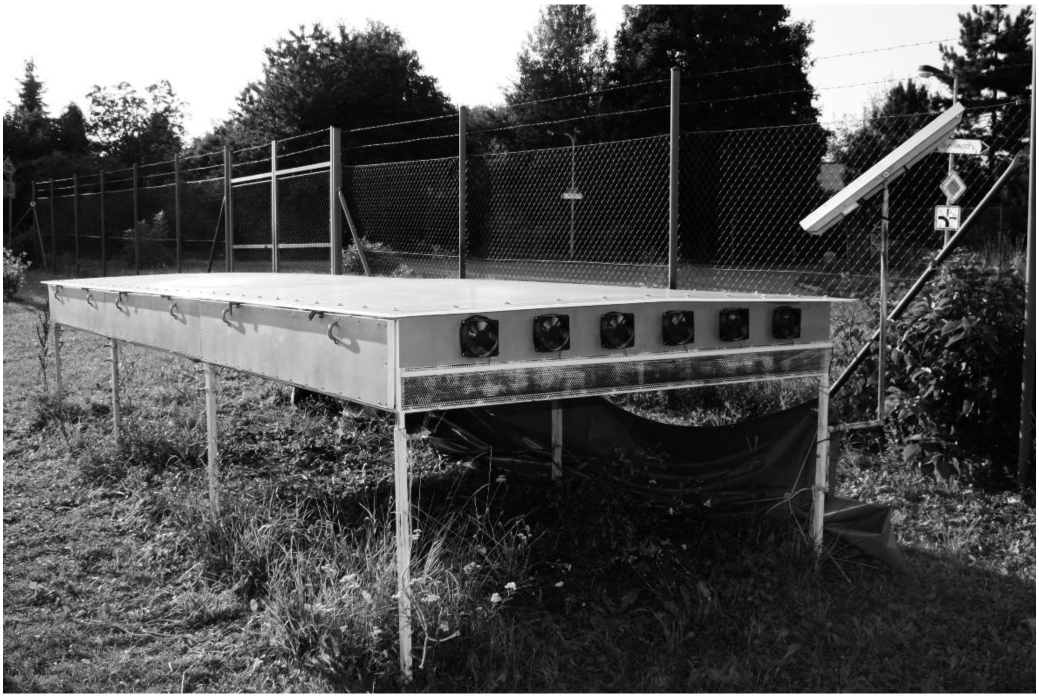

Figure 3.4 General view of Double-pass solar drier.

Solar drying test of meat was compared with drying in a laboratory oven (LO, standard dehydrator Memmert UFE 500 GmbH + Co. KG, Germany) at a constant temperature 55°C. A total of three full-scale experimental sets of eland and beef drying were conducted from June to September at Czech University of Life Sciences Prague (Czech Republic). The specific climatic and drying conditions of each solar drying experiment are presented in Table 3.1. Experiments conducted in the LO were replicated three times. Each set of solar drying experiments took 2 days and always started at 10:00 AM and stopped at 6:00 PM. During the night the samples were collected and placed in a room in closed plastic bags. Following operational parameters were measured every hour 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 and outlet parts of the drier- Anemometer Testo 425 (Lenzkirch, Germany)
- weight loss of reference samples of meat slices (g)- Balance Kern 572-30 (Kern&Sohn GmbH)
- ambient air temperature (°C) and ambient air RH (%)-Temperature- Humidity Logger S3121 (Comet System, Czech Republic)
- global solar radiation ($W\cdot m^{-2}$)- pyranometer CMP 6, along with a solar integrator (Kipp Zonen, Delft, The Netherlands)

Table 3.1 Climatic and drying conditions of all solar drying experiments (SD- standard deviations).

Experiment	Average ambient temperature		Average drying temperature		Average ambient RH		Average RH of drying air		Average insolation		Average air flow speed in collector	
	°C	SD	°C	SD	%	SD	%	SD	W.m^{-2}	SD	m.s^{-1}	SD
A	23.4	1.4	46.4	5.7	51.3	8.7	19.7	6.7	525.4	194.1	0.7	0.1
B	24.3	1.7	48.4	6.0	49.2	8.7	18.2	5.7	552.3	219.4	1.0	0.3
C	25.5	2.1	49.3	5.2	46.2	7.7	17.7	5.7	615.3	144.1	1.1	0.1

Note: A- solar drying experiment run from 2012-06-07 to 2012-06-08, total drying time 16 h excluding nights; B- solar drying experiment run from 2012-08-02 to 2012-08-03, total drying time 16 h excluding nights; C- solar drying experiment run from 2012-09-10 to 2012-09-11, total drying time 16 h excluding nights; RH- relative humidity.

Figure 3.5 Measuring instruments.

At the end of each drying test in the DPSD and LO the control samples were collected in triplicates and dry matter content was estimated by the oven method at 105°C for 24 h (Memmert UFE 500 GmbH + Co. KG, Germany). 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:

$$MC_{db} = \frac{water\ (kg)}{dry\ meat\ (kg)} \tag{3.1}$$

$$MC_{wb} = \frac{water\ (kg)}{water\ (kg) + dry\ meat\ (kg)} \tag{3.2}$$

3.5 Mathematical modeling of drying curves

To predict the drying curves of meat, processed by both solar and laboratory drying, the measured moisture content measured was transformed into the moisture ratio (MR) as described in eq. (3.3), and simplified in eq. (3.4) (Rayaguru and Routray, 2012). The MR could be simplified since the RH of the drying air continuously fluctuated in the case of solar drying experiments, so a correct equilibrium moisture content (M_e) could not be estimated. Also M_e is small compared to M_t or M_i, hence the error involved in the simplification is negligible. MR data plotted against t are then inserted into 10 mathematical models. Selected mathematical models are listed in Table 3.2.

$$MR = \frac{M(t) - M_e}{M_i - M_e} \quad (3.3)$$

$$MR = \frac{M_t}{M_i} \quad (3.4)$$

Table 3.2 Mathematical models used to describe the drying characteristic of meat strips (Verma *et al.*, 1985; Ozdemir and Devres, 1999; Mujumdar, 2006).

Model name	Models
Newton (Lewis)	$MR = \exp(-k\mathrm{t})$
Page	$MR = \exp(-k\mathrm{t}^n)$
Modified Page	$MR = \exp[-(kt)^n\,]$
Henderson and Pabis	$MR = a\,\exp(-k\mathrm{t})$
Two term	$MR = a\,\exp(-k_0 t) + b\,\exp(-k_1\mathrm{t})$
Two term exponential	$MR = a\,\exp(-k\,\mathrm{t}) + (1-a)\exp(-k\,a\,\mathrm{t})$
Diffusion approximate	$MR = a\,\exp(-k\,\mathrm{t}) + (1-a)\exp(-k\,b\,\mathrm{t})$
Wang and Singh	$MR = 1 + a\,\mathrm{t} + b\,\mathrm{t}^2$
Verma et al.	$MR = a\,\exp(-k\mathrm{t}) + (1-a)\,\exp(-g\mathrm{t})$
Logarithmic	$MR = a\,\exp(-k\mathrm{t}) + c$

Note: MR is the moisture ratio (decimal); M(t) is the moisture content at any time (% d.b.); M_i is the initial moisture content (% d.b.); M_e is the equilibrium moisture content (% d.b.); t is the time (min); *a,b,c,g,k* and *n* are the constants.

The parameters of the drying models were estimated from the experimental results using the nonlinear regression analysis. The coefficient of determination (R^2) was used as one of the primary criteria for selecting the best mathematical model describing the solar drying curve of the meat samples. In addition to R^2, the chi-square (χ^2) and root mean square error ($RMSE$) were used to analyze the relative goodness of fit. The model with the highest coefficient of determination and lowest χ^2 and $RMSE$ was selected as the best model describing the drying behavior of the investigated meat samples. The coefficient of determination (R^2), the root mean square error ($RMSE$) and the chi-square (χ^2) are described by equations (3.5)-(3.7) as follows (Doymaz, 2007; Wiriyaumpaiwong and Jamradloedluk, 2012):

$$R^2 = \frac{\sum_{i=1}^{n}\left(MR_{pre,i}-\overline{MR}_{pre,i}\right)^2}{\sum_{i=1}^{n}\left(MR_{exp,i}-\overline{MR}_{exp,i}\right)^2} \qquad (3.5)$$

$$RMSE = \left[\frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}}\left(\mathrm{X_{pre,i}} - \mathrm{X_{exp,i}}\right)^2\right]^{1/2} \qquad (3.6)$$

$$\chi 2\, \frac{\sum_{\mathrm{i=1}}^{\mathrm{N}}\left(\mathrm{X_{exp,i}}-\mathrm{X_{pre,i}}\right)}{\mathrm{N-n}} \qquad (3.7)$$

where $\overline{\mathrm{MR}}$ = mean moisture ratio

$\mathrm{MR_{exp,I}}$= *i*th experimental moisture ratio values

$\mathrm{MR_{pre,I}}$ = *i*th predicted moisture ratio values

$\mathrm{X_{exp,i}}$= moisture content obtained from the experiment

$\mathrm{X_{pre,i}}$= moisture content predicted by the models

N= number of observations

n= number of constants

3.6 Effective moisture diffusivity calculation

Drying of foods takes place at a constant rate period followed by a falling rate period, which is the dominant period during the drying process (Bal *et al.*, 2010). All phenomena during the falling rate period, such as molecular diffusion, capillary flow, Knudsen flow, hydrodynamic flow and surface diffusion are combined under the term "effective moisture diffusivity" (Erbay and Icier, 2010). According to Fick´s second law of diffusion for slabs, the diffusion is expressed by (Crank, 1975):

$$MR = \frac{M_t-M_e}{M_i-M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} \times \exp\left[-\frac{(2n+1)^2\pi^2 D_{eff}}{4L^2}t\right] \qquad (3.8)$$

where MR= moisture ratio

$\mathrm{M_t}$= mean moisture content at time t (kg water. kg dry matter^{-1})

$\mathrm{M_e}$= equilibrium moisture content (kg water. kg dry matter^{-1})

M_i= initial moisture content ($\text{kg water. kg dry matter}^{-1}$)

n= number of constants

D_{eff}= effective moisture diffusivity ($\text{m}^2.\text{s}^{-1}$)

t= time (s)

L= half thickness of the slice if drying occurs from both sides/ thickness of the slice if drying occurs from only one side (m)

For long drying times *n* = 1 and *L* is the half thickness of the slice if drying occurs from both sides, or *L* is the thickness of the slice if drying occurs from only one side, then eq. (3.8) can be reduced to the form (Brooker *et al.*, 1992; Erbay and Icier, 2010):

$$MR = \frac{M_t - M_e}{M_i - M_e} = \frac{8}{\pi^2} \exp\left[-D_{eff} t \left(\frac{\pi^2}{4L^2}\right)\right] \tag{3.9}$$

Equation (3.9) can be expressed in the form:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) + \left[-D_{eff}\left(\frac{\pi^2}{4L^2}\right)\right] t \tag{3.10}$$

which is the equation of a straight line of the form: $y = y_0 + ax$ (Mota *et al.*, 2010), where:

$$y_0 = \ln\left(\frac{8}{\pi^2}\right) \tag{3.11}$$

$$a = -D_{eff}\left(\frac{\pi^2}{4L^2}\right) \tag{3.12}$$

where a= constant

By plotting $\ln(MR)$ against time a straight line is obtained and D_{eff} can be then calculated.

3.7 Activation energy calculation

The activation energy indicates how much energy is required to remove moisture from the product. The effective moisture diffusivity varies with temperature and this could be generally described by an Arrhenius equation (Madamba *et al.*, 1996; Vega *et al.*, 2007):

$$D_{eff} = D_0 \exp\left(-10^3 \frac{E_a}{R(T+273.15)}\right) \tag{3.13}$$

where D_0= diffusivity for an infinite temperature ($\mathrm{m^2.s^{-1}}$)
E_a= activation energy for diffusion ($\mathrm{kJ.mol^{-1}}$)
R= universal gas constant ($\mathrm{kJ.mol^{-1}.K^{-1}}$)

The value of E_a shows the sensibility of the diffusivity against temperature (Kaymak-Ertekin, 2002):

$$\ln(D_{eff}) = \ln(D_0) - 10^3 \frac{E_a}{R} \times \frac{1}{(T+273.15)} \tag{3.14}$$

Plotting $\ln(D_{eff})$ against (1/T) a straight line is obtained and D_0 and E_a can be then calculated:

$$y_0^{'} = \ln(D_0) \tag{3.15}$$

$$a^{'} = -10^3 \frac{E_a}{R} \tag{3.16}$$

3.8 Organoleptic properties and sensory analysis

All the sensory analysis was in accordance with ISO standards (ČSN ISO 8589:2008, ČSN ISO 8587: 2008, ČSN ISO 5496:2009, ČSN ISO 5492: 2009, ČSN ISO 6658: 2009, ČSN ISO 13300-1:2011, ČSN ISO 13300-2:2011, ČSN ISO 16820:2010, CSN EN ISO 8586-2:2008, CSN EN ISO 8586-2:2008). Two independent panels, first of 15 expert panelists and second of 22 panelists, were organized. Panelists were selected and trained. Each panelist 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 3.3. Original sensory analysis form see in Annex A. First panel evaluated only four samples (C samples of eland and beef in DPSD and LO). Based on the results of the first panel, the second panel evaluated only samples dried in DPSD with 4 pre-treatments (TM, TMH, TMP, and TMCCL).

Table 3.3 Parameters and orientation.

Parameter / Orientation	0	100
General look	like	dislike
General likableness of taste	like	dislike
General likableness of meat taste*	like	dislike
Intensity of meat taste*	slightly intensive	extremely intensive
Intensity of fatty taste*	slightly intensive	extremely intensive
Color intensity	light	dark
Color likableness	like	dislike
Hardness	very soft	very hard
Mastic ability	bad	very gut
Fibrousness*	soft	chewy
Sappiness	juicy	dry
General structure	excellent	bad

*these parameters were evaluated only by the first panel whose aim was to evaluate difference between drying in DPSD and LO and differences between eland and beef

The surface color values of the jerky samples were measured with a spectrophotometer CM-2600d (MINOLTA) in the CIE L* a* b* color space using software Spectra Magic CM-S100w).

To evaluate the effect of different pretreatments on the overall combined color of dried meat, the index ΔE as given by the following equation (Chua *et al.*, 2000; Kashaninejad and

Tabil, 2004) was calculated by taking the color of the control sample (C) as the reference value.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \qquad (3.16)$$

where $\Delta L = L - L_{base}$

$\Delta a = a - a_{base}$

$\Delta b = b - b_{base}$

L, a and b= colors coordinates of the sample

L_{base}, a_{base} and b_{base}= color coordinates of the control C sample

3.9 Statistical analysis

Data were analyzed with the IBM SPSS Statistics software version 22.0 (IBM, US) for analysis of variance of main (fixed) effects, as well as all interactions among fixed effects. As a standard test was chosen One-way Anova test and Tukey test was used as a post hoc test. T-test was used in this study too.

4 RESULTS AND DISCUSSION

4.1 Physicochemical characteristic of raw meat

Results of physicochemical characteristics of raw meat are shown in Table 4.1. A comparison of eland and beef meat showed lower pH values (5.497, p <0.001) of eland sample. According to Huff-Lonergan and Lonergan (2005) and Muchenje *et al.* (2009) this result leads to the development of lower water holding capacity (44.87± 2.17) in an eland. Warner- Bratzler shear force for beef was higher, but statistically (p< 0.05) doesn´t differ from eland. A higher WB shear force for beef in comparison with eland meat was already published by Bartoň *et al.* (2014). Pigment concentrations in the muscles of eland were higher (4339.36, p < 0.05) and therefore was darker (lower value L= 38.88, p < 0.05) and contained less redness (a= 9.13) and less yellowness (b= 6.86). The significant difference (p <0.001) was found for yellowness (b), caused by the low accumulation level of carotenoids of eland (Slifka *et al.*, 1999) compared to a high accumulation level of cattle (Urich, 1994). These data are in accordance with a lighter color found in beef compared to eland (Bartoň *et al.*, 2014) and compared to other venison (Koch *et al.*, 1995; Rincker *et al.*, 2006; Farouk *et al.*, 2007). Weight loss during cooking was almost the same for both samples of eland and beef as well as water content. Muscles of eland content less of crude fat (0.84, p <0.05) as it is already noted by La Chevallerie *et al.* (1971).

Table 4.1 Results of physicochemical characteristics of raw meat.

	Eland	Beef
pH 24 hours after slaughter	5.497 ± 0.006	5.553 ± 0.006
Dry matter content (%)	23.03 ± 0.27	23.35 ± 0.34
Warner-Bratzler Shear force (N)	68.84 ± 15.43	89.32 ± 19.68
Pigment concentration (mg.kg^{-1})	4339.36 ± 51.57	3482.41 ± 103.14
Weight loss during cooking (%)	27.23 ± 0.18	27.55 ± 0.42
Water holding capacity (%)	44.87 ± 2.17	52.13 ± 5.97
Water content (%)	75.05 ± 0.05	75.2 ± 0.11
Crude fat content (%)	0.84 ± 0.09	2.8 ± 0.53
Color L	38.88 ± 2.59	42.41 ± 1.64
a	9.13 ± 1.05	10.33 ± 0.74
b	6.86 ± 1.02	9.72 ± 0.49

4.2 Drying performance of eland jerky as compared to beef jerky

As it is clear from Table 3.1 the data of all experimental sets show a relative uniformity which is due to similar climatic conditions during each solar drying test. The values of mean ambient temperature, RH and solar radiation during all experiments were 24.4±1.7°C, 48.9±8.4% and 564±185.8 W.m^{-2}, respectively. Further the values of mean drying air temperature, drying air RH and mean drying air velocity during all solar drying experiments were 48.3±5.6°C, 18.5±6.0% and 0.9±0.1 m.s^{-1}, respectively. For further performance analyses the data from experiment run B were considered to represent optimal average values. The ambient temperature, ambient RH and solar radiation curves during the typical solar drying experiment B are presented in Figure 4.1, and the daily mean values of the drying chamber temperature, drying chamber RH and drying air velocity are presented in Figure 4.2. From this figure, 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 954.5 W.m^{-2}, the second day 864.3 W.m^{-2}. Ambient temperature varied during the whole experimental run between 20.6°C and 26.8°C, and ambient RH between 35.7 % and 64.1 %. Corresponding daily mean values of the drying air temperature and RH in the drying chamber of the DPSD varied from 24.5±1.7°C to 60.3±0.9°C and 11.9±0.5% to 60.3±4.9%. Obtained drying temperatures in the DPSD 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 0.04 to 1.87 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 DPSD 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.

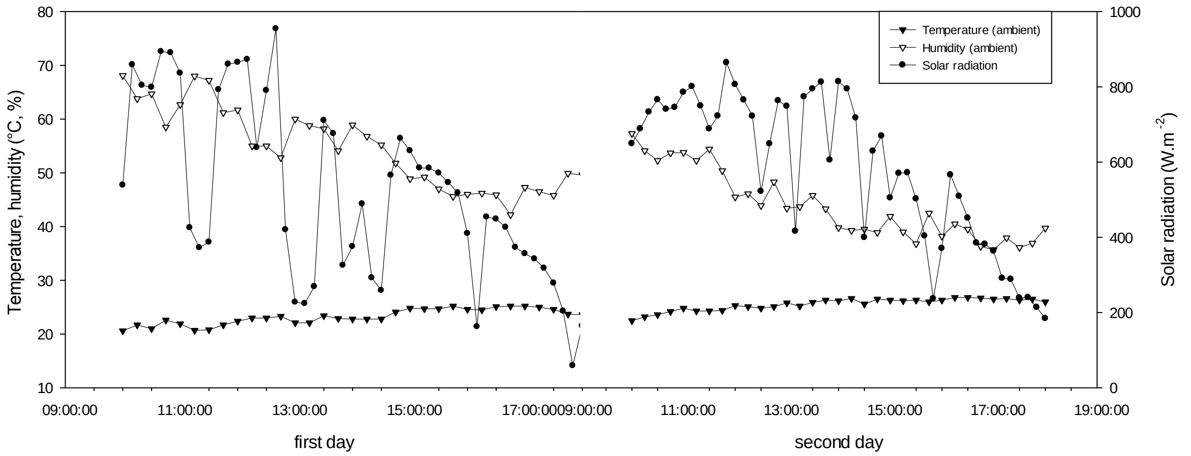

Figure 4.1 Ambient temperature, ambient relative humidity and solar radiation.

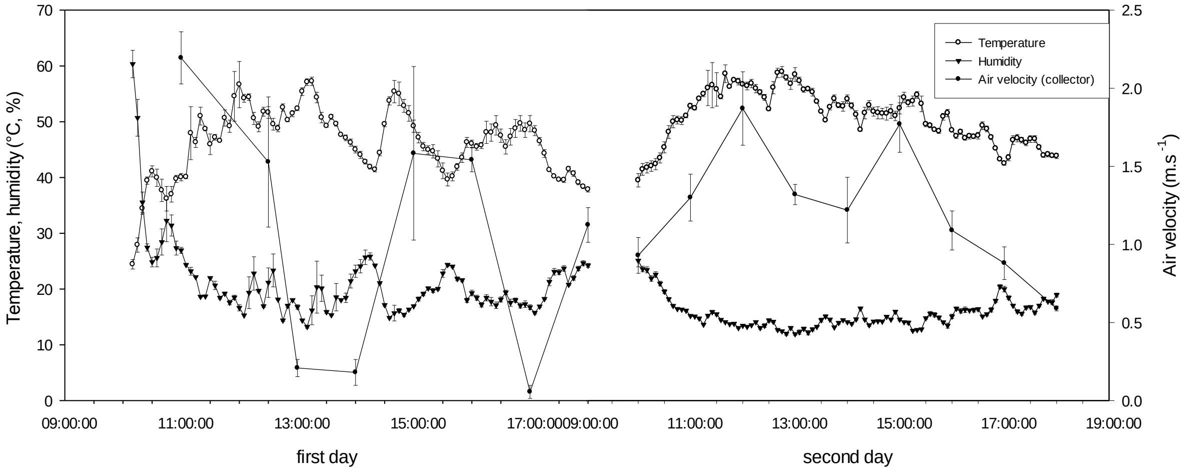

Figure 4.2 Drying chamber air temperature, relative humidity and air velocity.

The drying curves (time versus *MR*) of the eland and beef samples with all pretreatments TM, TMP, TMH, TMCCL and C dried in the DPSD and LO are presented in Figure 4.3. The *MR* decreased exponentially with the time in both meat samples and all the used selected pretreatments which is in agreement with the results reported in previous studies (Perea-Flores *et al.*, 2012). Values of eland and beef *MR*s were analyzed using *t*-test. There was no statistically significant difference (95% confidence level) between eland and beef meat *MR* dried in the DPSD or between eland and beef meat dried in LO. It means from a statistical point of view, it is possible to conclude that the drying behavior of eland and beef meat is the same, even though beef generally contains more lipids, which could affect the drying process (Faith *et al.*, 1998) as well as beef with higher water holding capacity. From Figure 4.3 it is also evident that the drying rate in the DPSD was higher as compared to the LO mainly in the initial period of drying. This is due to higher maxim drying temperatures in the solar drier as compared to the LO. 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).

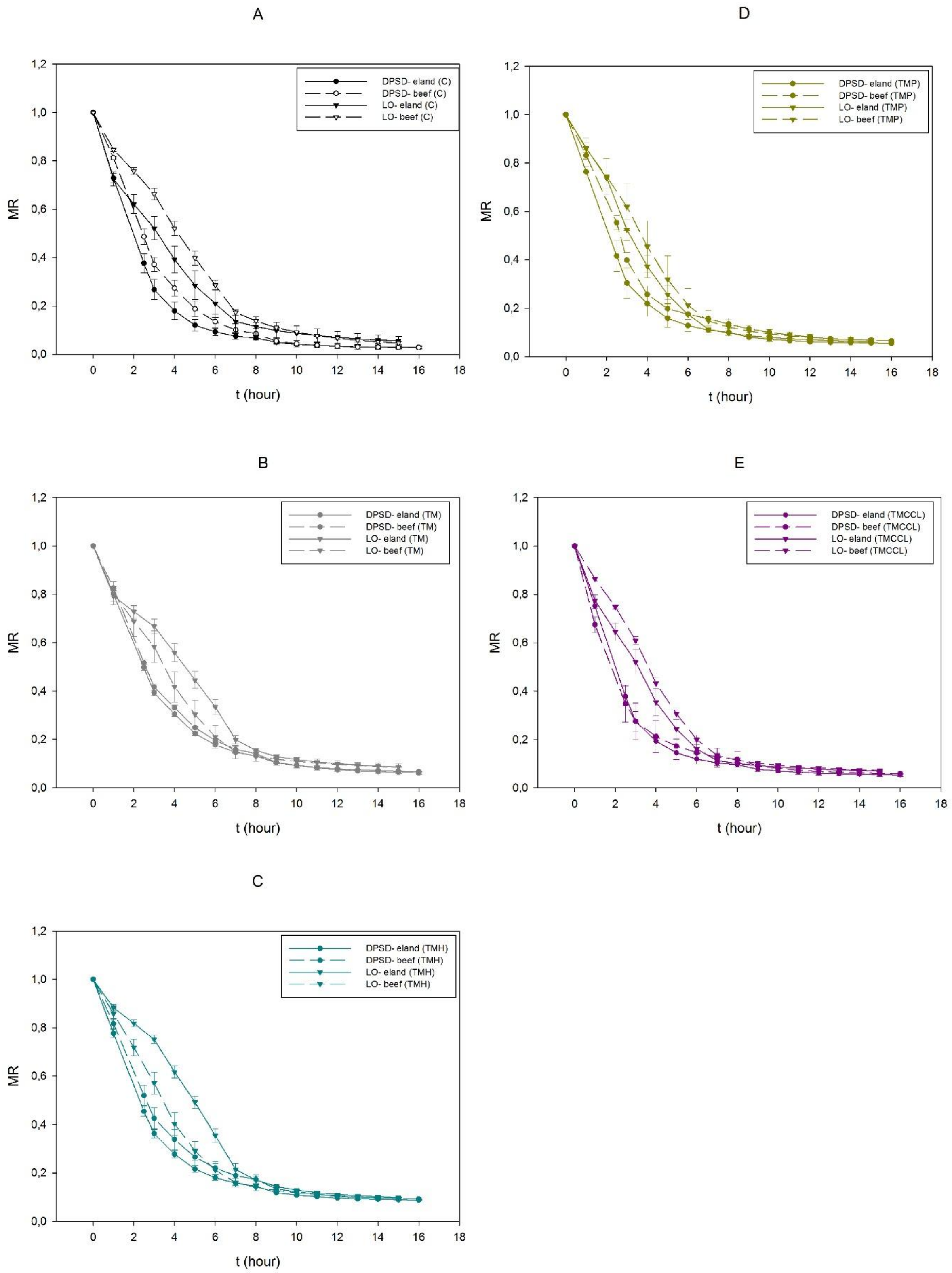

Figure 4.3 Experimental moisture ratio of samples of eland meat and beef dried in the DPSD and LO with standard deviations ((a) control samples; (b) traditional marinade, TM; (c) traditional marinade with honey samples (TMH); (d) traditional marinade with fresh pineapple juice samples (TMP); (e) traditional marinade with Coca Cola samples (TMCCL).

The average initial and final moisture contents of eland meat samples for C, TM, TMH, TMP and TMCCL dried in the solar drier were 2.79± 0.04 kg.kg^{-1} (d.b.) and 0.08±0.01 kg.kg^{-1} (d.b.), 2.51±0.016 kg.kg^{-1} (d.b.) and 0.17±0.01 kg.kg^{-1} (d.b.), 2.39±0.04 kg.kg^{-1} (d.b.) and 0.21±0.01 kg.kg^{-1} (d.b.), 2.63±0.06 kg.kg^{-1} (d.b.) and 0.14±0.01 kg.kg^{-1} (d.b.), 2.71±0.7 kg.kg^{-1} (d.b.) and 0.15±0.01 kg.kg^{-1} (d.b.), respectively. From these 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 analyze the influence of drying pre-treatments on the *MR* of dried eland meat. Data were tested with the Tukey test as the pairwise multiple comparison procedure with 95% confidence level and the results are summarized in Table 4.2. From this table is evident that there are a statistically significant differences in *MR* between the pre-treated samples and the control sample without pre-treatment. 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 behavior (Albright *et al.*, 2003; Bower *et al.*, 2003; Calicioglu *et al.*, 2003; Nummer *et al.*, 2004; DiPersio *et al.*, 2007).

Table 4.2 All pairwise multiple comparison (Tukey test) of MR between treatments used.

Comparison	Diff of Ranks	q	P<0.05
TMH vs C	59	9.05	Yes
TMH vs TMCCL	43	6.596	Yes
TMH vs TMP	27	4.142	Yes
TMH vs TM	6	0.92	No
TM vs C	53	8.13	Yes
TM vs TMCCL	37	5.676	Yes
TM vs TMP	21	3.221	No
TMP vs C	32	4.909	Yes
TMP vs TMCCL	16	2.454	No
TMCCL vs C	16	2.454	No

4.3 Mathematical modeling of drying curves

Experimental moisture content data (d.b.) from both solar drying and on LO drying were converted to more useful *MR* values and compared to drying time. Two representative pre-treatments (TM, TMH) and control sample C were selected according to the results shown in the Table 4.2., where statistical differences were found just between some pre-treatments. Ten thin layer drying models, commonly cited in literature, shown in Table 3.2, were fitted with experimental data of selected pre-treatments (TM, TMH) and control sample C using the software SigmaPlot 12.5 (SPSS, Inc.). Data were evaluated by the coefficient of determination (R^2), the root mean square error ($RMSE$) and the reduced chi-square (χ^2) test. The results of this comparison are given in Table 4.3. As may be seen the best suitability in describing the drying kinetics in case of solar drying for both eland meat and beef was based on highest value of R^2 and lowest values of $RMSE$ and χ^2 as shown by the Two term model apart from one case of beef meat, the C sample, where the Diffusion approximate and Verma et al. models show the best results. The Two term model shows a good predicting capacity and the values of R^2, $RMSE$ and χ^2 ranged between 0.9954 to 0.9972, 0.0150 to 0.0182 and 0.00030 to 0.00043, respectively. The Diffusion approximate and Verma et al. models, in case of C sample of beef, differ in the value of χ^2 with the difference of 0.00002 only.

In case of LO, the Wang and Singh model was evaluated as the best one for both eland and beef meat. Except of the beef C and TMH samples where the best results were obtained by Diffusion approximate model with the highest R^2 (0.9928), lowest $RMSE$ (0.0267) and χ^2 (0.00088) and the Two term model with highest R^2 (0.9875), lowest $RMSE$ (0.0327) and χ^2 (0.00143), respectively. It is necessary to point out that the differences between the best values of Wang and Singh model and Diffusion approximate model (beef C sample) and between Wang and Singh model and Two term model (beef TMH sample) are quite insignificant. The Wang and Singh model shows good predicting capacity and the values of R^2, $RMSE$ and χ^2 ranged between 0.9827 and 0.9944, 0.0210 and 0.0416, 0.0005 and 0.0021, respectively, see Table 4.4.

Table 4.3 Statistical results of mathematical models and their constants and coefficients for eland and beef jerky dried in DPSD an LO (SEM, standard error).

Drier	Meat	Treat.	Model name	R^2	RMSE	x^2	Constants							
								SEM		SEM		SEM		SEM
DPSD	Eland	C	Page	0.9909	0.0256	0.00074	k=0.3780	0.0311	n=1.0348	0.0623				
			Modified Page	0.9909	0.0013	0.00074	k=0.3905	0.0144	n=1.0348	0.0623				
			Two term exp.	0.9914	0.0249	0.00070	a=0.5887	0.1737	k=0.4951	0.1186				
			Diff. approximate	0.9948	0.0194	0.00046	a=0.0082	0.0147	k=-0.0875	0.1314	b=-4.6943	7.2337		
			Verma et al.	0.9948	0.0194	0.00046	a=0.0082	0.0147	k=-0.0875	0.1314	g=0.4107	0.0202		
			Logarithmic	0.9952	0.0186	0.00042	a=1.0007	0.0192	k=0.4352	0.0175	c=0.0260	0.0074		
			Newton	0.9907	0.0258	0.00071	k=0.3930	0.013						
			Henderson and P.	0.9910	0.0254	0.00073	a=1.0166	0.0243	k=0.3991	0.0159				
			Two term*	**0.9954**	**0.0182**	**0.00043**	**a=1.0140**	**0.0234**	**b=0.0110**	**0.0178**	**k0=0.4230**	**0.0241**	**k1=-0.0685**	**0.12**
			Wang and Singh	0.9796	0.0383	0.00178	n=0.7687	0.0955	a=0.2956	0.1714	b=-0.6717	0.1468		
		TM	Page	0.9861	0.0315	0.00113	k=0.3194	2.89E-02	n=0.8939	0.0533				
			Modified Page	0.9861	0.0020	0.00113	k=0.2789	0.0115	n=0.8939	0.0533				
			Two term exp.	0.9891	0.0280	0.00089	a=0.4243	0.118	k=0.4646	0.1367				
			Diff. approximate	0.9960	0.0169	0.00035	a=0.0177	0.0189	k=-0.0820	0.0737	b=-3.7016	3.4863		
			Verma et al.	0.9960	0.0169	0.00035	a=0.9823	0.0189	k= 0.3036	0.0152	g=-0.0820	0.0737		
			Logarithmic	0.9963	0.0162	0.00032	a=0.9698	0.0161	k=0.3342	0.0122	c=0.0581	0.0076		
			Newton	0.9831	0.0347	0.00128	k=0.2734	0.0101						
			Henderson and P.	0.9831	0.0347	0.00136	a=0.9976	0.0306	k=0.2727	0.0131				
			Two term*	**0.9966**	**0.0155**	**0.00031**	**a=0.9999**	**0.0244**	**b=0.0247**	**0.0236**	**k0=0.3161**	**0.0187**	**k1=-0.0614**	**0.0661**
			Wang and Singh	0.9881	0.0291	0.00103	n=0.9601	0.0977	a=1.8743	4.8459	b=-2.1567	4.8284		
		TMH	Page	0.9773	0.0384	0.00167	k=0.9773	0.0391	n=0.7740	0.0575				
			Modified Page	0.9773	0.0030	0.00167	k=0.2946	0.017	n=0.7740	0.0575				
			Two term exp.	0.9772	0.0385	0.00168	a=0.3459	0.179	k=0.5903	0.3485				
			Diff. approximate	0.9958	0.0166	0.00033	a=0.9370	0.0338	k=0.3558	0.0231	b=-0.0604	0.1127		
			Verma et al.	0.9958	0.0166	0.00033	a=0.9370	0.0338	k= 0.3558	0.0231	g=-0.0215	0.0389		
			Logarithmic	0.9963	0.0156	0.00030	a=0.9376	0.0158	k=0.3783	0.0136	c=0.0858	0.0067		
			Newton	0.9608	0.0505	0.00271	k=0.2802	0.0153						
			Henderson and P.	0.9617	0.0499	0.00282	a=0.9722	0.044	k=0.2716	0.0193				
			Two term*	**0.9963**	**0.0155**	**0.00031**	**a=0.9491**	**0.0357**	**b=0.0731**	**0.0363**	**k0=0.3705**	**0.0266**	**k1=-0.0120**	**0.0363**
			Wang and Singh	0.9848	0.0315	0.00120	n=0.8415	0.0946	a=0.4151	0.312	b=0.0182	0.2921		

Note: extrabold type signs the most appropriate mathematical model.

Table 4.3 (Continued) 1

Drier	Meat	Treat.	Model name	R^2	RMSE	χ^2	Constants							
								SEM		SEM		SEM		SEM
DPSD	Beef	C	Page	0.9948	0.0205	0.00047	k=0.2630	0.0186	n=1.1214	0.048				
			Modified Page	0.9948	0.0008	0.00047	k=0.3039	0.0073	n=1.1214	0.048				
			Two term exp.	0.9947	0.0206	0.00048	a=1.6857	0.0845	k=0.4074	0.0205				
			Diff. approximate*	**0.9972**	**0.0151**	**0.00028**	**a=1.1414**	**0.0303**	**k=0.3504**	**0.0104**	**b=37.7957**	**3371.028**		
			Verma et al.*	**0.9972**	**0.0151**	**0.00028**	**a=-0.1414**	**0.0303**	**k=13.2431**	**1181.0657**	**g=0.3504**	**0.0104**		
			Logarithmic	0.9942	0.0216	0.00057	a=1.0278	0.0214	k=0.3310	0.0153	c=0.0112	0.0102		
			Newton	0.9925	0.0245	0.00064	k=0.3099	0.0086						
			Henderson and P.	0.9937	0.0225	0.00057	a=1.0344	0.0206	k=0.3197	0.0102				
			Two term	0.9972	0.0151	0.00030	a=1.1414	NAN	b=-0.1941	NAN	k0=0.3504	NAN	k1= 3172.8363	NAN
			Wang and Singh	0.9867	0.0327	0.00130	n=1.0285	0.1091	a=-3.0096	11.087	b=2.7268	11.068		
		TM	Page	0.9891	0.0285	0.00092	k=0.2849	0.0241	n=0.9373	0.0493				
			Modified Page	0.9891	0.0016	0.00092	k=0.2620	0.0091	n=0.9373	0.0493				
			Two term exp.	0.9915	0.0251	0.00072	a=0.4672	0.1069	k=0.4002	0.0914				
			Diff. approximate	0.9955	0.0182	0.00040	a=0.9913	0.0142	k=0.2778	0.0132	b=-0.4179	0.4163		
			Verma et al.	0.9955	0.0182	0.00040	a=0.9913	0.0142	k=0.2778	0.0132	g=-0.1161	0.1109		
			Logarithmic	0.9960	0.0172	0.00036	a=0.9821	0.0169	k=0.3073	0.012	c=0.0489	0.0087		
			Newton	0.9881	0.0298	0.00094	k=0.2590	0.008						
			Henderson and P.	0.9881	0.0297	0.00100	a=1.0062	0.0259	k=0.2606	0.0105				
			Two term*	**0.9963**	**0.0165**	**0.00036**	**a=0.0151**	**0.0211**	**b=1.0124**	**0.0227**	**k0=-0.0824**	**0.0951**	**k1=0.2905**	**0.0174**
			Wang and Singh	0.9893	0.0282	0.00096	n=1.0315	0.1034	a=-2.4891	7.8269	b=2.2288	7.8105		
		TMH	Page	0.9836	0.0334	0.00126	k=0.3157	0.0289	n=0.8271	0.0502				
			Modified Page	0.9836	0.0022	0.00126	k=0.2480	0.0107	n=0.8271	0.0502				
			Two term exp.	0.9860	0.0308	0.00108	a=0.3528	0.1284	k=0.4960	0.2045				
			Diff. approximate	0.9961	0.0162	0.00032	a=0.0426	0.0328	k=-0.0442	0.0523	b= -6.5384	8.1114		
			Verma et al.	0.9961	0.0162	0.00032	a=0.0426	0.0328	k=-0.0442	0.0523	g=0.2891	0.0183		
			Logarithmic	0.9966	0.0153	0.00028	a=0.9418	0.015	k=0.3162	0.0113	c=0.0832	0.0075		
			Newton	0.9731	0.0428	0.00194	k=0.2396	0.0103						
			Henderson and P.	0.9737	0.0422	0.00202	a=0.9774	0.0358	k=0.2337	0.0133				
			Two term*	**0.9967**	**0.0150**	**0.00029**	**a=0.9666**	**0.0374**	**b=0.0562**	**0.0391**	**k0=0.3034**	**0.0225**	**k1=-0.0274**	**0.0475**
			Wang and Singh	0.9894	0.0269	0.00088	n=0.9768	0.0974	a=3.0891	13.4147	b=-3.3527	13.3986		

Note: extrabold type signs the most appropriate mathematical model.

Table 4.3 (Continued) 2

Drier	Meat	Treat.	Model name	R^2	RMSE	x^2	Constants							
								SEM		SEM		SEM		SEM
LO	Eland	C	Page	0.9913	0.0262	0.00078	k=0.2573	0.0202	n=0.9735	0.0454				
			Modified Page	0.9913	0.0014	0.00078	k=0.2480	0.0075	n=0.9735	0.0454				
			Two term exp.	0.9917	0.0255	0.00074	a=0.0361	0.035	k=6.5849	6.6326				
			Diff. approximate	0.9931	0.0233	0.00067	a=9.8491E-005	0.0007	k=-0.3988	0.4847	b=-0.6284	0.7752		
			Verma et al.	0.9931	0.0233	0.00067	a=9.8491E-005	0.0007	k=-0.3988	0.4847	g=0.2506	0.0082		
			Logarithmic	0.9921	0.0250	0.00077	a=0.9756	0.0242	k=0.2577	0.0168	c=0.0186	0.0169		
			Newton	0.9911	0.0264	0.00075	k=0.2466	0.0067						
			Henderson and P.	0.9913	0.0261	0.00078	a=0.9862	0.0221	k=0.2432	0.0087				
			Two term	0.9932	0.0231	0.00071	a=7.2030E-005	0.0006	b=0.9920	0.022	k0=-0.4184	0.5523	k1=0.2484	0.0108
			Wang and Singh*	**0.9944**	**0.0210**	**0.00055**	**n=1.1520**	**0.0938**	**a=-0.5775**	**0.2908**	**b=0.3418**	**0.2791**		
		TM	Page	0.9798	0.0421	0.00203	k=0.1335	0.0206	n=1.1791	0.0816				
			Modified Page	0.9798	0.0036	0.00203	k=0.1813	0.0067	n=1.1791	0.0816				
			Two term exp.	0.9808	0.0411	0.00193	a=1.7238	0.1169	k=0.2495	0.0186				
			Diffusion	0.9808	0.0411	0.00208	a=-0.9422	7.1553	k=0.4021	0.7382	b=0.6389	1.6734		
			Verma	0.9808	0.0411	0.00208	a=-0.9422	7.1551	k=0.4021	0.7382	g=0.2569	0.2034		
			Logarithmic	0.9751	0.0468	0.00269	a=1.0550	0.0532	k=0.1732	0.0256	c=-0.0384	0.0556		
			Newton	0.9728	0.0488	0.00254	k=0.1850	0.0083						
			Henderson	0.9739	0.0479	0.00262	a=1.0278	0.0378	k=0.1901	0.0112				
			Two term	0.9815	0.0403	0.00217	a=-0.9269	5.0355	b=1.8974	5.0469	k0=0.4311	0.6692	k1=0.2585	0.1665
			Wang and Singh*	**0.9869**	**0.0339**	**0.00141**	**n=2.1680**	**0.3324**	**a=-0.1383**	**0.0137**	**b=0.0034**	**0.0035**		
		TMH	Page	0.9796	0.0452	0.00233	k=0.0770	0.0155	n=1.4184	0.1044				
			Modified Page	0.9796	0.0041	0.00233	k=0.1640	0.0056	n=1.4184	0.1044				
			Two term exp.	0.9819	0.0425	0.00207	a=1.9873	0.0855	k=0.2623	0.0143				
			Diffusion	0.9819	0.0425	0.00223	a=-0.9178	1.7335	k=0.5362	0.4305	b=0.4833	0.532		
			Verma	0.9819	0.0425	0.00223	a=1.9178	1.7335	k=0.2592	0.0799	g=0.5362	0.4305		
			Logarithmic	0.9641	0.0599	0.00441	a=1.1426	0.0769	k=0.1556	0.0299	c=-0.0724	0.0849		
			Newton	0.9513	0.0698	0.00520	k=0.1671	0.0104						
			Henderson	0.9610	0.0624	0.00446	a=1.0882	0.0487	k=0.1817	0.0131				
			Two term	0.9712	0.0537	0.00384	a=1.1876	0.0698	b=-0.7497	28894404.79	k0=0.1983	0.0153	k1=13852.9168	3.85393E+11
			Wang and Singh*	**0.9827**	**0.0416**	**0.00213**	**n=3.0732**	**0.6259**	**a=-0.1111**	**0.0079**	**b=0.0002**	**0.0004**		

Note: extrabold type signs the most appropriate mathematical model.

Table 4.3 (Continued) 3

Drier	Meat	Treat.	Model name	R^2	RMSE	x^2	Constants							
								SEM		SEM		SEM		SEM
LO	Beef	C	Page	0.9924	0.0274	0.00086	k=0.1080	0.0123	n=1.3492	0.0631				
			Modified Page	0.9924	0.0015	0.00086	k=0.1921	0.0044	n=1.3492	0.0631				
			Two term exp.	0.9925	0.0272	0.00084	a=1.8989	0.0636	k=0.2938	0.0119				
			Diff. approximate*	**0.9928**	**0.0267**	**0.00088**	**a=-106.4957**	**891000.46**	**k=0.3798**	**12.1979**	**b=0.9924**	**63.3676**		
			Verma et al.	0.9722	0.0524	0.00338	a=-0.0837	418165.18	k=0.1990	914.9071	g=0.1991	65.4965		
			Logarithmic	0.9820	0.0422	0.00220	a=1.1175	0.0465	k=0.1796	0.0219	c=-0.0702	0.0474		
			Newton	0.9722	0.0524	0.00293	k=0.1991	0.0099						
			Henderson and P.	0.9775	0.0472	0.00254	a=1.0677	0.0384	k=0.2118	0.0122				
			Two term	0.9842	0.0396	0.00209	a=1.1585	0.0567	b=-0.2783	6456245.899	k0=0.2290	0.0143	k1=5630.6529	2.31974E+11
			Wang and Singh	**0.9920**	**0.0282**	**0.00098**	**n=2.2150**	**0.2745**	**a=-0.1409**	**0.0108**	**b=0.0030**	**0.0026**		
		TM	Page	0.9837	0.0368	0.00155	k=0.2009	0.024	n=1.0607	0.0672				
			Modified Page	0.9837	0.0027	0.00155	k=0.2202	0.0084	n=1.0607	0.0672				
			Two term exp.	0.9834	0.0371	0.00158	a=1.5276	0.171	k=0.2682	0.0267				
			Diff. approximate	0.9873	0.0326	0.00130	a=8.4677E-005	0.0006	k=-0.4395	0.4852	b=-0.5175	0.5839		
			Verma et al.	0.9873	0.0326	0.00130	a=8.4677E-005	0.0006	k=-0.4395	0.4852	g=0.2275	0.01		
			Logarithmic	0.9854	0.0349	0.00150	a=1.0014	0.0338	k=0.2496	0.0225	c=0.0329	0.0245		
			Newton	0.9829	0.0378	0.00152	k=0.2219	0.0083						
			Henderson and P.	0.9834	0.0372	0.00158	a=1.0210	0.0308	k=0.2267	0.011				
			Two term	0.9885	0.0309	0.00128	a=0.0002	0.0011	b=1.0320	0.0292	k0=-0.3927	0.4168	k1=0.2357	0.0137
			Wang and Singh*	**0.9905**	**0.0282**	**0.00098**	**n=1.5189**	**0.1614**	**a=-0.2322**	**0.0412**	**b=0.0426**	**0.0284**		
		TMH	Page	0.9798	0.0415	0.00197	k= 0.1892	0.0261	n=1.0842	0.0772				
			Modified Page	0.9798	0.0035	0.00197	k=0.2153	0.009	n=1.0842	0.0772				
			Two term exp.	0.9783	0.0431	0.00212	a=0.6932	0.4437	k=0.2439	0.0938				
			Diff. approximate	0.9840	0.0370	0.00169	a=0.0002	0.001	k=-0.4061	0.4482	b=-0.5516	0.626		
			Verma et al.	0.9840	0.0370	0.00169	a=0.0002	0.001	k=-0.4061	0.4482	g=0.2240	0.0116		
			Logarithmic	0.9838	0.0372	0.00170	a=1.0139	0.036	k=0.2574	0.0241	c=0.0446	0.0252		
			Newton	0.9782	0.0432	0.00199	k=0.2171	0.0092						
			Henderson and P.	0.9801	0.0412	0.00194	a=1.0401	0.0342	k=0.2260	0.0119				
			Two term*	**0.9875**	**0.0327**	**0.00143**	**a=1.0546**	**0.0309**	**b=0.0005**	**0.0023**	**k0=-0.2383**	**0.0155**	**k1=-0.3373**	**0.3281**
			Wang and Singh	**0.9873**	**0.0330**	**0.00134**	**n=1.5951**	**0.1967**	**a=-0.2141**	**0.0382**	**b=0.0312**	**0.024**		

Note: extrabold type signs the most appropriate mathematical model.

According to the fact given above it can be summarized that the Two term model adequately described the drying behavior of both eland and beef jerky in the forced solar drying process (DPSD drier) with drying air temperature. RH and airflow rates of 48.3±5.6°C. 18.5±6.0% and 0.9±0.1 m.s^{-1}, respectively, while the Wang and Singh model best described the drying behavior of eland and beef jerky for standardized drying conditions in LO at 55°C. In both cases the R^2 values are close to unity which implies a good fit of the predicted data with those experimentally measured, namely the relationship between the time and *MR*. This means that the *MR* of the investigated meat samples could be predicted by these models at any time. On the other hand the accuracy of selected mathematical model, which represents the difference between the predicted and experimental values, is estimated by the χ^2 and *RMSE* where the values close to zero indicate high accuracy (Erbay and Icier, 2010). This fact is demonstrated in Figure 4.4 where the experimental data from the solar drying of eland meat are plotted against the data predicted by the Two term model.

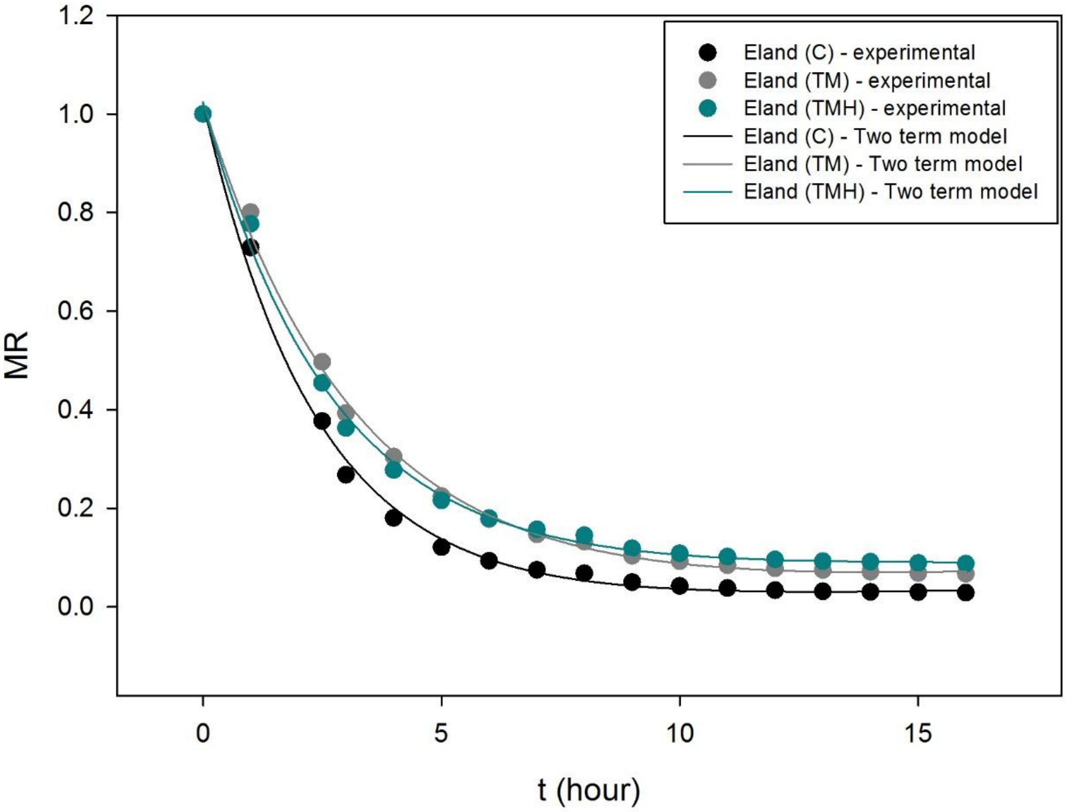

Figure 4.4 Experimental and predicted moisture ratio (the best model) for solar drying of eland: C, TM, TMH samples

Validation of the established model for the solar drying of eland jerky was made by comparing computed *MR*s with the experimentally measured ones. The performance of the Two term model for thin-layer solar drying is illustrated in Figure 4.5. The experimental data are concentrated around a straight line representing data found by computation, which indicates the suitability of the mathematical model in describing the drying behavior of both not treated and marinated eland meat samples. A similar method of mathematical model validation for different, mainly dehydrated plant products with similar results was reported in the literature (Sacilik, 2007; Akpinar, 2008; Doymaz and Ozdemir, 2014). Obtaining drying kinetics data and their modeling is necessary to design, simulate and optimize the drying process of drying facilities. Modelling the drying behavior at the determined condition is important to obtain higher quality dried products, which are provided by controlling and optimizing the process parameters (Clemente *et al.*, 2011). This research brings new knowledge about solar drying behavior of both eland meat itself and eland meat marinated by traditional and modified jerky marinade.

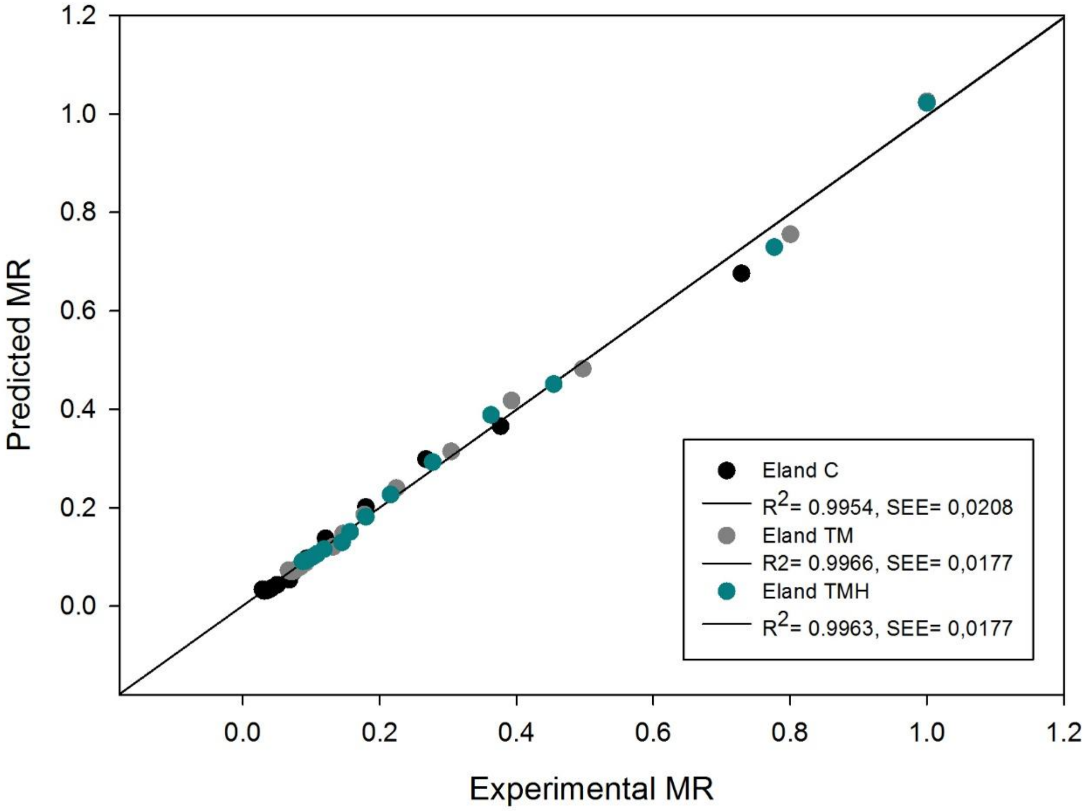

Figure 4.5 Comparison of experimental with predicted moisture ratios from the Two term model of different pre-treatments of eland meat in DPSD.

4.4 Effective moisture diffusivity and activation energy

As described in Figure 4.6 the calculated effective moisture diffusivity (D_{eff}) values ($m^2. s^{-1}$) of selected eland meat for C, TM and TMH samples and beef for C, TM and TMH samples were ranged between 1.4706×10^{-10} and 2.6818×10^{-10}, 1.0986×10^{-10} and 1.809×10^{-10}, 0.98075×10^{-10} and 1.8907×10^{-10}, 1.48149×10^{-10} and 2.10787×10^{-10}, 1.1368×10^{-10} and 1.6696×10^{-10}, 0.95852×10^{-10} and 1.5719×10^{-10}, respectively. All these values are in the standard range for food and agricultural products (Aghbashlo *et al.*, 2010). However, it must be pointed out that there are no available data of effective moisture diffusivity for eland meat in scientific literature. From Figure 4.6 it is evident that the values of D_{eff} decreased with the pre-treatment regardless of the type of meat. This fact can be explained by the content of marinades used as drying pre-treatments. Namely the soya sauce and Worcester sauce as the main components of traditional jerky and mainly the sugar content in the marinade which was combined with honey. In contrast with other types of drying pre-treatments for example based on the addition of salts or oleic acids that increase the values of effective moisture diffusivity (Wiriyaumpaiwong and Jamradloedluk, 2012; Doymaz and Ozdemir, 2014), the higher concentration of sugars may have inhibiting effects on water transfer. The sugar in the marinated meat samples might form a barrier to the movement of water during the drying period because it has higher stickiness and lower moisture diffusivity than water which dominates in the fresh untreated meat samples. This fact was observed by previous studies investigating the influence of sugar based pre-treatments on the drying process of blueberries (Aghbashlo *et al.*, 2010).

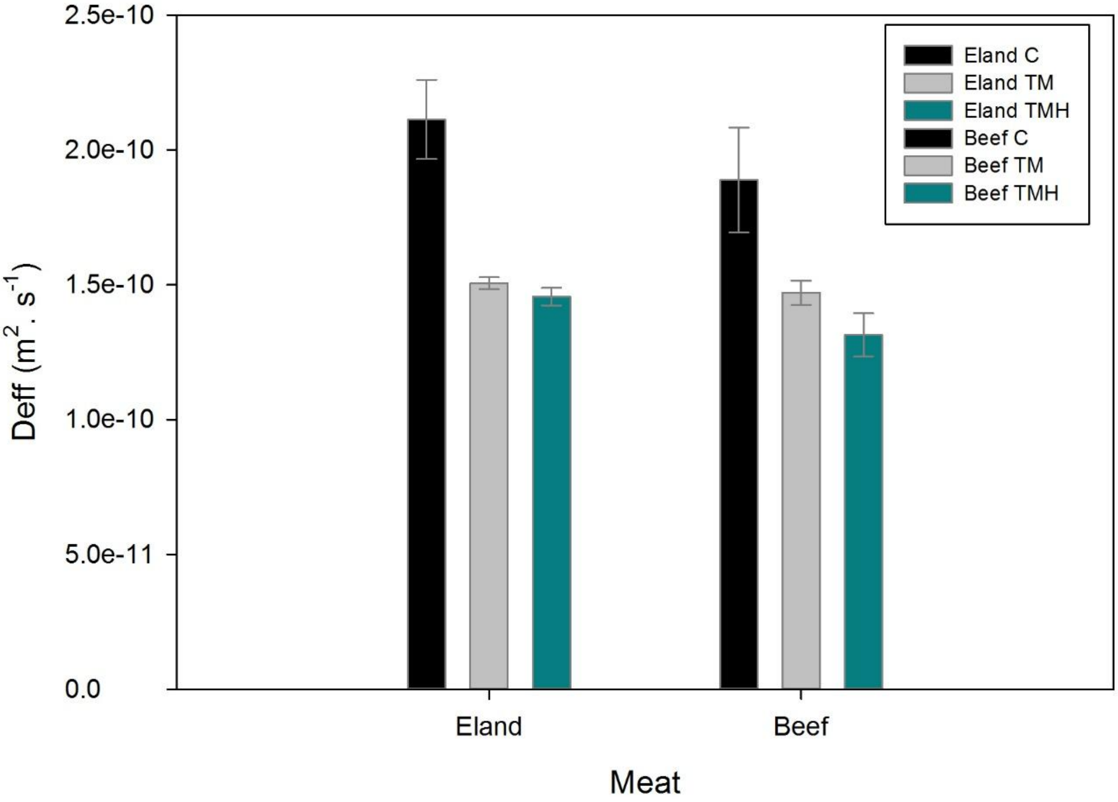

Figure 4.6 The effective moisture diffusivity of eland and beef samples with selected different pre-treatments dried in DPSD with standard deviations.

Vice versa the marinated jerky samples show higher values of the activation energy (E_a) than the control samples. The activation energy was calculated by plotting the ln(D_{eff}) versus reciprocal absolute temperature $1/(T + 273.15)$ indicating Arrhenius dependence, see Figure 4.7. The influence of temperature on D_{eff} of solar dried eland meat is presented by equations (4.1), (4.2) and (4.3) for C, TM and TMH, respectively.

C: $$D_{eff} = 8.57 \times 10^{-7} \exp\left(-\frac{2856.15}{(T+273.15)}\right) \quad (R^2: 0.931) \qquad (4.1)$$

TM: $$D_{eff} = 1.82 \times 10^{-6} \exp\left(-\frac{3002.53}{(T+273.15)}\right) \quad (R^2: 0.9337) \qquad (4.2)$$

TMH: $$D_{eff} = 1.94 \times 10^{-6} \exp\left(-\frac{3153.84}{(T+273.15)}\right) \quad (R^2: 0.9235) \qquad (4.3)$$

The activation energy values were 23.75, 26.22 and 26.97kJ. mol^{-1} for C, TM and TMH samples of eland dried in DPSD, respectively. These values are in agreement with the general range of activation energy between 15 and 40 kJ. mol^{-1} for food as reported by previous studies (Maskan *et al.*, 2002). It is obvious that the TM and TMH resulted in an increase in activation energy required for mass diffusion during solar drying of eland meat. The similar effect of sugars on an increase in activation energy values during food drying were described by previous studies (Das Purkayastha *et al.*, 2013)

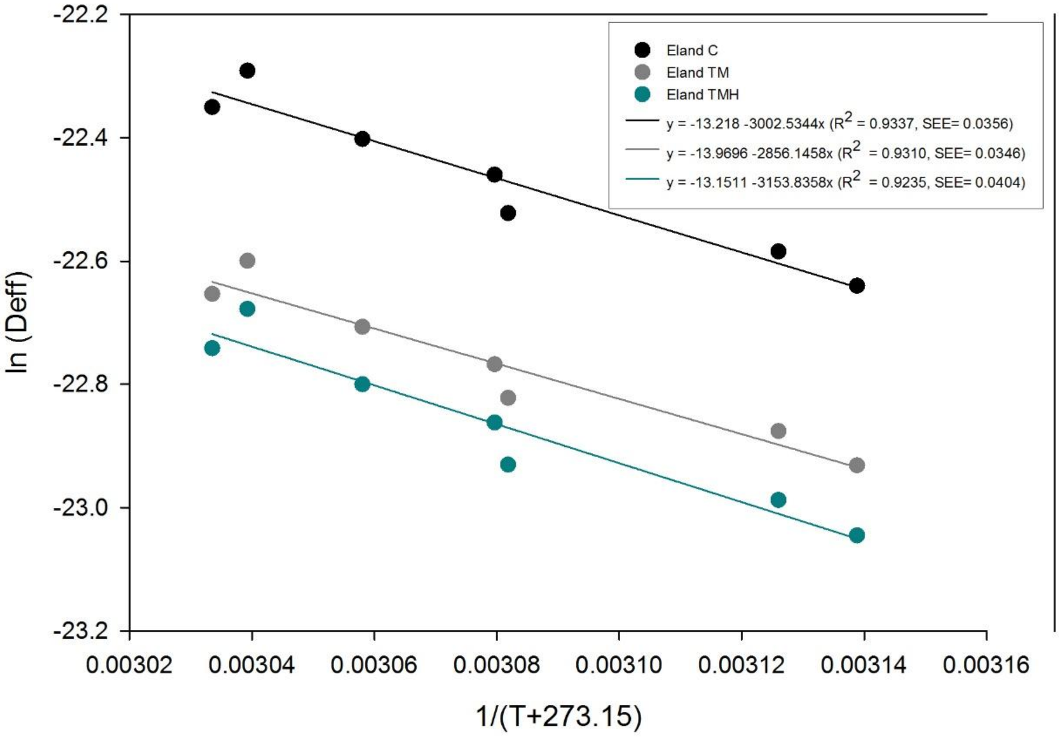

Figure 4.7 Arrhenius-type relationship between effective moisture diffusivity and the reciprocal of absolute temperature (in DPSD).

4.5 Sensory analysis

The results of the first sensory panel are shown in Figure 4.8. This sensory panel aimed to investigate if different drying devices (DPSD and LO) and different kind of meat (eland and beef- both control samples. C) can influence the results of sensory profile analysis.

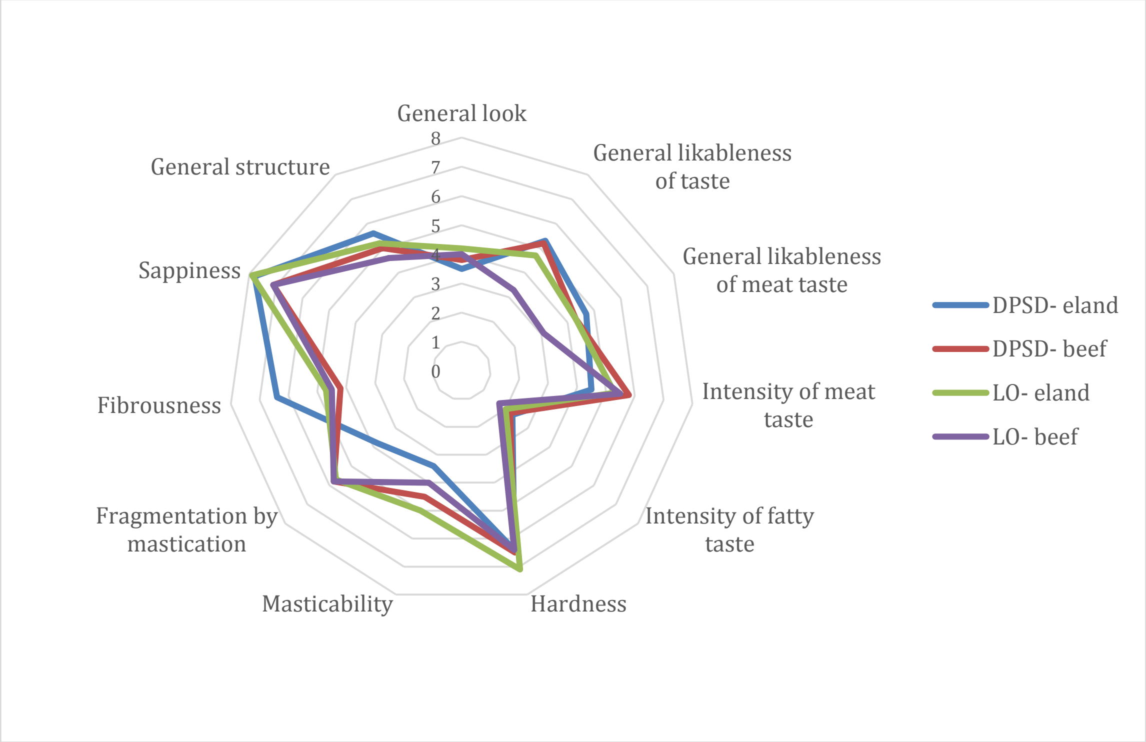

Figure 4.8 Sensory evaluation by profile method of control samples. C of both eland and beef meat dried in DPSD and LO (n= 15).

The results of the sensory profile analysis for the parameter General likableness of taste were transformed and processed by the Friedman test in SPSS Statistic 22. Friedman test ordered all samples in sequence and as the best in the parameter General likableness of taste evaluated a sample of beef meat dried in LO, where the differences between samples of beef dried in LO and eland dried in DPSD as well as beef dried in LO and beef dried in DPSD ($p < 0.05$) were found. This could be due to the higher humidity in LO, which could affect the flavor and odor components, especially by their dilution (Bejerholm and Aaslyng, 2004) in combination with higher water holding capacity (see Table 4.1) of beef meat. On the other hand eland meat dried in DPSD scored in the parameter General look, even the differences between samples were not significant. These findings are in accordance with data published by Speth (2010), where eland meat is considered as very similar to the beef meat. Assessors could not distinguish differences in intensity of fatty taste, even if beef meat contained more fat (as noticed in Table 4.1), but they assessed the beef samples as juicier than the eland samples, which is in accordance 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. Consumers concern about diet and health and low-content of fat is desirable (Resurreccion, 2004), nevertheless juiciness more precisely higher fat content could affect the assessment even of general likableness of taste. As the most important sensory attributes of this type of snack food are texture, color and flavor all together, determined by the selection of the raw material and the effect of numerous technological factors (Konieczny *et al.*, 2007), generally is not possible state that there is a statistical difference ($p< 0.05$) between samples dried in DPSD and LO and between beef and eland meat. This result is in agreement with those obtained by Mapesa *et al.* (2010) where the beef meat dried in a solar drier was not statistically different ($p< 0.05$) from the one dried in the oven. Difference between eland and beef in raw condition (precisely in cooked condition) was evaluated by (Bartoň *et al.*, 2014) and their results on the texture are in agreement with the dried meat in this study.

Based on the results from the first sensory analysis, whereas in most cases was no significant difference between beef and eland meat samples, the second assessment was focused only on eland meat dried in DPSD and the effect of different drying pre-treatments on organoleptic properties assessed by the 22 member panel. Results are shown in Table 4.4.

Table 4.4 Overall sensory evaluation of eland meat samples

	Pre-treatments							
	TM		TMP		TMH		TMCCL	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
General look	4.24^{a}	2.17	**3.24^{a}**	1.92	4.5^{a}	2.46	3.90^{a}	2.05
General likableness of taste	**2.65^{a}**	0.76	3.38^{ab}	1.83	4.61^{b}	1.69	4.34^{ab}	1.48
Color- Intensity	5.46^{ab}	2.32	**4.97^{a}**	2.31	7.63^{c}	1.97	7.06^{bc}	1.87
Color- Likableness	5.12^{b}	1.95	**3.64^{a}**	1.98	4.07^{ab}	1.81	3.81^{ab}	1.64
Hardness	5.42^{ab}	2.45	**5.11^{a}**	2.35	6.99^{b}	1.92	6.39^{ab}	2.07
Mastication	4.96^{a}	2.04	5.23^{a}	1.88	5.55^{a}	2.5	5.96^{a}	2.18
Sappiness	5.56^{a}	2.3	5.72^{a}	2.09	5.59^{a}	1.76	5.45^{a}	2.52
General Texture	4.83^{ab}	1.37	**3.89^{a}**	1.81	6.05^{b}	1.39	5.3^{ab}	2.14

$^{a-c}$ Mean values with different superscripts within a same row are significantly different ($p < 0.05$). Extrabold type signs the best evaluated parameter for the pre-treatment.

As the best eland meat sample dried in DPSD was evaluated the one treated with traditional jerky marinade with fresh pineapple juice (TMP). This treatment scored mostly in all categories. Fresh pineapple juice contains bromelain, which is known for its function of degradation of myosin (Kim and Taub, 1991). Therefore, meat treated with fresh pineapple juice is less tender. This is evident as well in the evaluation of hardness of meat samples or general texture too. Even that parameter such as mastication or juiciness were not significantly different, it didn´t influence the result for general texture. TMP sample as well scored in the parameter color likableness, where in correlation with results of color intensity is clear, that the lighter color is considered as better one, or the one with more pleasant color in term of evaluation of meat.

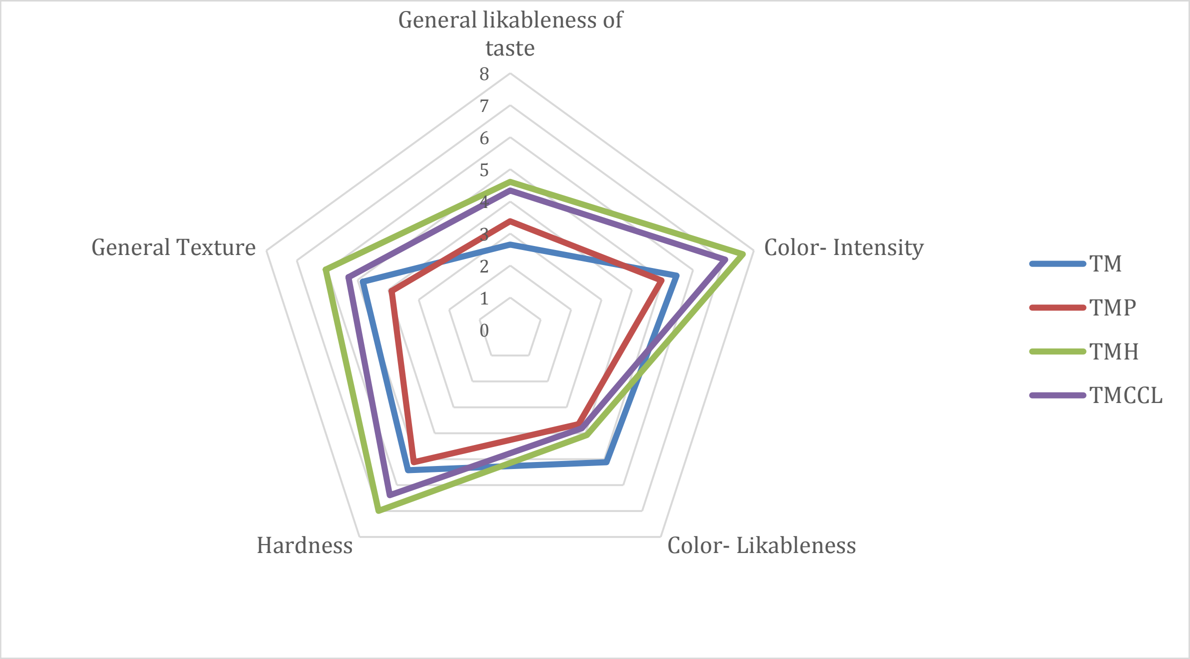

Figure 4.9 Spider diagram of sensory profiling of the eland meat dried samples in DPSD (n=22).

As it was mentioned above color is one of the most important attribute of jerky (Albright *et al.*, 2003) and is strongly associated with the concept of quality (Wibowo *et al.*, 2015). Meat of eland and beef contain a large quantity of free amino acids (Bartoň *et al.*, 2014) and with the sugar in pre-treatments can under relevant conditions of concentration, pH and temperature start Maillard reactions and form dark pigments (Marquez-Rios *et al.*, 2009). A comparison of color measured by spectrophotometer of pre-treated and control samples of eland and separately beef meat dried in DPSD and LO is presented in Figure 4.10.

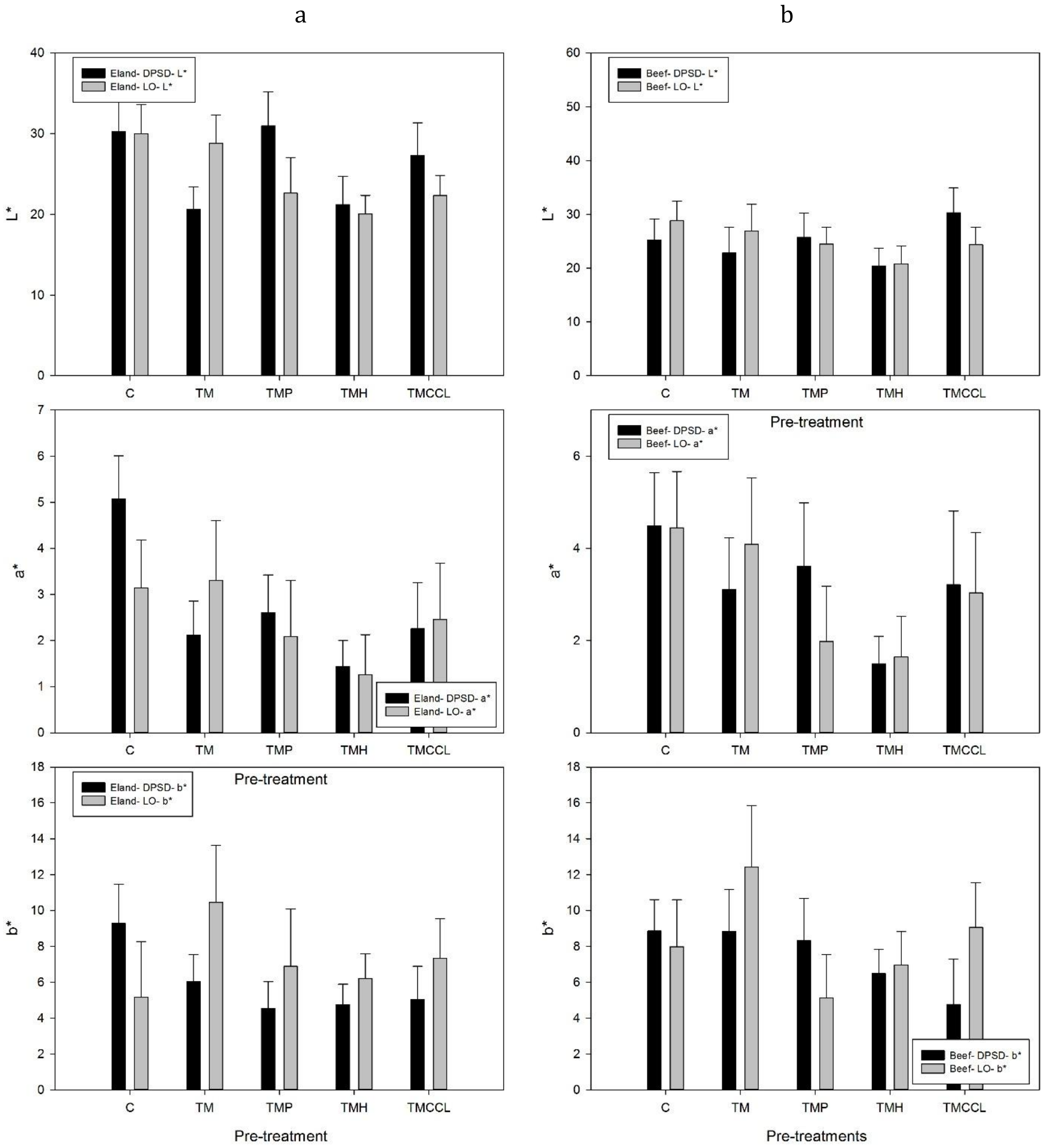

Figure 4.10 Combined effect of drying method and pre-treatment on parameters L, a, b in dried eland and beef jerky (a- eland. b- beef)

The lightness value *L* and value of the parameter *a* of the dried beef are similar to the values of beef jerky reported by Farouk and Swan (1999). As well some other color values reported in literatures it´s possible to compare with the results of this study. Values of *L*, *a*, *b* of beef jerky reported by Konieczny *et al.* (2007) were 30.66, 13.42 and 4.24, respectively, for ostrich jerky were 27.2, 2.0 and 2.3, respectively (Lee and Kang, 2003). In case of eland significant differences ($p < 0.05$) between DPSD and LO were in C sample (*a*, *b* parameters), TM sample (*L, a, b* parameters), TMP, TMCCL (*L, b* parameters) and TMH (*b* parameter). Significant differences ($p < 0.05$) between DPSD and LO in the case of beef were identified: sample C (*L* parameter), TM (*L, a, b* parameters), TMP (*a, b* parameters), TMCCL (*L, b* parameters). Thus, it is evident that type of drier can influence the final color of the product.

Comparison of used pre-treatment and their influence on *L, a, b* parameters see in Table 4.5. Results are evaluated separately for eland in DPSD and in LO, as well as beef in DPSD and in LO.

Table 4.5 Color of dried eland and beef meat in DPSD and LO (a- eland. b- beef).

a				b			
		DPSD				DPSD	
	L	a	b		L	a	b
C	$30.24 \pm 4.3^{b.c}$	5.07 ± 0.93^{d}	9.27 ± 2.19^{b}	C	$25.20 \pm 3.95^{b.c}$	4.49 ± 1.15^{c}	$8.86 \pm 1.75^{c.d}$
TM	20.65 ± 2.74^{a}	$2.11 \pm 0.74^{a.b}$	6.03 ± 1.51^{a}	TM	$22.83 \pm 4.74^{a.b.c}$	3.11 ± 1.12^{b}	$8.83 \pm 2.35^{c.d}$
TMP	30.95 ± 4.23^{c}	$2.6 \pm 0.82^{b.c}$	4.54 ± 1.49^{a}	TMP	25.71 ± 4.49^{c}	3.61 ± 1.37^{b}	$8.31 \pm 2.36^{c.d}$
TMH	21.21 ± 3.5^{a}	1.44 ± 0.56^{a}	4.75 ± 1.14^{a}	TMH	20.41 ± 3.25^{a}	1.49 ± 0.6^{a}	$6.49 \pm 1.36^{a.b}$
TMCCL	$27.21 \pm 4.01^{b.c}$	2.25 ± 1.00^{b}	5.05 ± 1.84^{a}	TMCCL	30.3 ± 4.6^{d}	3.21 ± 1.6^{b}	4.76 ± 2.53^{a}
		LO				LO	
	L	a	b		L	a	b
C	29.98 ± 3.61^{b}	3.14 ± 1.04^{d}	5.17 ± 3.10^{a}	C	28.80 ± 3.63^{c}	4.45 ± 1.22^{c}	$7.99 \pm 2.61^{b.c}$
TM	28.80 ± 3.51^{b}	3.31 ± 1.30^{d}	10.46 ± 3.19^{b}	TM	$26.86 \pm 5.01^{b.c}$	4.09 ± 1.43^{c}	12.41 ± 3.44^{d}
TMP	22.62 ± 4.44^{a}	$2.09 \pm 1.22^{a.b.c}$	6.89 ± 3.19^{a}	TMP	$24.45 \pm 3.10^{a.b}$	$1.98 \pm 1.20^{a.b}$	5.12 ± 2.41^{a}
TMH	20.04 ± 2.31^{a}	1.26 ± 0.87^{a}	6.20 ± 1.39^{a}	TMH	20.79 ± 3.33^{a}	1.64 ± 0.88^{a}	$6.96 \pm 1.86^{a.b}$
TMCCL	22.32 ± 2.51^{a}	$2.46 \pm 1.22^{b.c.d}$	7.33 ± 2.20^{a}	TMCCL	$24.35 \pm 3.22^{a.b}$	3.04 ± 1.31^{b}	9.06 ± 2.50^{c}

$^{a\text{-}d}$ Mean values with different superscripts within a same column are significantly different ($p < 0.05$).

The total color difference ΔE as determined by Eq. (3.16) can be classified analytically according to Cserhalmi *et al.* (2006) as not noticeable (0–0.5), slightly noticeable (0.5–1.5), noticeable (1.5–3.0), well visible (3.0–6.0) and great (>6.0). Results of ΔE of eland and beef dried in DPSD and LO are shown in Figure 4.11.

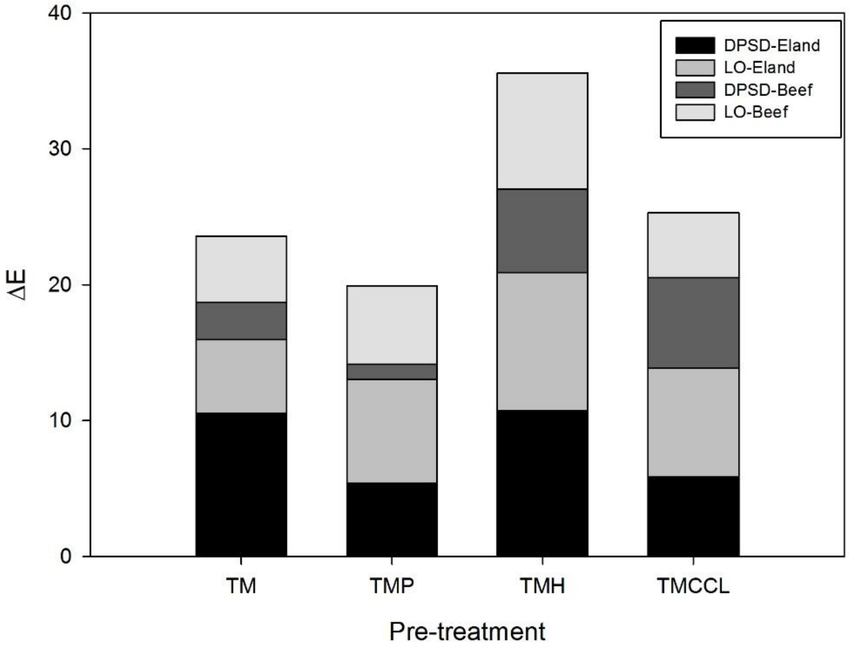

Figure 4.11 Total color difference Δ*E*.

Generally for both meat dried in both driers TMH marinade was evaluated as the one with the highest total difference ΔE contrariwise meat dipped in TMP pre-treatment has the lowest total difference ΔE. This result correlates with the result of sensory panel, where the TMP sample was evaluated as the lightest one and therefore is possible to point out that assessors prefer lighter meat with lower total color change than the darker one.

5 CONCLUSION

Double pass solar drier (DPSD) and laboratory oven (LO) were used for thin-layer drying process of eland and beef meat. Four pre-treatments (TM, TMP, TMH and TMCCL) and control (C) samples of both eland and beef meats were selected for this study. Average temperature, relative humidity (RH) and air velocity in the drying chamber during solar drying were 48.3±5.6°C, 18.5±6.0% and 0.9±0.1 $m.s^{-1}$, respectively. Average solar radiation was 563±185.8 $W.m^{-2}$. The difference in drying behavior between eland and beef jerky was statistically not significant. In contrast, statistically significant differences in drying behavior were observed between control samples without any treatment and TM, TMP, TMH and TMCCL samples. According to the results of the pairwise multiple comparison of *MR*s of all samples, where statistical differences were found just between some pre-treatments, 2 samples with TM, TMH pre-treatment and control sample (C) were selected. These samples were compared by 10 mathematical models: Page, Modified Page, Two-term exponential, Diffusion approximate, Verma et al., Logarithmic, Newton, Henderson and Pabis, Two term and Wang and Singh. Coefficient of determination (R^2). *RMSE* and chi-square (χ^2) were used for the determination of the best predicting capacity model. The Two-term model was selected as the most suitable model describing the solar drying kinetics and the Wang and Singh model was the most suitable for control LO drying. Effective moisture diffusivity (D_{eff}) and activation energy (E_a) were calculated for solar drier eland meat. The effective moisture diffusivity values of eland meat for selected sample C, TM and TMH samples ranged between 1.4706 x 10^{-10} $m^2.s^{-1}$, 1.0986 x 10^{-10} $m^2.s^{-1}$ and 1.809x10^{-10} $m^2.s^{-1}$, respectively. The activation energy values were 23.75, 26.22 and 26.97 $kJ.mol^{-1}$ for C, TM, and TMH samples of eland meat jerky dried in DPSD, respectively.

Prior to drying both meat samples were analyzed for physicochemical characteristics of raw meat. The pH 24 h after slaughter, Warner-Bratzler shear force, pigment concentration, weight loss during cooking, water holding capacity, water content and color *L*, *a*, *b* was measured for eland as follows 5.497±0.006, 68.84±15.43 N, 4339.36±51.57 $mg.kg^{-1}$, 27.23±0.18%, 44.87±2.17%, 75.05±0.05%, 0.84±0.09%, 38.88±2.59, 9.13±1.05, 6.86±1.02, respectively.

Organoleptic properties of dried eland and beef meat were assessed by selected and trained member degustation panel. Generally there were no statistically significant differences between control (C) samples of eland and beef meat and eland and beef meat dried in DPSD and LO. Contrary there were significant differences ($p< 0.05$) between pre-treatments (TM, TMP, TMH and TMCCL) used. The best scored pre-treatment was TMP (traditional jerky marinade with fresh pineapple juice), which has a significant effect on texture, color and taste. The effect of the different pre-treatments on the overall combined color (ΔE) was calculated. Generally for both meat dried in both driers TMH marinade was evaluated as the one with the highest total difference ΔE contrariwise meat dipped in TMP pre-treatment has the lowest total difference ΔE.

Dried meat jerky is one of the important and relatively safe nutrient source mainly in developing countries. There is a lack of information and profound studies published in scientific literature describing the drying behavior and organoleptic properties of eland meat. This study brings a new knowledge about the drying behavior, mathematical modeling of thin-layer drying process and sensory analysis, including color change during drying of eland jerky which might be important for possible industrial processing. Further, it maybe concluded that solar drying technology brings compatible results as a standard laboratory drier in terms of drying kinetics. Finally the study indicates that the drying behavior of eland jerky is similar to widely recognized traditional beef jerky.

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ANNEX A

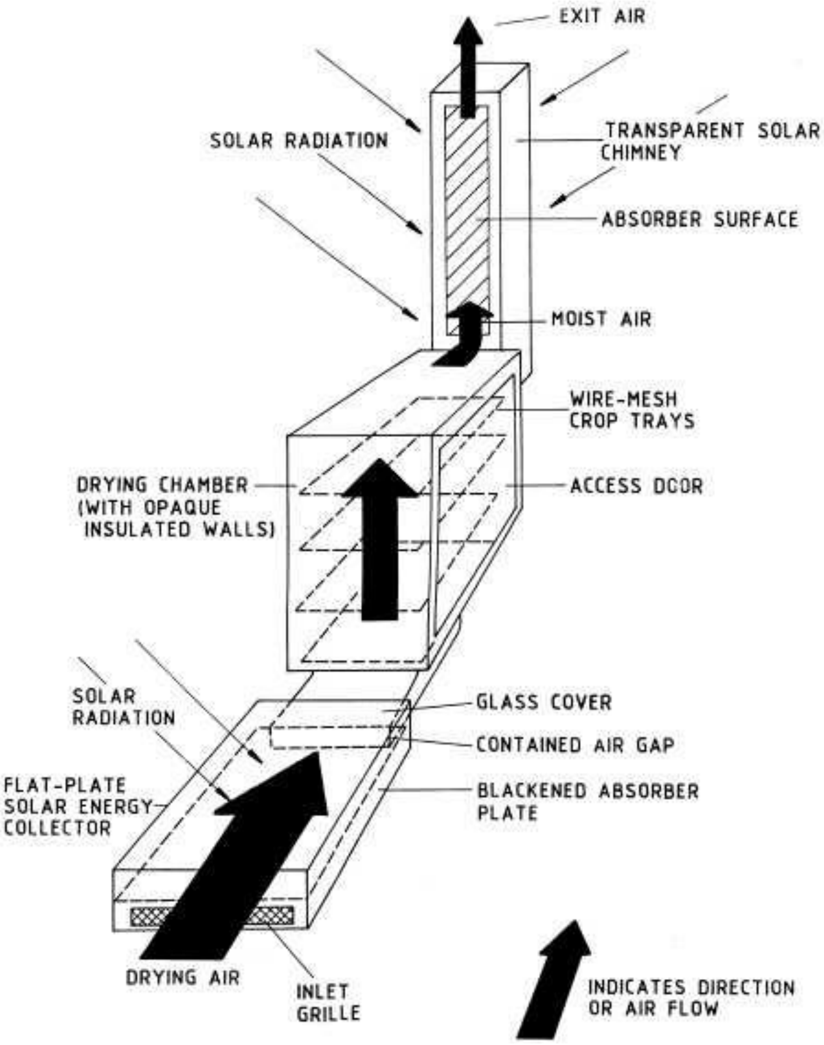

Figure A.1 Features of a typical distributed-type (indirect) natural-circulation drier (Ekechukwu and Norton, 1999).

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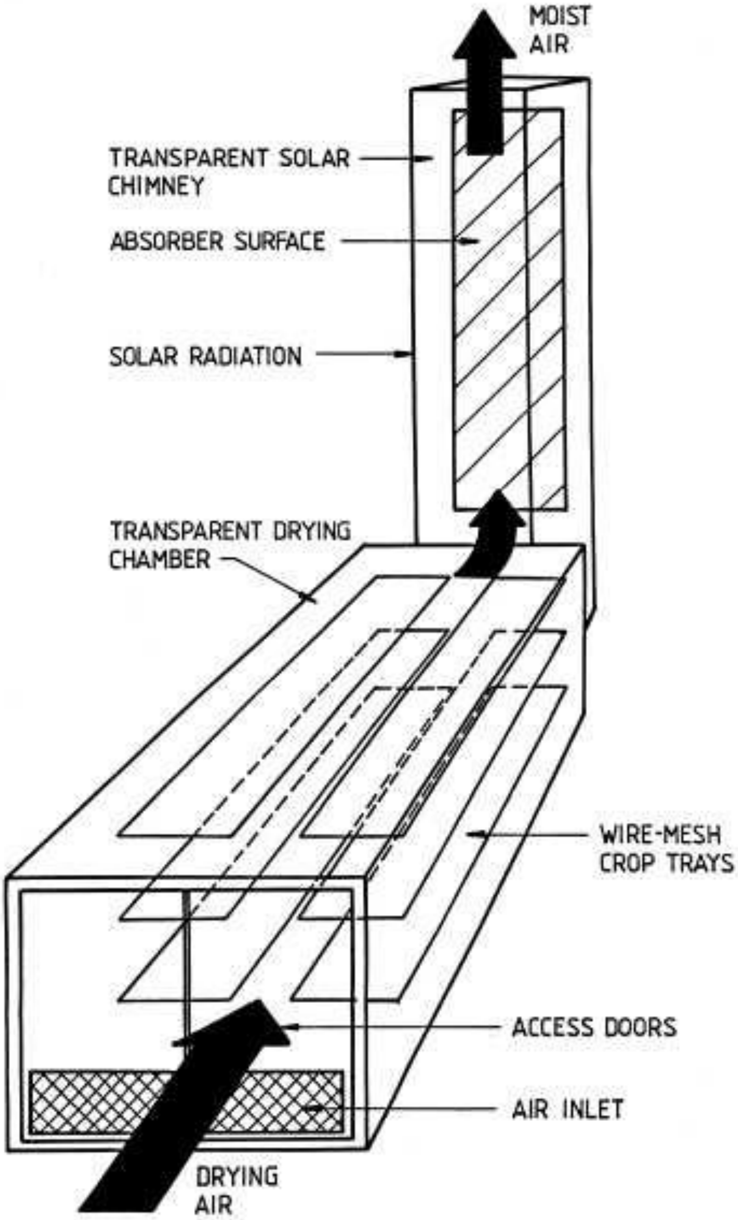


Figure A.2 Features of a typical integral-type (direct) natural circulation drier (Ekechukwu and Norton, 1999).

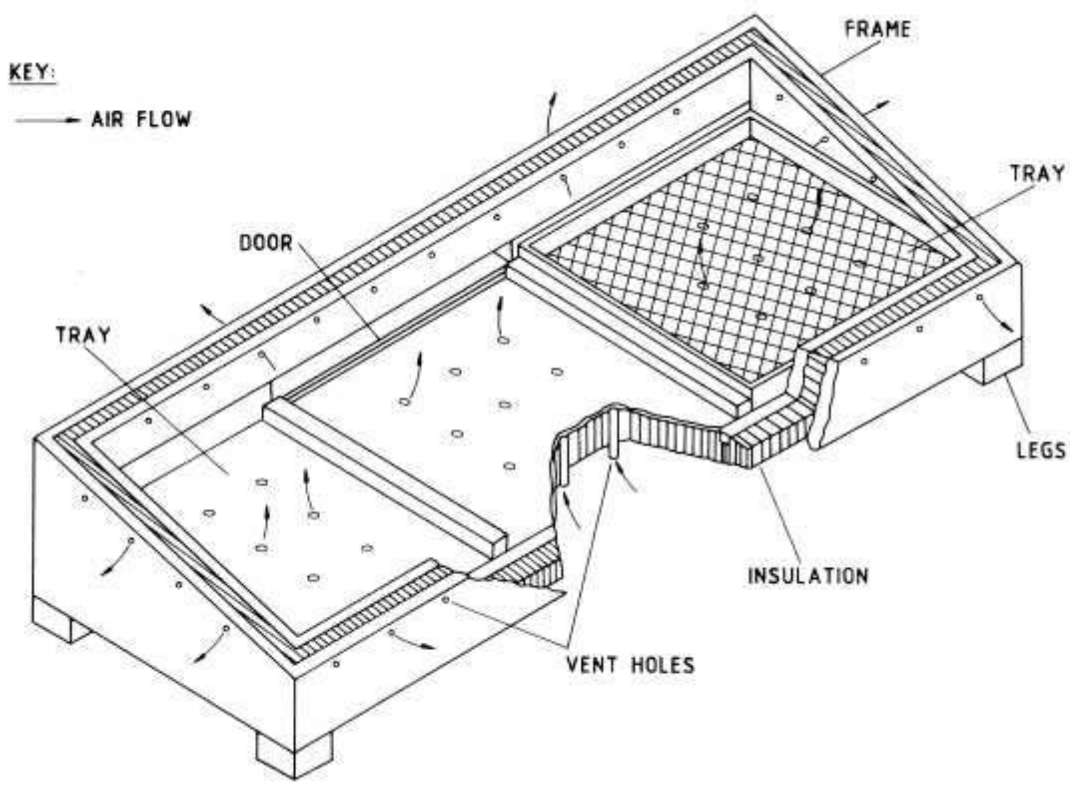


Figure A.3 A typical natural-circulation solar-energy cabinet drier (Ekechukwu and Norton, 1999).

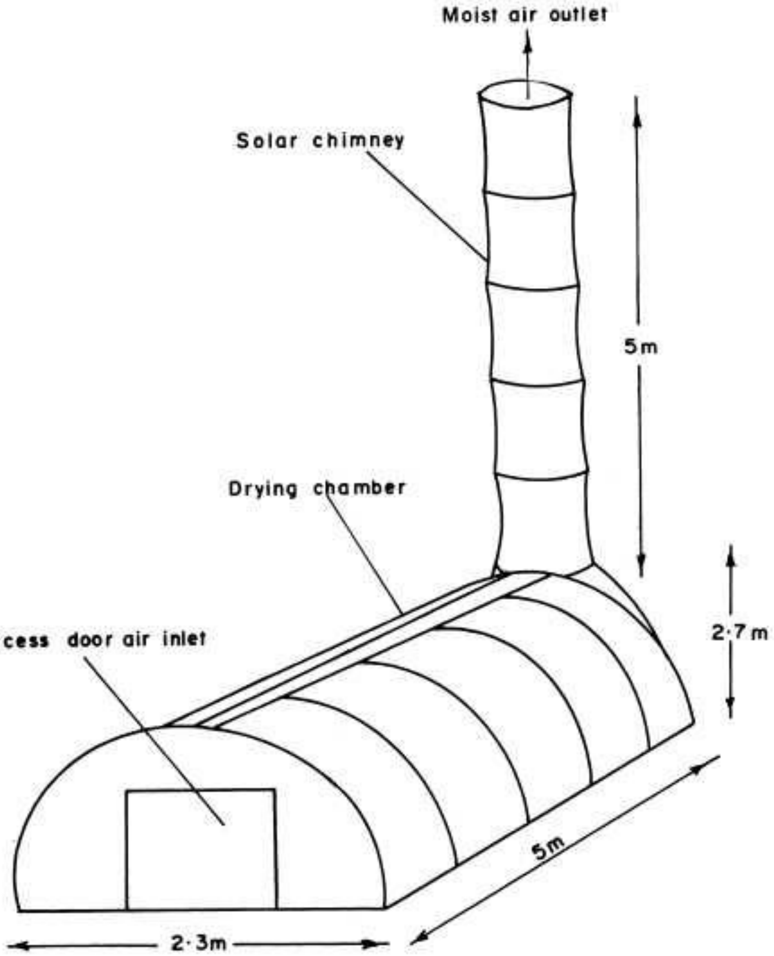


Figure A.4 A greenhouse-type natural-circulation solar-energy drier (Ekechukwu and Norton, 1999).

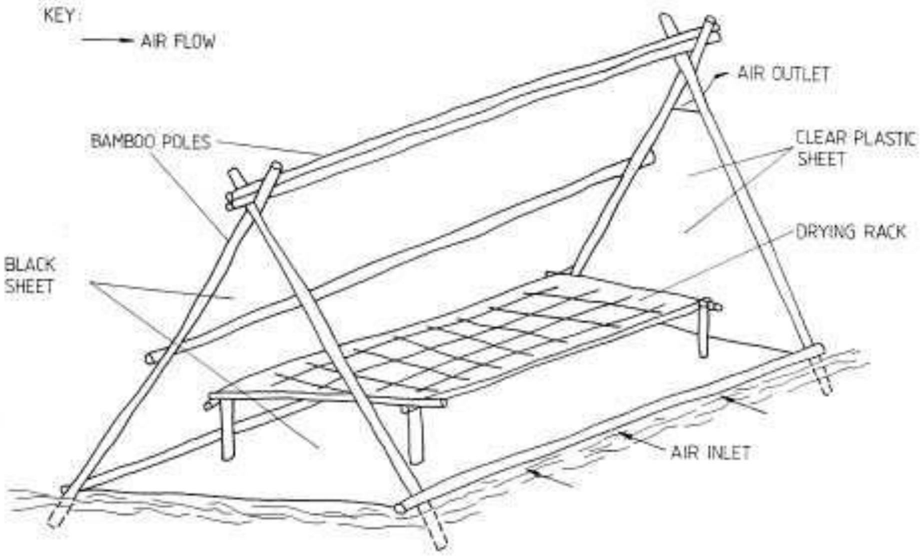


Figure A.5 Natural-circulation polythene-tent drier (Ekechukwu and Norton, 1999).

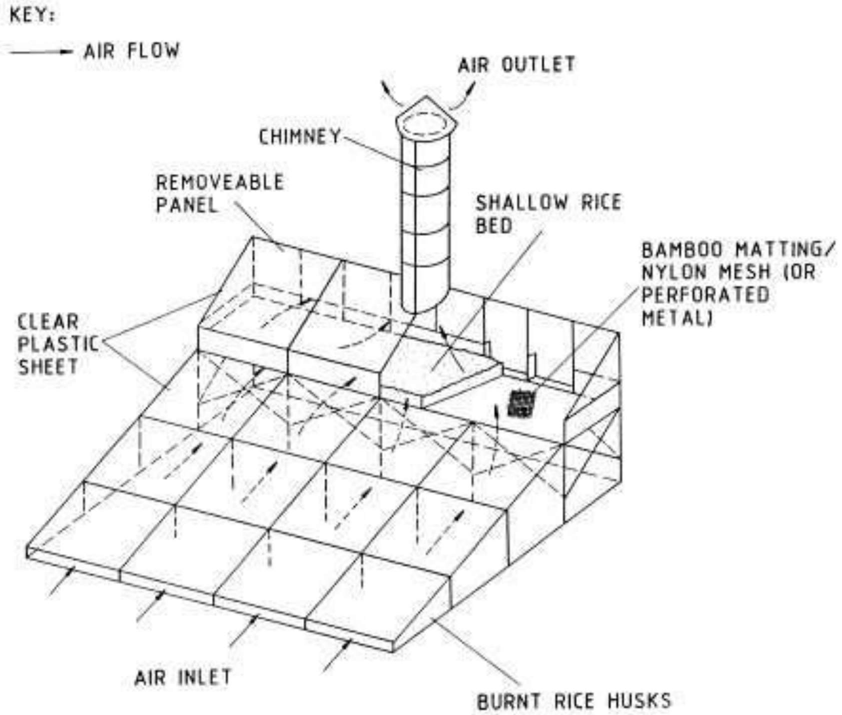


Figure A.6 A mixed-mode natural-circulation solar rice drier (Ekechukwu and Norton, 1999).

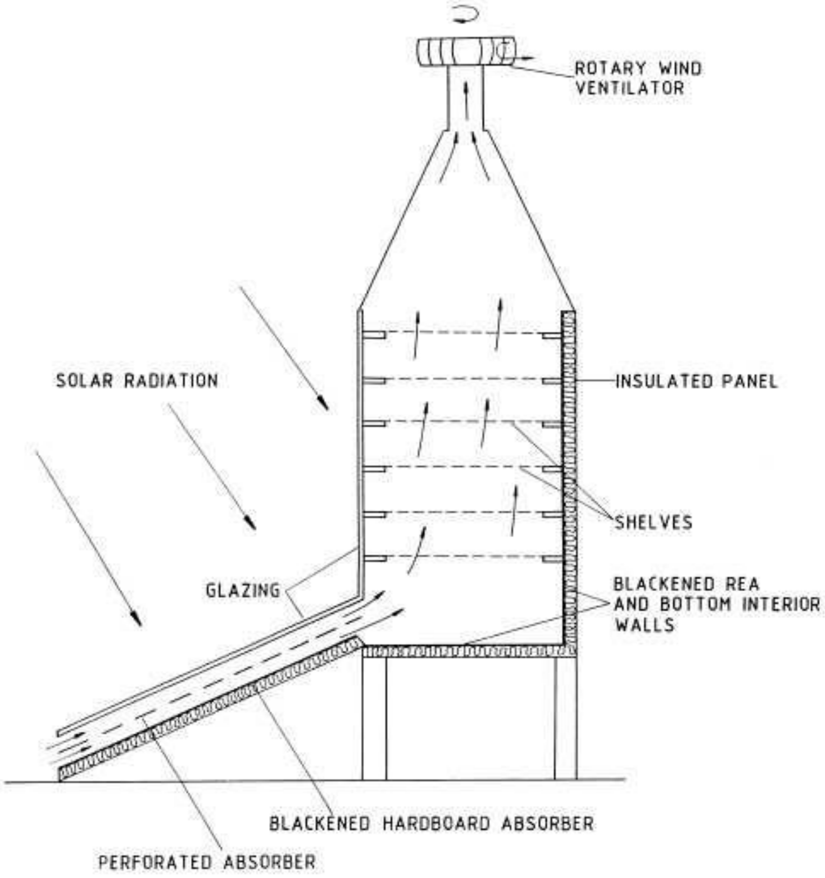


Figure A.7 A mixed-mode natural-circulation solar energy drier with thermal storage (Ekechukwu and Norton, 1999).

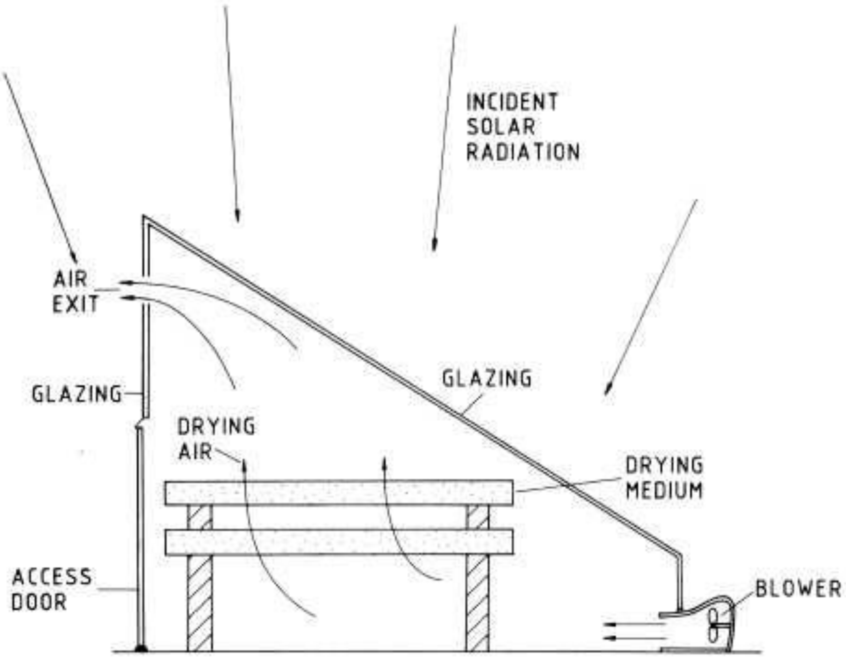


Figure A.8 A forced-convection greenhouse drier (Ekechukwu and Norton, 1999).

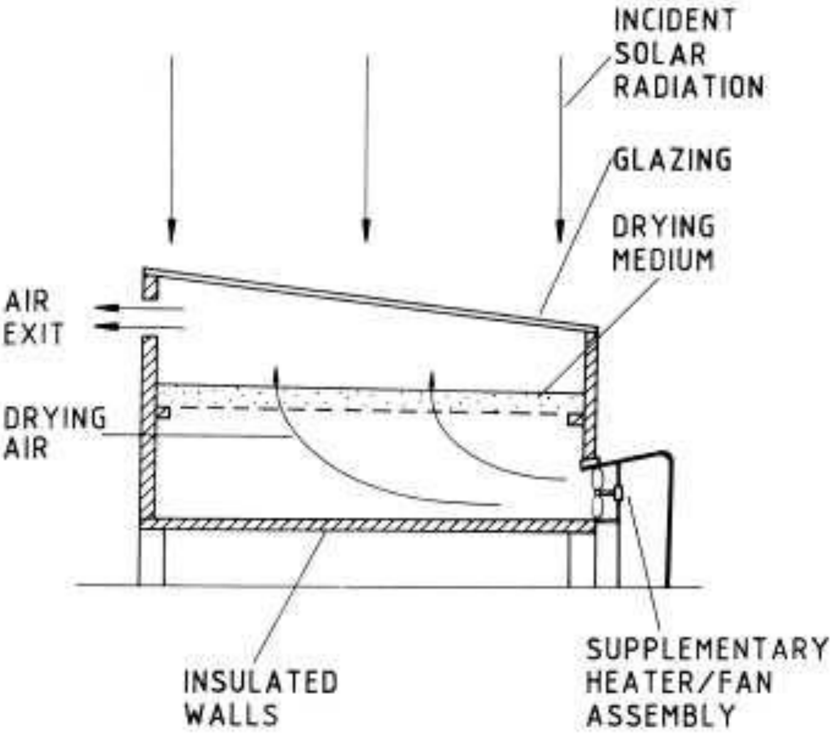
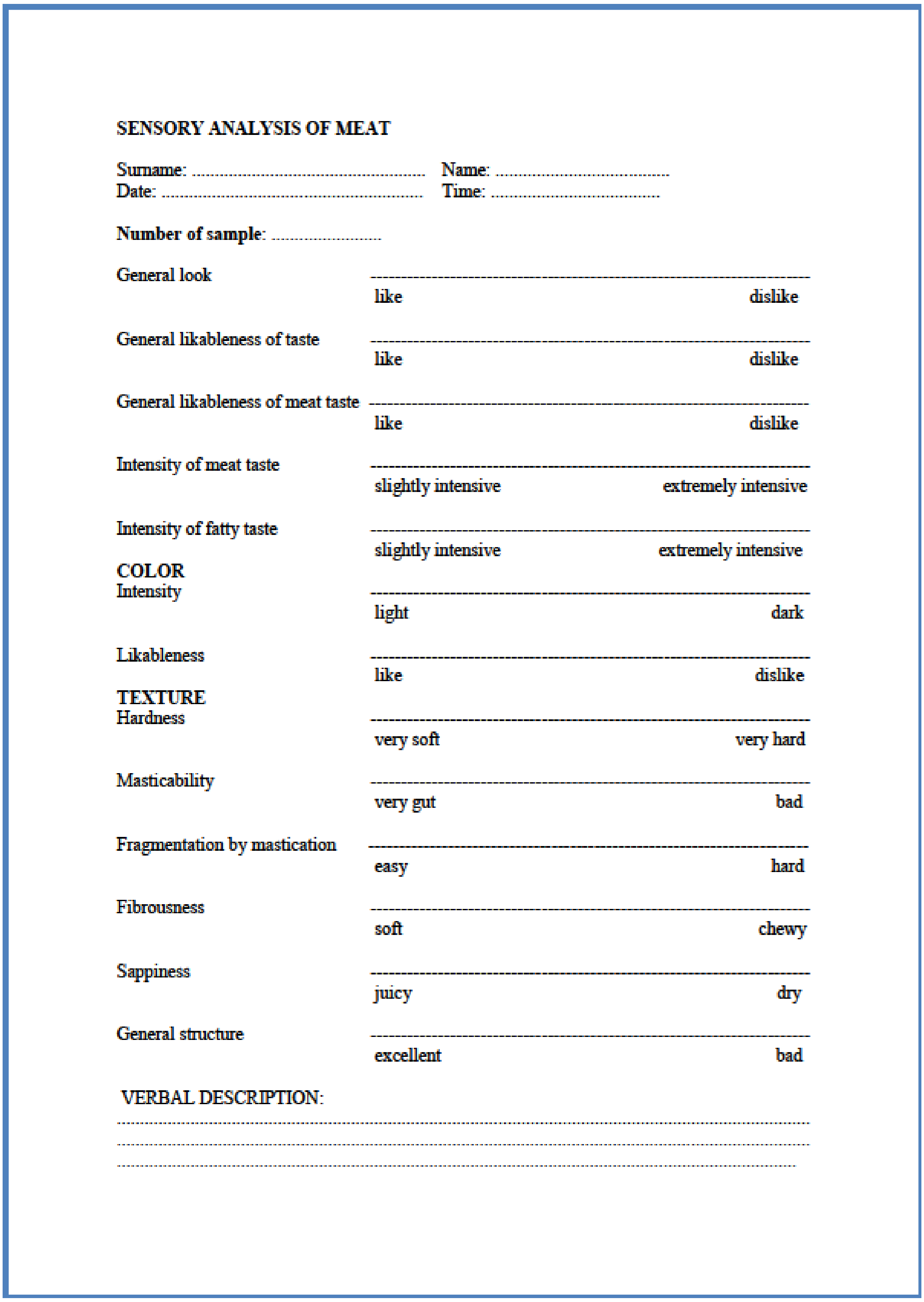


Figure A.9 Features of a typical active solar-energy cabinet drier (Ekechukwu and Norton, 1999)

ANNEX B



SENSORY ANALYSIS OF MEAT

Surname: .... Name: ....
Date: .... Time: ....

Number of sample: ....

General look	like	dislike
General likableness of taste	like	dislike
General likableness of meat taste	like	dislike
Intensity of meat taste	slightly intensive	extremely intensive
Intensity of fatty taste	slightly intensive	extremely intensive
COLOR Intensity	light	dark
Likableness	like	dislike
TEXTURE Hardness	very soft	very hard
Masticability	very gut	bad
Fragmentation by mastication	easy	hard
Fibrousness	soft	chewy
Sappiness	juicy	dry
General structure	excellent	bad

VERBAL DESCRIPTION:
....
....
....

Figure B.1 Sensory analysis form.

ANNEX C

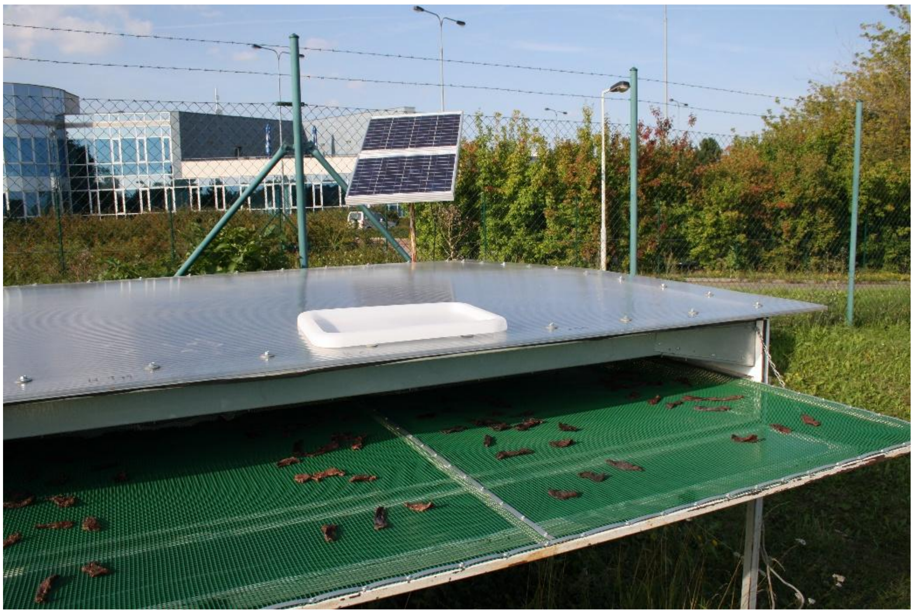


Figure C.1 Drying of both eland and beef samples.

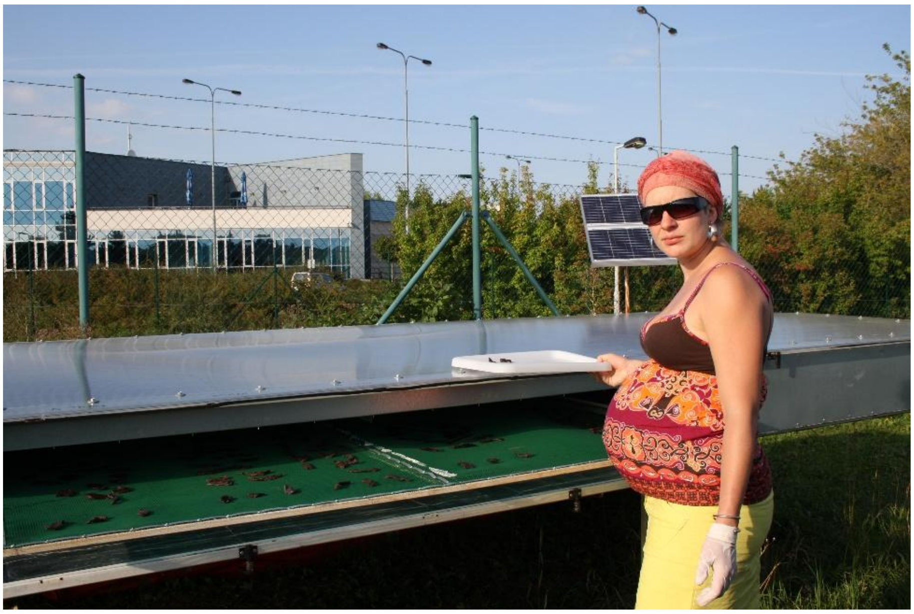


Figure C.2 Collecting and weighting reference samples.

Figure C.3 Samples of dried eland meat.