UNIVERSITÄT KASSEL

OPTIMUM DRYING PROCESS

Best drying conditions to grind fruits and vegetables

Author: Meritxell Pina Laguna

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This thesis is about finding the best drying conditions in order to get afterwards high quality pulverized fruits and vegetables. It is focused on the drying part of the process to use the results later in grinding studies. With this process it's expected to take advantage of most of the fruits and vegetables that are wasted for not meeting quality criteria.

Author: Meritxell Pina Laguna

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1 INTRODUCTION

World's population is increasing annually, thereby increasing world's food demand. Considering current trends, changes in food production must be done in order to meet the estimated future demand. This problem and its possible solutions such as drying or pulverizing the foods, in which this thesis is focused on, are described in detail below.

1.1 World population

As said before, world's population is increasing every year. This increase, though, correspond to the whole world since there are some regions, especially in developed countries, whose population growth is negative. Despite, world's population growth is positive and even though it has decreased in the past years, world's population is still increasing every year. This increase, however, is unevenly distributed across regions. The department of Food and Agriculture of the United Nations (FAO) calculated world population annual growth across regions from 2000 to 2011. The results can be seen in percent in the next graphic [1]:

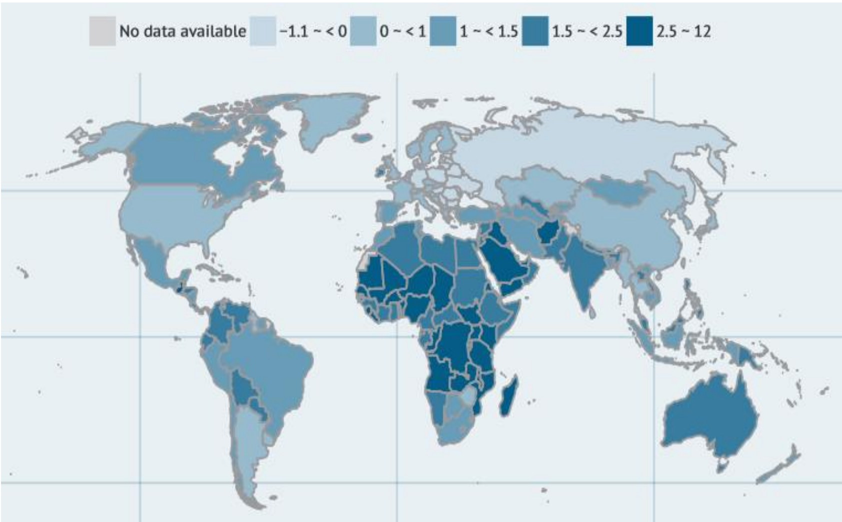

Figure 1. World population annual growth across regions.

As shown below, the greatest population growth is found in most regions of Africa while Europe presents lower population growths. Despite the region differences, world population increases annually in absolute terms. Its evolution from 1950 to 2050, which was also estimated by FAO, can be seen in the following graphic:

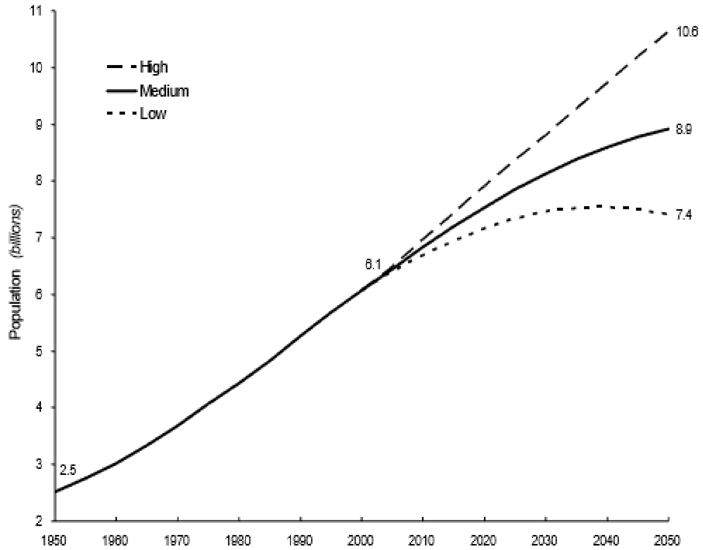

Figure 2. Estimation of world population from 1950 to 2050 [2]

As seen below, there are different estimations for world's population depending on different scenarios given by FAO. In one of these scenarios, it could exceed 10 billions while in another one it could be less than 7.5. Nevertheless, world's population is suggested to be almost 9 billions by the end of 2050. However, it must be remarked that whereas world's population increases annually, its growth rate is estimated to decline. The next graphic shows the average growth rate evolution from 1950 to 2050, which was estimated by FAO, separated by major areas [2]:

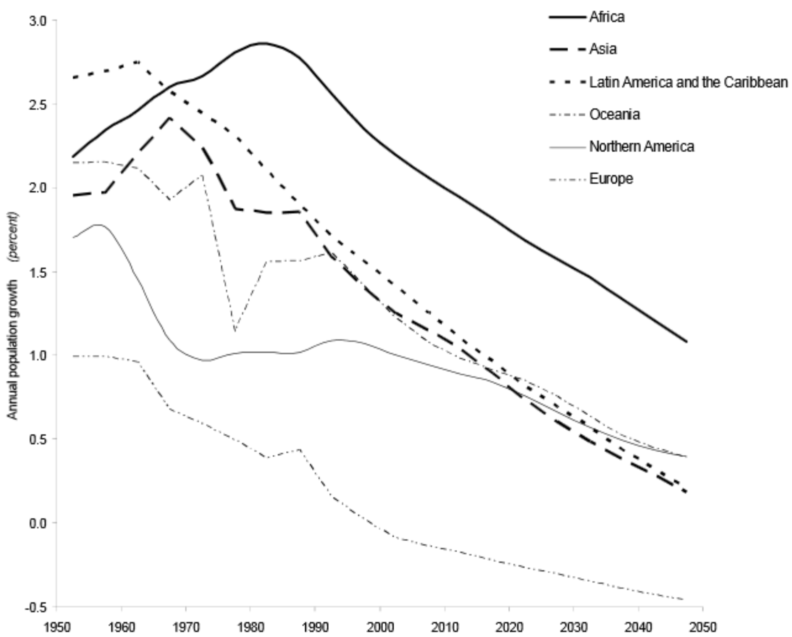

Figure 3. Average growth rate evolution from 1950 to 2050.

It can be seen that all population growth rates in major areas are estimated to decline at a similar rate in last decades. Northern America is the major area whose growth rate seems to decline at a smaller rate. This graphic shows too that Africa and Europe have the greatest and the smallest population growth, respectively. Albeit at different absolute values, all growth rates present approximately the same trend. Except Europe, the rest of major areas increase slightly in the beginning until reaching a peak to decline afterwards almost steadily. This behaviour can be described theoretically with a model called "demographic transition". According to this paradigm, population growth can be modelized as a general pattern divided into four idealized stages as shown below:

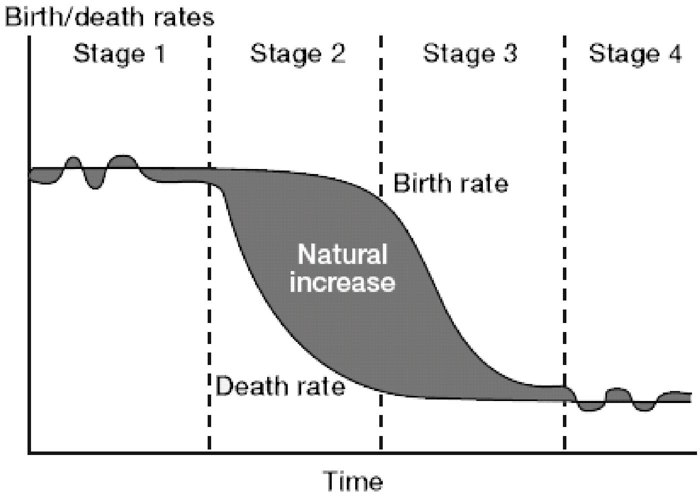

Figure 4. Demographic transition model [3].

In the first stage, both birth and death rates are high and similar (about 5% per year). In the second one, whereas birth rates remain high, death ones decrease. As a consequence, population growth rises, which is called "natural increase" or "population explosion". In the third stage, birth rates decrease and hence the population growth decline. In the last stage, birth and death rates are similar again (about 1% per year) and for this reason, growth rate may be near zero or negative. It must be said that stages 1 and 4 are different because in the last one both size of the population and longevity will have increased during the demographic transition (stages 2 and 3) [3].

This model can be applied to individual nations or to the whole world. In the first case, it has become clear that most of the developing nations have low death rates and their birth rates are going down. What is the same, according to this model, most developing nations are in stages 3 or 4 of their demographic transition. However, in some developing countries demographic transition has stalled. Whereas their death rates are low (for instance, 1.5% per year or less), birth rates stagnate around 4 and 5% per year. In other words, their population annual growth is around 3%. Most of the least developed countries are still in the "population explosion" of their demographic transition. The fact that developed countries don't have a population growth should not eclipse the quick growth in less developed countries, which makes increase the whole world population [3].

As said before, world population still increases annually despite the growth rate decrease. One example of this is that whereas it rose averagely 71 million a year between 1950 and 2000, it is supposed to increase 57 million a year between 2000 and 2050. Nevertheless, world population increment is still significant. Some countries will have little or no population growth but the whole world will have substantial population growth though. Indeed, population in less developed regions will increase about 58% next 50 years whereas in more developed regions this increase will be just 2%. In other words, less developed regions are responsible for 99% of estimated world population growth. This growth is a reason of concern because natural resources and farming could not meet world's population food demand. As a consequence, world hunger would increase too.

It must be said that even though world population growth has slowed down in last years, it is still significant and it complicates social and economic development. It is not clear how the slowing of population growth would facilitate development but it is clear that this growth will not help it. However, it should be pointed out that these estimations are not forecasts rather extrapolations of the current trends. Thus, these estimations are just used to study other implications such as in food, in which this thesis is focused on.

1.2 Hunger dimensions

The Millenium Development Goals (MDGs) are eight international development goals that were established in the United Nations Millenium Declaration to be achieved by the year 2015. All United Nations member states committed in September 2000 to try to combat poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. The MDGs are derived from these big goals and each one has targets and indicators to follow the progress from 1990 levels. In the case of eradicating extreme poverty and hunger, its target is to halve the proportion of people who suffer from hunger between 1990 and 2015. Albeit unevenly across regions, the proportion of underweight children in developing countries has diminished from 25% to 15% between 1990 and 2012. There are different factors related to hunger that affect its diminishment like food security/insecurity, the prevalence of food inadequacy and food availability [4].

First, food security is the condition of having continuous availability of food. In the beginning, this term was used at a national level when there was enough food to sustain the population considering fluctuations in production and prices. At 1996 World Food Summit, this term was also defined at an individual level. According to FAO, there is food security "when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life"[5]. This can also be explained with its opposite indicator: food insecurity. According to United States Department of agriculture (USDA), there is food insecurity when having "limited or uncertain availability of nutritionally adequate and safe food or limited or uncertain ability to acquire acceptable food in socially acceptable ways" [6]. There are several indicators to measure food security and insecurity, from which the prevalence of undernourishment is the most important one. Nevertheless, these indicators depend on the reliability of the collected data and on the possibility of comparing them across different regions and time periods. Although food security is too complex to be understood with one single indicator, the prevalence of undernourishment gives an idea of the extent and distribution of world hunger. It also indicates the number and proportion of the population whose food intake is below minimum requirements. In the graphic below, it can be seen the number of undernourished people across major areas between periods 1990-1992 and 2010-2012:

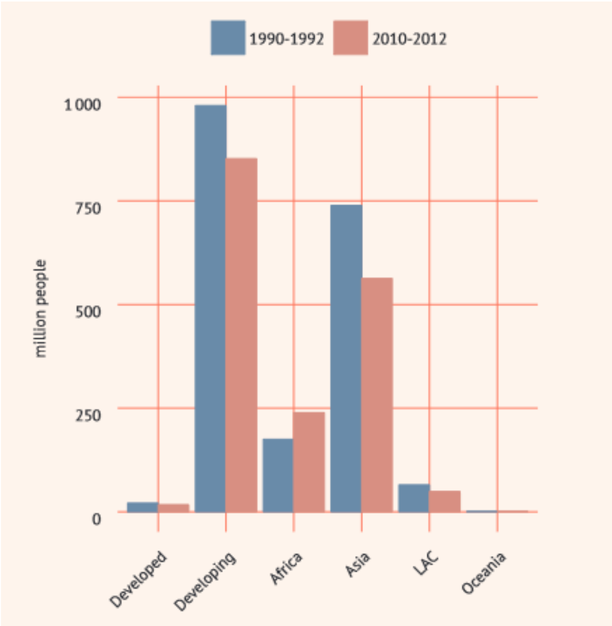

Figure 5. Number of people undernourished in 1990-1992 and 2010-2012 [1]

Even though reduction of world hunger has slowed down in the last few years, undernourishment has remarkably decreased since 1990 in most areas. However, it is currently still high in absolute terms since the number of undernourished people between 2010 and 2012 was around 870 million, from which 852 million were from developing countries [7]. This number was presented in the United Nations (UN) publication *The State of Food Insecurity in the World 2012* (SOFI) and its reduction involves that the MDG hunger target is closer to be achieved. Furthermore, the world's ability to feed itself has become more uncertain. This uncertainty has caused consequences in food security such as an increase in food prices. This increase caused consumers to adjust their food intake and save more for future increases. The poorer the consumer is, the greater the impact. This is because poorer households spend a higher share of their incomes on food. As comes to the supply side, changes in food prices suppose more uncertainty when investing and thus, a higher risk of losing the investment. Vulnerability to price changes varies from country to country and it depends on their quantity of exportations. That is the reason why the value of basic food imports relative to the value of merchandise exports is used as an indicator of food security. For example, Oceania and several african countries are the ones whose indicator is higher. Fluctuations in food production, supply and prices are related to the vulnerability of countries and their population. In developing countries, fluctuations in food production are usually lower than in prices. In some other countries, a high prevalence of undernourishment is usually related to low fluctuations in food supply. Nevertheless, there are other factors related to food insecurity such as presence of armed conflicts and natural hazards or social and economical situation (income levels, food prices, political instability, etc.). On the armed conflicts side, those countries whose most population is at risk such as Eritrea, Sierra Leone or Liberia have high values of prevalence of undernourishment from about 30 to 65%. There are also other countries such as Afghanistan and Somalia whose population is at risk but data are difficult to gather or not available. On the natural disasters side, CRED (Centre for Research on the Epidemiology of Disasters) recorded 332 natural disasters in 2011, which caused more than 30 000 deaths. In many countries, there is a big correlation between food insecurity and exposure to natural disasters. What it comes to social situation, unhealthy diets such as a lack of vitamins, micronutrients and macronutrients can also make food insecurity rise. Sometimes, even though a balanced diet is available, there is food insecurity too due to a lack of food safety and hygiene or of health care. It usually produces low labour productivity, low incomes and thus, food insecurity, creating a vicious circle known as "hunger trap". For this reason, food security outcomes need quality health care systems and good food access conditions, especially in poor population groups [1].

Secondly, another indicator used to measure hunger and poverty is the prevalence of food inadequacy. As opposed to the prevalence of undernourishment, this indicator also includes people with a food energy deficit. These individuals, who may not be included as undernourished in normal conditions, can be considered as ones when working physically intense. The difference between both indicators is significant in some countries, revealing that a remarkable part of the population don't intake food adequately even though chronic undernourishment is not widespread. This is the case of some countries such as Bangladesh, India, the Dominican Republic or Ecuador. The percent of prevalence of food inadequacy across regions in 2012 is shown in the following figure:

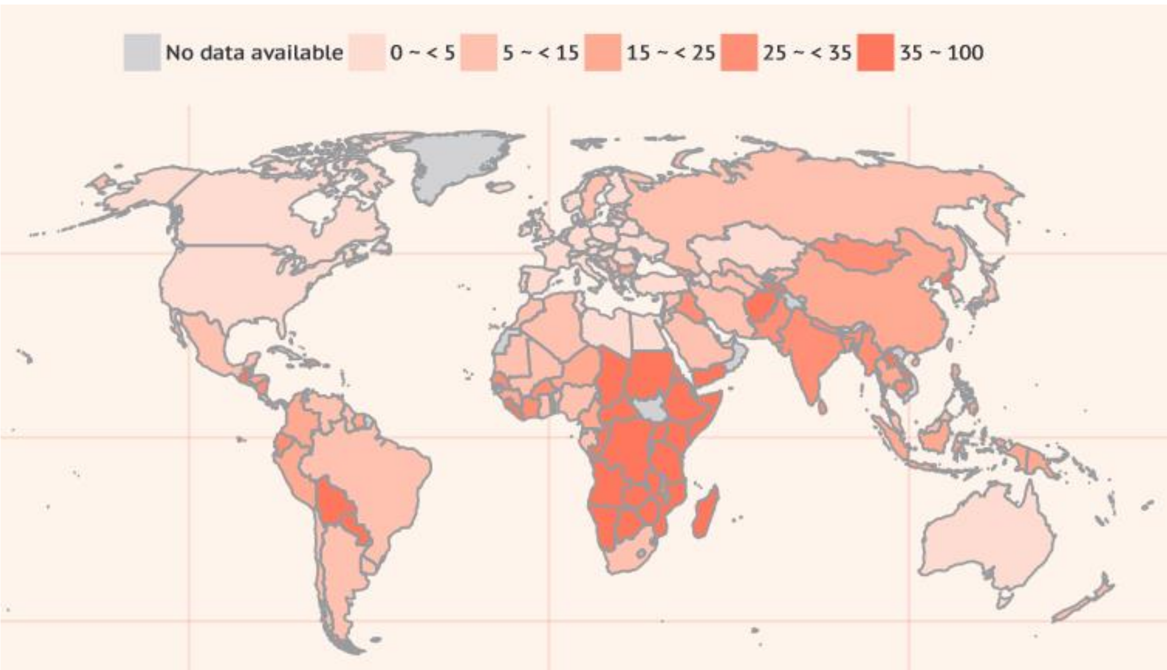

Figure 7. Prevalence of food inadequacy across regions in 2012 [1]

Last but not least, food availability (or difficult access to food) is another important factor to measure hunger, which is responsible for its increase and associated with poverty. Albeit insufficient, supplying enough food is necessary to guarantee adequate access for individuals. Economic affordability and physical access to food are the two important issues when referring to food availability. Physical access includes adequate infrastructures, which help reduce price arbitrage and improve the transport of food between rural and urban areas. Since the mid-2000s, food and agricultural markets have suffered large supply shortfalls and price changes. Whereas in most developing countries food production per capita have increased about 2% per year, in Africa it has increased slightly less than 1%. In most countries and regions, high food availability is related to low prevalence of undernourishment but, as other indicators seem to confirm, this relationship is not always valid. For instance, even though Egypt has a dietary supply 45% higher than the average required, 31% of its children under 5 years old is affected by stunting (prolonged inadequate nutrition and/or repeated infections). Similarly, other countries such as Malawi, the Niger, Kazakhstan or Nicaragua seem to be in the same situation as Egypt. This fact points out that despite enough food supply, part of the population of some countries still suffer undernourishment. Incomes, food prices or the ability to get access to social support are some factors that determine food availability. According to Engel's law [8], when there is growth, demand starts with high income elasticity and afterwards, it declines as income rises much more. In other words, poor individuals use a great part of their incomes on food, which leaves them vulnerable to food prices increases. One index used to indicate this vulnerability is the domestic food price level, which is the ratio of the food purchasing power parity. Whereas this index is high in least developed countries, it is low in more developed ones. Recently, this index has stabilized in most countries but it still has a rising trend in developing ones. It must be said that the rise in food prices has had several consequences for consumers, which vary from country to country. For example, while in some countries high prices resulted into a decrease of purchasing power of consumers, in others it remained unaffected. Another consequence is the increase of the prevalence of the undernourishment. For instance, in Uganda food prices increased by 25% between 2003 and 2012 and the prevalence of undernourishment increased by almost 30% between those years. However, in other countries like China, Nepal or Pakistan, the pattern has been the opposite. In those countries the decline of the prevalence of undernourishment has provoked a rising in food prices [1].

World hunger is also related to world's food scarcity and malnutrition, which according to the International Centre for Trade and Sustainable Development are caused by the lack of agricultural market regulation and anti-dumping mechanisms [9]. It is currently one of the biggest problems in the world and, as many people could think, it doesn't affect just less developed countries. If the trends continue this way, hunger in developing countries could suppose 50% of hunger throughout the world by 2015. In order to defeat chronic hunger, it is necessary to improve population's potential and their ability to generate sustainable incomes. For this reason, it is important to invest in improving production techniques, especially in staple foods as fruits and vegetables.

1.3 Production of fruits and vegetables

Fruits and vegetables are two really important basic food groups in human diet. According to World Health Organization (WHO), low consumption of fruits and vegetables is responsible for 1.7 million deaths worldwide annually and contributes to approximately 16 million disability-adjusted life years (DALYs). These years measure the potential and productive life loss due to premature mortality and disability, respectively. That is the reason why WHO and FAO recommend a minimum of 400 g of fruit and vegetables per day to prevent chronic diseases such as cancer, diabetes or obesity. In order to achieve this minimum requirements, current production must increase since world's population is increasing too. FAO estimates that global agricultural production should increase by 60% from its levels to meet global food demand [1].

Global food demand is mostly grown locally but there is agricultural trade when local production cannot meet local demand. This trade has highly increased (around fivefold) over the past 50 years but its distribution, however, is different across regions. Theoretically, agricultural production should be equal to consumption at a global level or in other words, agricultural growth rate should be null. Nevertheless, in recent decades global agriculture has had a greater production potential than its population growth and as a consequence, food availability per capita has increased steadily. FAO Statistical Yearbook gathered the results of production volumes of each commodity group for each large region in 2007. These results, which are expressed in million tonnes, can be seen in the next graphic:

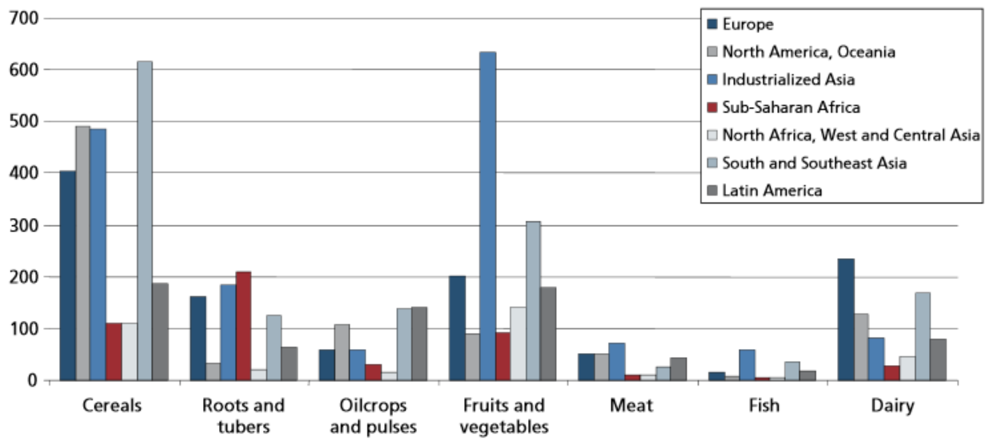

Figure 10. Production volumes in million tonnes per region in 2007 [10]

As seen below, the greatest volume productions correspond to cereals and fruits and vegetables. It also can be seen that the greatest fruits and vegetables producer is industrialized Asia, which produced roughly 630 million tonnes in 2007. In last years, global fruit and vegetables production has increased remarkably, reaching in 2011 almost 640 million and 1 billion tonnes of fruits and vegetables, respectively. Currently, the greatest fruit and vegetable producer is China, whose output contributes to about 20% and more than 50% of fruit and vegetables global production, respectively. Even though in some developed countries this production growth has stagnated, it has become strong in some food-insecure and low-income regions such as sub-Saharan Africa and Southern Asia.

However, increasing supply per capita is not enough to reduce hunger since there are other factors involved such as low availability, low ability to use food and unstable conditions. Moreover, since 2007 food prices have become higher, not allowing most of poor people to purchase enough food. It must be said that changes in food consumption patterns are also expected to happen in some areas due to urbanization and increasing incomes. Over the past 50 years, growth of world crop production was caused mostly by increased yields and higher cropping intensity. This is expected to happen in the future considering limitation and high costs of expanding agricultural land. Similar to population growth, rates of yield growth have been decreasing for most crops even though yields have increased in absolute terms. Currently, yield gains come from the improvement of cropping techniques, fertilization and irrigation. Nevertheless, they could increase reducing the difference between average farm yields and theoretical potential yields, what it is known by "yield gap". In several developing countries, this difference is very significant and in some cases average yields reach 30% of potential yields. Furthermore, crops and pastures use 30% of the Earth's land and 70% of withdrawn freshwater resources is used as irrigation and watering to a stable food and livestock supply. This huge use of land and water natural resources are threatening severally the environment. What is more, the use of fertilizers and other chemicals can pollute the air, water and soils and thus, risk ecosystems and human health. For example, agriculture is the main polluter of nitrate and ammonia in ground and surface water and of phosphate in waterways. Another example is that around 30% of all human-induced greenhouse gases (GHGs) are caused by the land sectors. Considering that by 2050 food production should double to achieve the estimated global population demand, it is important to concern about sustainable production like organic agriculture [12].

Organic agriculture promotes and enhances ecosystem sustainability such as biological cycles and the biological activity of the soil. For this reason, it is based on minimizing the use of external inputs and making a responsible use of the natural resources. Its management system tries to minimize pollution of air, soil and water. It has also increased but it is a small share of total agriculture in developing countries. Whereas in 1999 the land area used for organic agriculture was 11 million ha, it was 37.2 million ha in 2011. Currently, organic agriculture is carried through in 162 countries by 1.8 million farmers. Despite the economic slowdown, organic agriculture has increased significantly since 2002 unlike the rest of the food sector [12].

Trying to achieve the increasing global fruit and vegetables demand can improve the situation of poor farmers who live in developing countries. However, it must be remarked that production values do not correspond to available produced edible food since about one third of it is lost or wasted. What is the same, roughly 1.3 billion ton per year is wasted throughout the food supply chain (FSC) [10]. Furthermore, the intensification of production can cause significant negative environmental effects such as groundwater pollution, soil erosion and a loss in biodiversity. For this reason, another sustainable solution to meet fruit and vegetables demand and diminish hunger during the process is a reduction of post-harvest losses.

1.4 Importance of reducing wastage of fruits and vegetables

Per definition, food losses are the decrease in edible food mass during the FSC destined to human consumption. In other words, if food directed to human consumption leaves the FSC, it is considered food loss or waste even if directed to a non-food use (like feed, bioenergy,...) afterwards. They can appear in different stages of the FSC such as production, post-harvest or processing. According to FAO, depending on this stage, they can be classified in the following five types of food loss [10]:

- Agricultural production: these are the losses related to mechanical damage and/or dumping during harvesting, crops selection, etc.
- Post-harvest handling and storage: as its name implies, these are losses due to dumping and degradation during handling, storage and transportation from farm to distribution.
- Processing: this group includes losses due to dumping and degradation during industrial or household processing. For instance, losses can take place during peeling, slicing or as an accidental spillage during process interruptions.
- Distribution: this group refers to losses and waste in the market system.
- Consumption: these losses take place during consumption at a domestic level and they are commonly known as “food waste”.

These losses along the FSC are schematically represented in the following figure:

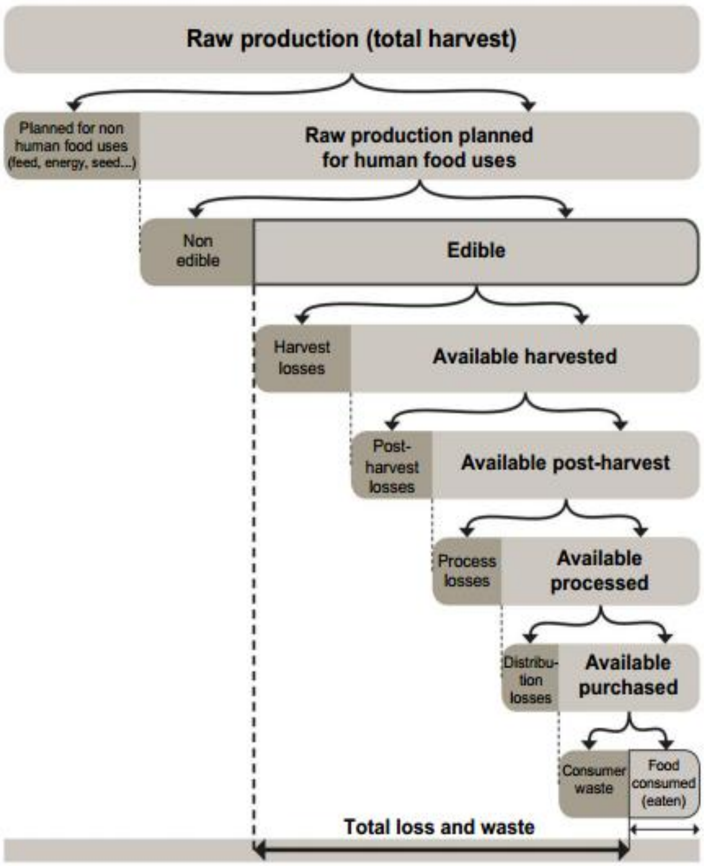

Figure 11. Types of losses along the food supply chain [14]

The Swedish Institute for Food and Biotechnology (SIK) carried out a study about food losses and waste. This study identifies their causes and informs about ways of preventing them. It suggests that around one third of the global food for human consumption is lost or wasted, which constitutes about 1.3 billion tons per year. It occurs throughout all the supply chain but depending on the country, the greatest amounts are usually in the beginning (such as in agricultural production) or in the end (such as in household consumption). For instance, in medium- and high-income countries, this waste is more significant at the consumption stage. In other words, food is dismissed even though it is adequate for human consumption. In industrialized regions, losses are more significant in the beginning of the food supply. In low-income countries, the most significant losses are in early and middle stages of supply chain. Nevertheless, it must be pointed out that at a general level, food waste is bigger in industrialized regions than in the developing ones. For example, SIK estimates that per capita waste in Europe and North-America is 95-115 kg per year whereas in sub-Saharan Africa and South Africa is 6-11 kg/year. In order to reduce these losses, it is important to identify their causes, which obviously depend on the stage where they take place [10].

On the one hand, in low-income countries losses are mainly in the beginning of supply chain and thereby caused by financial and technical limitations in harvesting, storage, infrastructure, packaging and marketing systems. Considering that in developing countries food insecurity levels are high, a reduction in food losses could mean a significant improvement in most smallholder farmers' livelihoods. According to SIK, farmer-buyer sales agreements can also be one of the reasons of wasting farm crops. On the other hand, in medium- and high-income countries, food is specially wasted at a consumption level, which means that it is thrown away even though it is adequate for human consumption. In this case, food losses are related to quality criteria, which dismiss bad looking products, lack of purchase planning, expiring dates and the careless attitude of consumers who can afford to waste food. The next graphic shows food losses per capita in kg/year at consumption and pre-consumption stages for each major area [10]:

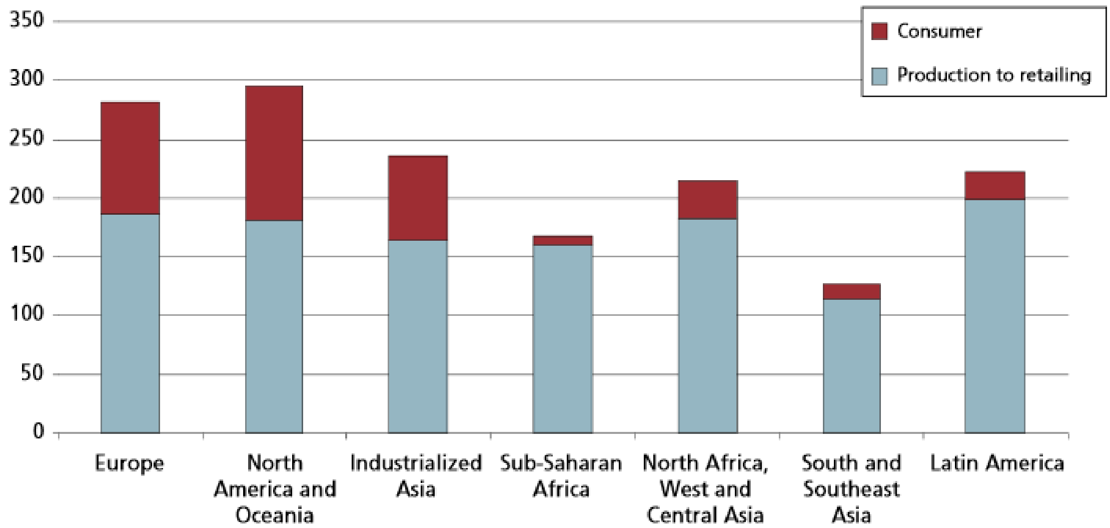

Figure 11. Per capita food losses at consumption and pre-consumption level (kg/year) [10]

Author: Meritxell Pina Laguna

As seen below, most part of food losses take place at pre-consumption stage, from production to retailing. Even though food losses are more or less equal in industrialized and developing countries, it must be pointed out that the first ones have greater food losses in consumption stage (about 40% of the total food loss). This loss is about 220 million tons, which almost correspond to net food production in sub-Saharan Africa (about 230 million tons). More specifically, losses can also be divided in the five categories given by FAO, as seen in the following graphic [10]:

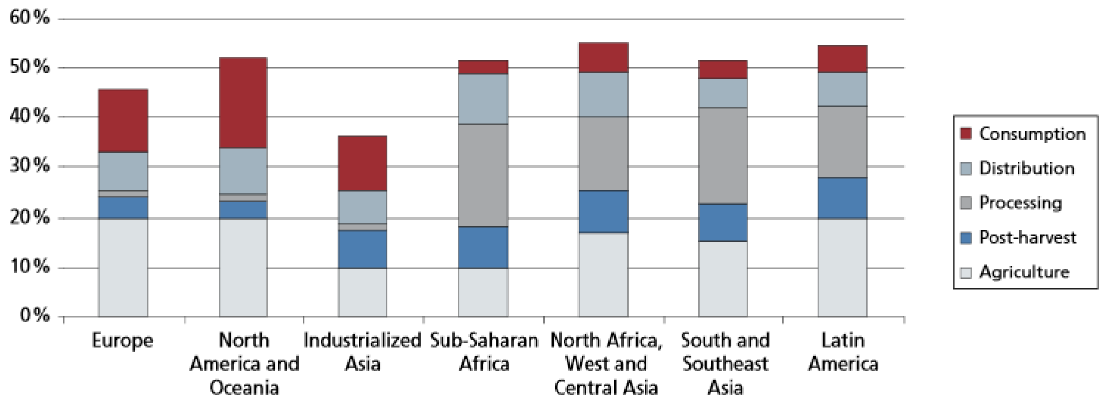

Figure 12. Percentage of food loss per region in the different stages of the FSC [10].

As explained before, losses are greater in different stages of the FSC depending on the region. This graphic corroborates that in industrialized regions (Europe, North America and Oceania and industrialized Asia), the percentage of food loss at a consumption level is greater than in the rest of the regions. The major part of these losses are because of high appearance quality standards, which most fruits and vegetable cannot meet. For this reason, they are discarded and sometimes used as animal feed or as other non-human consumption uses. In this case, quality standards could be different considering that these products were originally destined to human consumption [14]. Moreover, between 15 and 30% of purchased food is discarded by consumers. On the contrary, losses in developing countries are mostly during production such as agriculture, post-harvesting and processing. As opposed to industrialized areas, losses in distribution are really significant in developing countries. One of the reasons could be the warm and humid climate that most developing countries have, deteriorating this way crops.

Increasing primary food production could be necessary to meet the future increase in demand but reducing the gap between potential and real food production is also important. Reducing food losses is of high importance not only to combat hunger but also to improve food security in the world, especially in the less developed countries. Food losses affect negatively food quality, economic development and environment since they contribute to a waste of resources such as land, water and energy. For this reason, it is important to try to reduce or prevent them.

2 DIFFERENT WAYS OF PREVENTING FOOD WASTE

There are different ways of preventing food waste depending on their causes, which in their turn depend on countries. In order to prevent food waste, it is important to analyze across regions the causes that create it.

On the one hand, in developing countries and in some developed ones, food losses are focused more in the agriculture stage rather than in consumption one. This happens because in developing countries consumers buy small amounts of food to meet their dairy demand due to low incomes and poverty. In the agricultural stage, losses are usually due to early harvesting and inadequate infrastructures for transportation and storage. The first situation takes place because some poor farmers harvest prematurely due to food deficiency or a need for cash. Consequently, food with less nutritional and economic value is produced, which may be thrown away when not adequate for consumption. One way of preventing this could be diversifying and upscaling small farmers' production and marketing. For instance, small farmers could form a group to produce significant quantities of crop. Referring to inadequate infrastructures losses, most industries of developing countries do not have the necessary capacity to process and preserve fresh fruits and vegetables and consequently, great amounts of food are wasted. For this reason, government or/and private sectors should invest in infrastructures to improve cold chain, storage and transportation in order to avoid them [14].

On the other hand, in industrialized countries food waste is usually caused during production and especially in consumption.

At a production level, food is wasted when production exceeds demand or in processing. First situation is usual to happen because farmers sometimes produce more to meet the possible demand considering bad weather or pest attacks. For this reason, sometimes they overproduce, having greater quantities than needed, especially if weather conditions are normal. This overproduction is sometimes sold to processors or as animal feed, which is not profitable as they are sold at lower prices. In order to prevent it, it is necessary to improve communication and cooperation between farmers. This way, overproduction could be reduced as one farmer's surplus of crops could help another one's shortage of crops. In processing, food processing lines are often to trim to have final products with "adequate" shape, size and appearance. These trimmings could be used for human consumption instead of discarded. In processing lines, food is also lost due to spoilage or mistakes during processing, which contributes to final products with wrong size, shape or appearance but with adequate taste or nutritional value. As a consequence, safe food is discarded for not meeting quality standards even though it is safe. One way of preventing it would be developing "sub-standard" products marketing. Sale and charity organizations could sell or use the discarded food, which are still safe and conserve its original taste and nutritional value [10].

At a consumption level, there are different reasons why so much food is wasted. First of all, the most important one is the affordability of this waste. For instance, it has been an increase in the amount of food in small stores and restaurants. Policies like buffets or packages such as "getting one for free" encourage people to waste food, since they are going to eat/buy more food than necessary. This could be avoided by raising awareness of the excessive food waste, especially in children. As opposed to developing countries, consumers buy foods abundantly, generating high food waste. Secondly, supermarkets need to supply a big range of products and brands and consumers expect shelves to be filled. Some products reach their sell-by dates while waiting to be sold and as a consequence, most of them must be thrown away. Even though it is profitable for supermarkets to have continuously filled shelves, food products on the verge to expiry are usually not bought by consumers. In order to minimize these losses, food should be sold efficiently. There are some organisms called marketing cooperatives that help to reduce this kind of losses. They are in charge of transporting food from small farmers to markets and other distributors. Thirdly, supermarkets throw away a lot of food because they are sure they will not sell it when not meeting quality standards such as size, weight or appearance. However, surveys show that this is not exactly true since most consumers will buy fruits and vegetables if their taste were not affected. Quality standards set by retailers are now too demanding and thus there is great food waste. This could be avoided by asking the consumers, creating wider ranges in small stores and reducing the distance between farmers and consumers. This way, food losses will be reduced by not having to pass supermarkets quality standards but consumers ones, which are not so demanding. Furthermore, a lot of food is wasted not only for not meeting appearance standards but also safety criteria. Unsafe food can appear due to toxins in food itself, contaminated water or inadequate temperature control or storage conditions. Unsafe food is not adequate for human consumption and thus it is wasted, thereby generating food losses and in some cases, affecting food security of a country. For this reason, it is necessary adequate food managing and storing in order to produce safe food and protect the final consumer [10] [14].

To sum up, in low income countries measures should be focused at production levels by improving harvest techniques, farmer education, storage facilities and cooling chains. Conversely, in industrialized countries improvements at a production level will be secondary if losses at a consumption level continue at current levels. Households must change their attitude towards excessive consumption in order to reduce food waste. Nevertheless, as said before, most food is wasted for not meeting quality standards although its nutritional value is not affected. One solution to benefit these foods is to dry them and powder them afterwards in order to get higher value profitable products.

3 DRYING FRUITS AND VEGETABLES

Drying and powdering afterwards fruits and vegetables is a solution that takes advantage of all these foods that are thrown away for not meeting appearance standards. This solution not only reduces food waste but also generates a way of benefiting these products that are otherwise dismissed. Moreover, drying food prolongs its conservation time without refrigerating. This is of high importance especially in developing countries, where adequate refrigerating infrastructures are not always available. In order to dry food properly and save energy during the process, it is important to know which are the best conditions of drying, which is the main purpose of this thesis. These conditions can be measured with different variables, namely thickness of foods slices and temperature and time of drying. A lot of experiments have been carried out changing these variables in order to get a wide range of results and thereby find the optimum drying conditions.

3.1 Drying variables

As said before, the three variables used in this experiment are slices thickness and temperature and time of drying. First of all, it is necessary to select a working range of these variables in order to make a sweep over them to get the results. For the first variable, the range selected was from 1 to 10 mm with a step of 1 mm; for the second one, it was from 40 to 70^{o}C with a step of 10^{o}C. For the last one, there was no range selected since every experiment was finished when all samples of all thicknesses were dry enough to be grinded. However, the step was fixed to one hour. In other words, for each temperature all samples of all thicknesses were dried until grindable, measuring the results every hour. Next, there is a summary table with the selected ranges for each variable:

Table 1. Summary of the drying variables

VARIABLE	RANGE	STEP
Thickness	1-10 mm	1 mm
Temperature	40-70^{o}C	10^{o}C
Time of drying	Until grindable	1 h

It must be pointed out that these were the chosen variables to manipulate but there were other ones such as food moisture content, which was fixed by each food. Referring to moisture content, it must be said that considering the length of this study, it was only possible to work with potatoes, tomatoes and bananas. However, it can be extended to other fruits and vegetables with similar moisture contents and characteristics. The procedure carried out in the experiments was the same for each fruit and vegetable and it is described in more detail below.

3.2 Procedure for the experiments

The main idea of the experiments carried out in this thesis is to find the optimum drying conditions for different products, namely potatoes, tomatoes and bananas, to grind them afterwards. Logically, when these foods are not dried enough, it is impossible to grind them because they are too juicy or jelly. Alternatively, when they are too dried, it is more difficult to grind them because they are tougher and moreover, their flavour is also different. This optimal dry percentage to grind is expected to be achieved at different drying times depending on the food and the temperature. The higher the temperature, the lower time required to reach this optimum. Referring to thickness, drying time is also expected to be lower when the slice is thinner. In order to find these results, it is necessary to know the initial and final moisture content of each sample. This is also important to determine the precise moisture content from which each kind of food is grindable. The whole procedure to do it is described in detail below.

First of all, the initial moisture content of each fruit/vegetable was determined by calculating the total water loss of some pieces of them after drying them completely. More specifically, these little pieces were weighed, dried totally and weighed afterwards. To ensure that all water was evaporated, these pieces were dried at a temperature higher than water evaporation one (about 105^{0}C) during more than 24 hours. Knowing initial and final weights of these pieces, initial moisture content for each product can be determined as follows:

$$h_0 = \frac{m_{H_2O}}{m_0} \cdot 100 = \frac{m_0 - m_f}{m_0} \cdot 100 \qquad (1)$$

Secondly, fruits and vegetables were peeled and sliced transversely with thicknesses from 1 to 10 mm, having five slices for each thickness. Each slice was weighed initially in order to calculate afterwards its final moisture content (after drying). It must be said that more than one fruit/vegetable was used for each experiment since just one was not enough to cover samples with all thicknesses. Thirdly, the slices were disposed in a tray to be dried at the respective temperature (40, 50, 60 or 70^{0}C) for one hour and weighed afterwards. With both initial and final slice weight and with the initial moisture content of the original fruit/vegetable, it is possible to calculate the final moisture content as seen below:

$$h_f = \frac{m_{H_2O}}{m_0} \cdot 100 = \frac{m_f - m_{dry}}{m_0} \cdot 100 \qquad (2)$$

Where m_{dry} is the mass that correspond to the rest of fruit/vegetable that is not water. Thus, this term can be calculated multiplying the opposite percentage of initial moisture with the initial mass as follows:

$$m_{dry} = \frac{(100 - h_0)}{100} \cdot m_0 \qquad (3)$$

If the slices were dried enough to be grinded, they were removed from the drying tray. If not, they were dried for one more hour at the corresponding temperature and weighed again afterwards. Finally, the process ended when all slices were dried enough to be grinded. As expected, thinner slices achieved this final moisture content for grindability before thicker ones. It must be said that this experiment has been realized three times for each temperature. Once all the ranges of thickness, temperature and time of drying were swept for each product, the results can be analyzed.

4 DRYING RESULTS FOR POTATOES, TOMATOES AND BANANAS

In order to determine the optimum conditions to grind some fruits and vegetables, the final moisture content for each product was studied. Since there are three different variables, the results can be plotted with one according to another one and keeping the third one constant. In this case, all results have been plotted according to time of drying and keeping thickness or temperature constant. All the results obtained in all experiments for each product are shown below.

4.1 Drying results for potatoes

The results obtained in the experiments with potatoes are described in this part of the thesis. In the next graphics, final moisture content is plotted according to time of drying across thicknesses for each temperature:

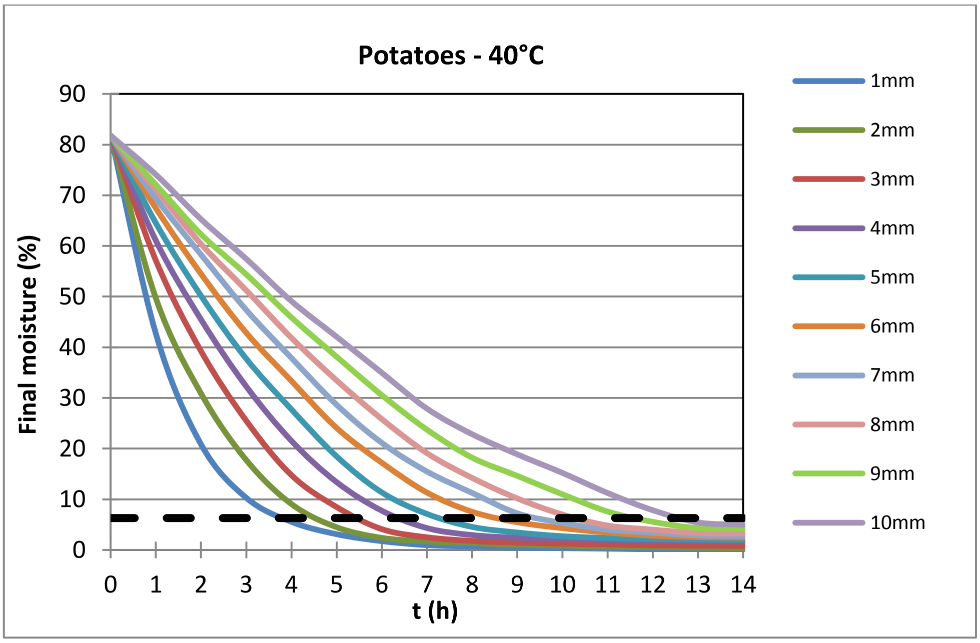

Figure 13. Results for potatoes at 40°C.

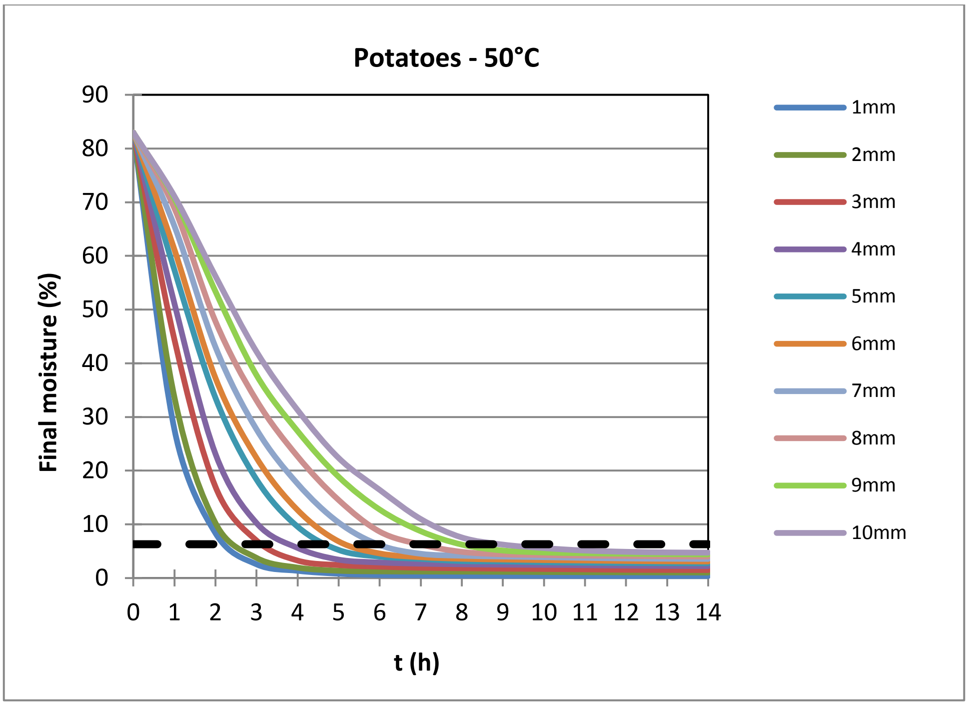

Figure 14. Results for potatoes at 50°C.

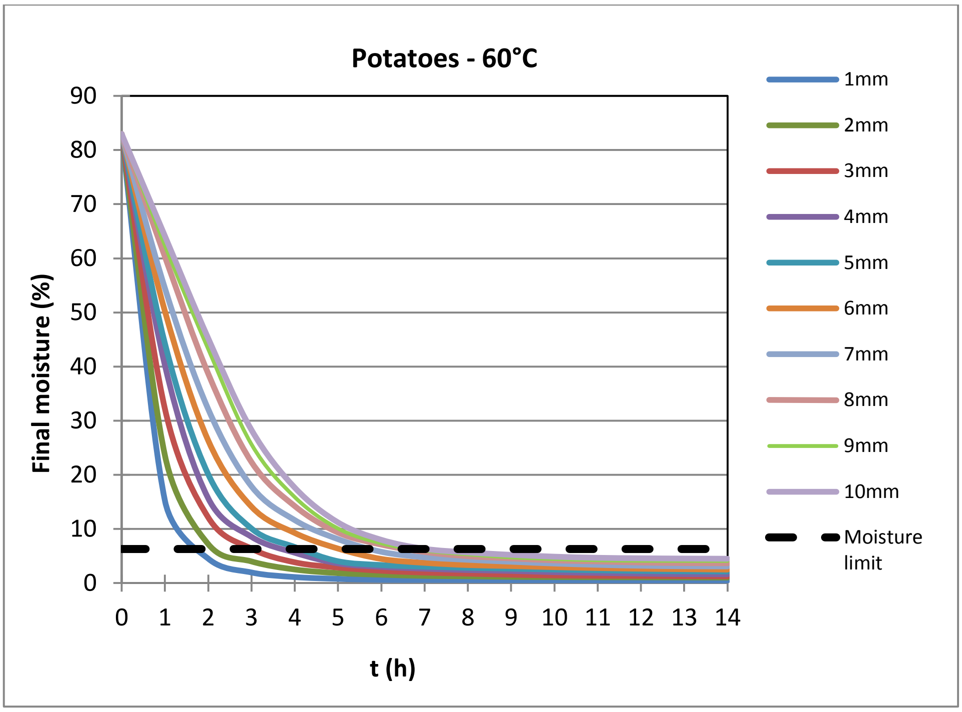

Figure 15. Results for potatoes at 60°C.

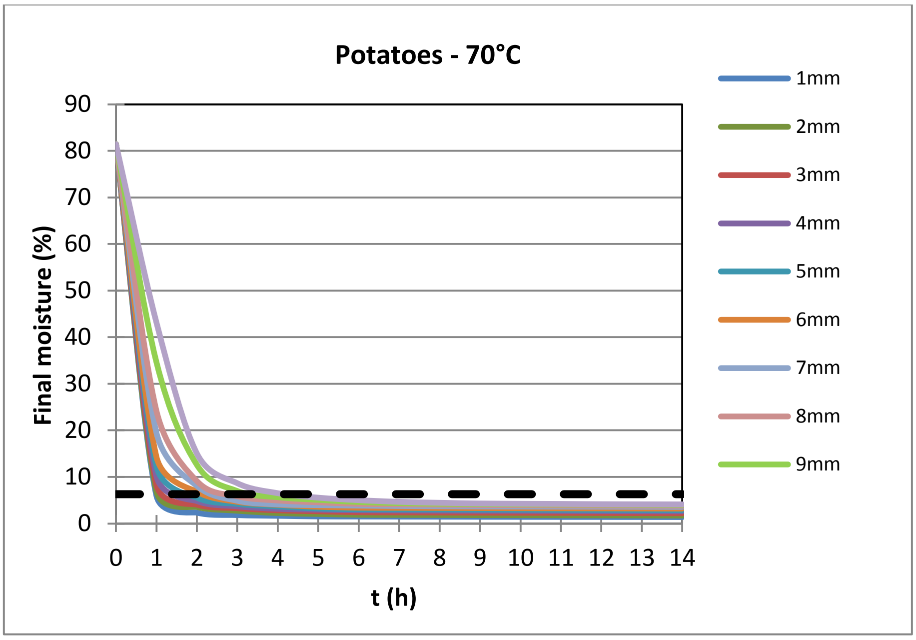

Figure 16. Results for potatoes at 70°C.

As seen below, all the results present the same pattern in each temperature. As expected, the final moisture content decrease with the time of drying until reaching a constant value. Some differences can also be seen with the slice thickness. Obviously, the thicker the slice is, the more difficult is to reduce its water content. For this reason, it is necessary a higher time of drying to achieve the moisture limit from which slices are grindable (dashed line on graphics). Comparing all the graphics above, it can be seen that the higher the temperature, the higher the drying rate is. In other words, the set of drying curves is thinner when increasing the temperature. In order to see more clearly how temperature affects drying times, the results for some thicknesses (1, 5 and 10mm) have been plotted across temperatures:

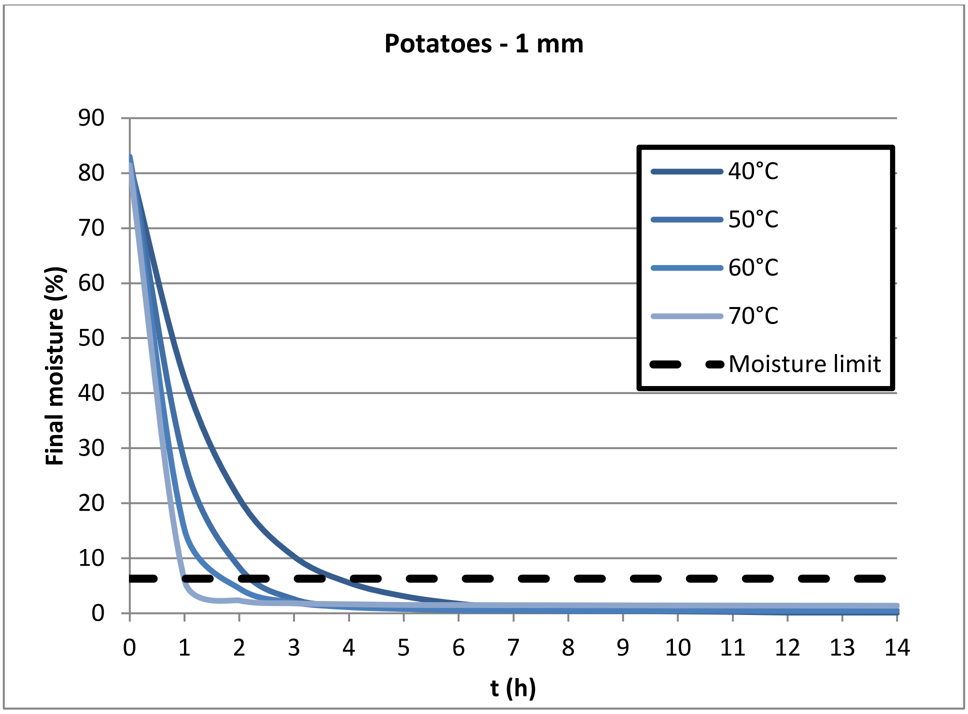

Figure 17. Results for potatoes with thickness of 1 mm.

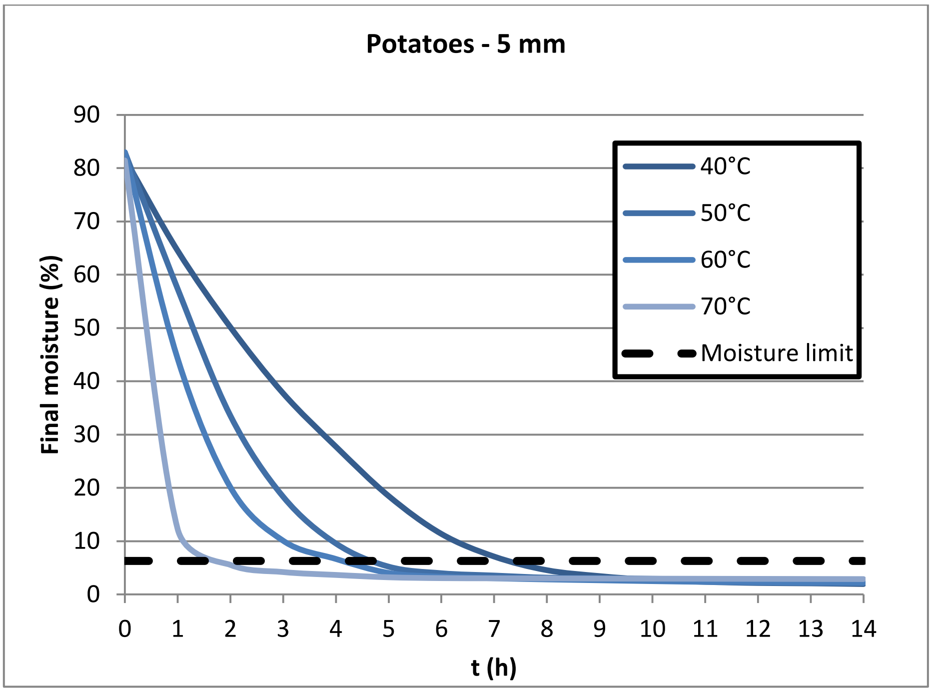

Figure 18. Results for potatoes with thickness of 5 mm.

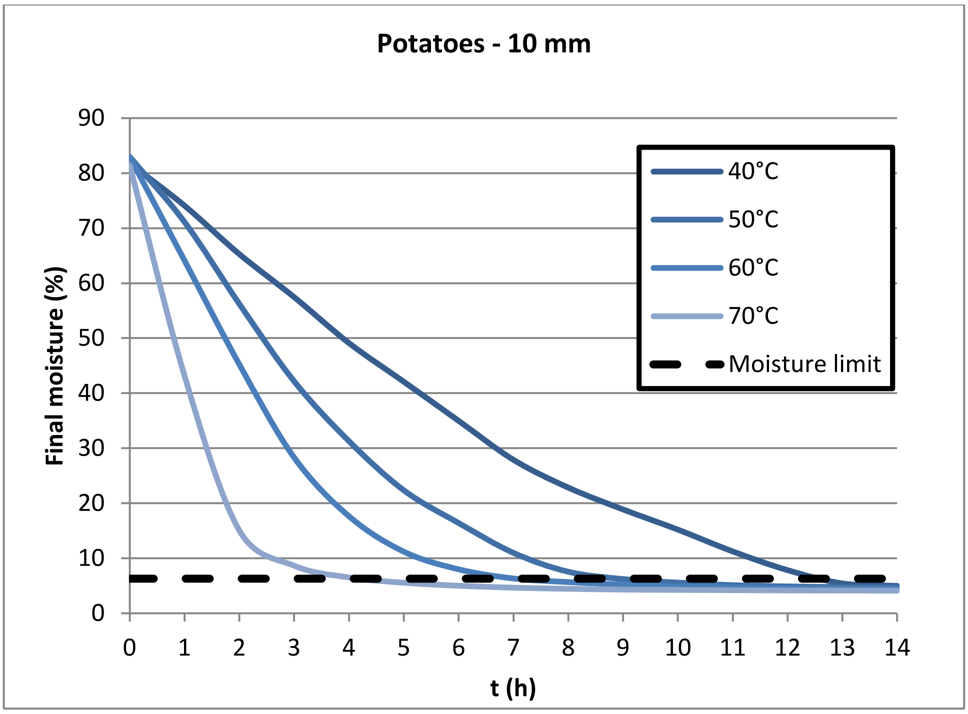

Figure 19. Results for potatoes with thickness of 10 mm.

As seen in graphics, it is corroborated that the higher the temperature is, the less time of drying is required to achieve the moisture limit. As it happened with temperatures, the set of curves is wider when the thickness increase. In other words, differences between drying times across temperatures are bigger when the sample to dry is thick than when thin. For instance, for samples of 1mm, drying times are roughly 1 and 4 hours for 70 and 40°C, respectively. Alternatively, for samples of 10 mm, drying times are about 4 and 13 hours for 70 and 40°C, respectively.

4.2 Drying results for tomatoes

The results obtained in the experiments with tomatoes are shown below. In the next graphics, final moisture content is plotted according to time of drying across thicknesses for each temperature:

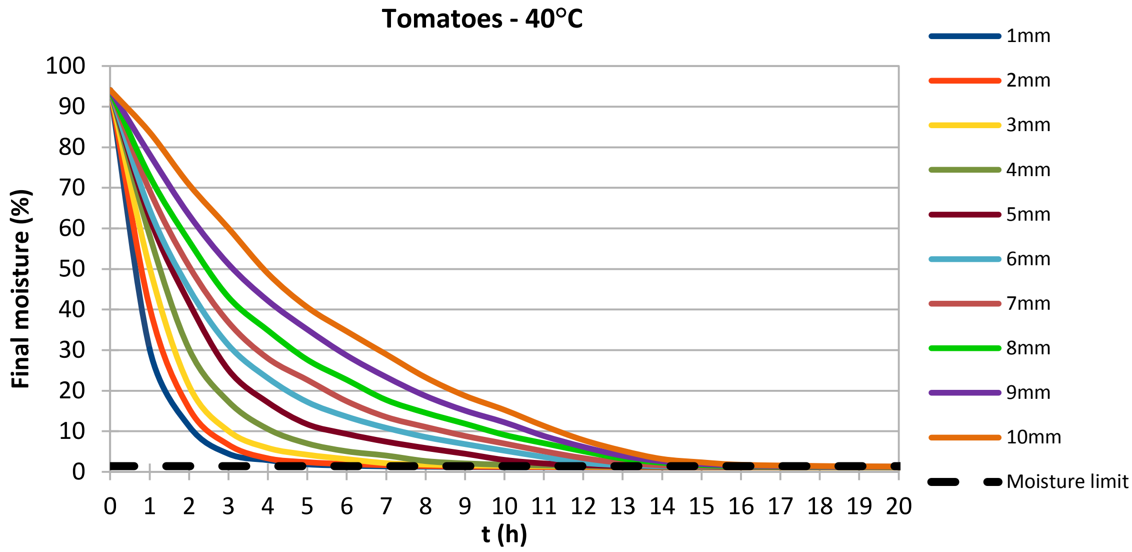

Figure 20. Results for tomatoes at 40°C.

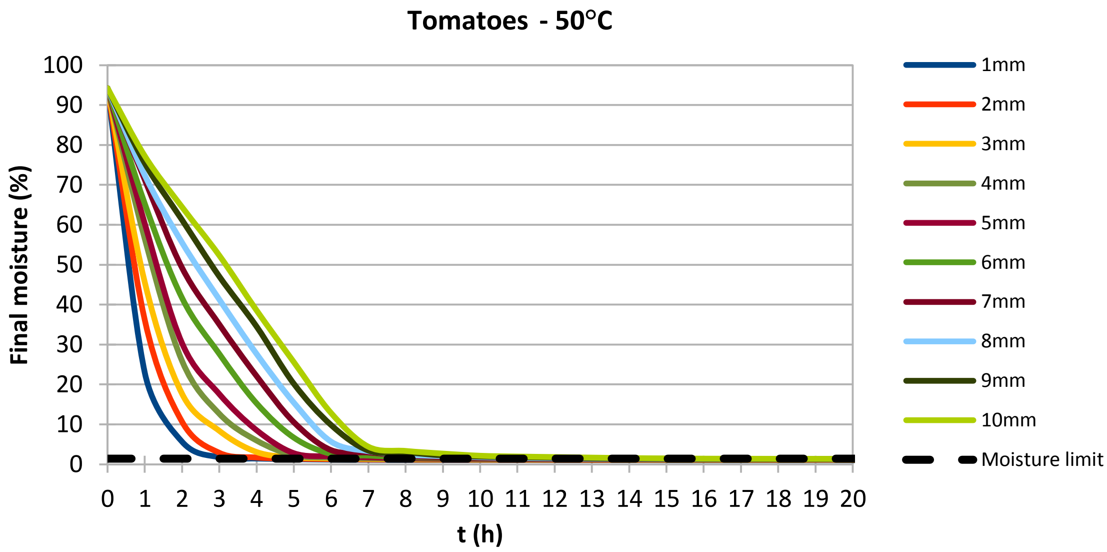

Figure 21. Results for tomatoes at 50°C.

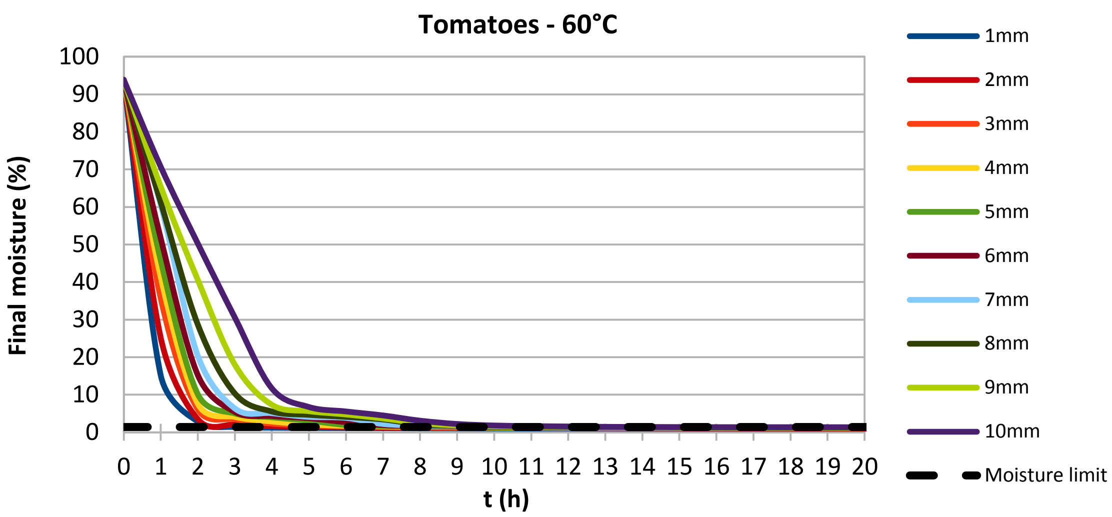

Figure 22. Results for tomatoes at 60°C.

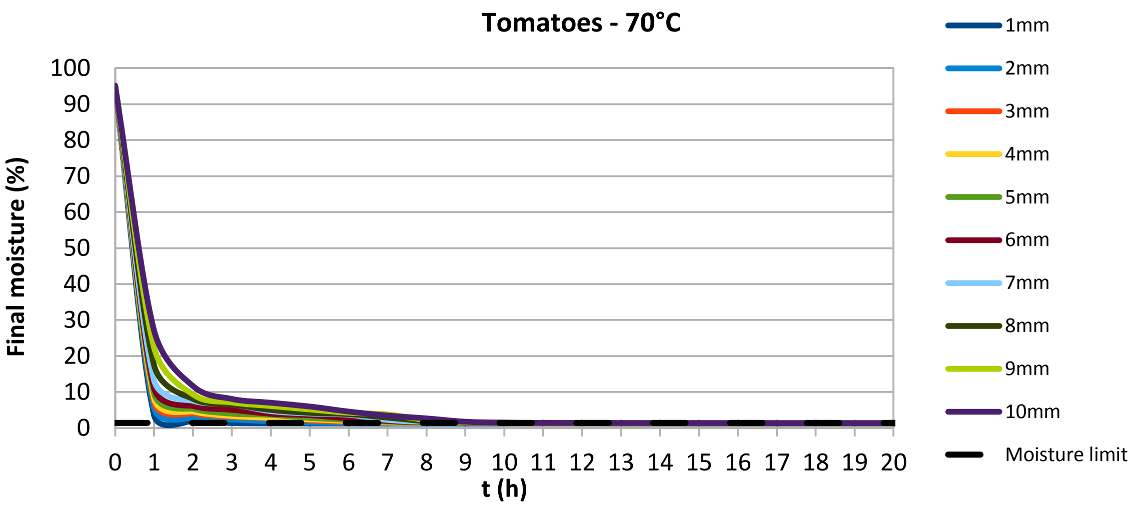

Figure 23. Results for tomatoes at 70°C.

As seen in the graphics below, all the results present the same pattern in each temperature as it happened with potatoes. However, when it comes to tomatoes, higher drying times are needed to reach the moisture limit in the same conditions (thickness and temperature). This could be explained because tomatoes have initially on average higher moisture contents and a lower moisture limit than potatoes. Referring to thickness, its behaviour is analog to the potatoes one: the thicker the slice is, the more difficult is to reduce its water content. Similarly, the temperature behaviour is the same as potatoes: the higher the temperature, the higher the drying rate is. In order to study better the effect of temperature on drying times, the results for some thicknesses (1, 5 and 10mm) have been plotted across temperatures below:

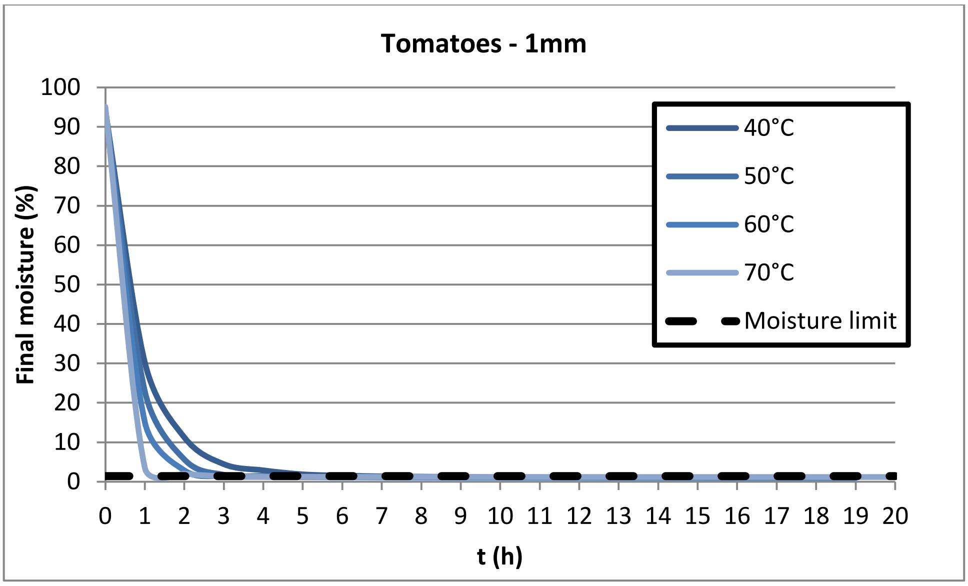

Figure 24. Results for tomatoes with thickness of 1 mm.

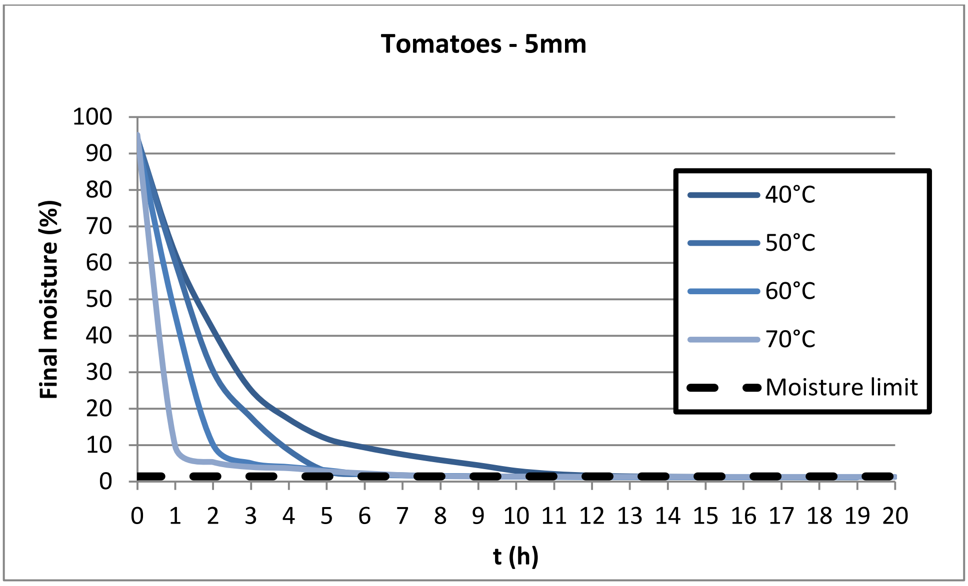

Figure 25. Results for tomatoes with thickness of 5 mm.

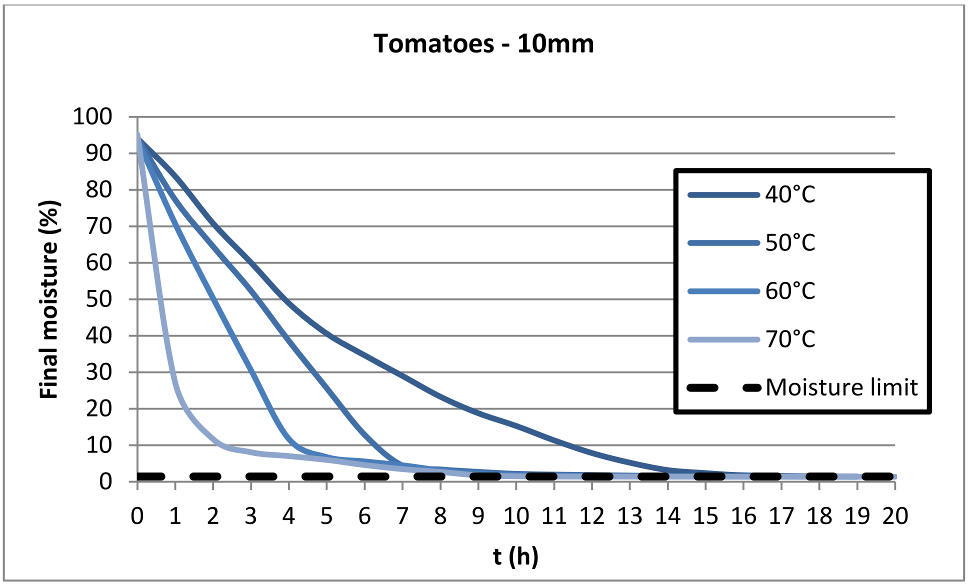

Figure 26. Results for tomatoes with thickness of 10 mm.

As seen in graphics, the behaviour with temperature is exactly the same as it happened with potatoes. It can be seen how the set of curves is wider when the thickness increase. In other words, differences between drying times across temperatures are bigger when the sample to dry is thick than when thin.

4.3 Drying results for bananas

Lastly, the results obtained in the experiments with bananas are outlined below, where final moisture content is plotted according to time of drying across thicknesses for each temperature:

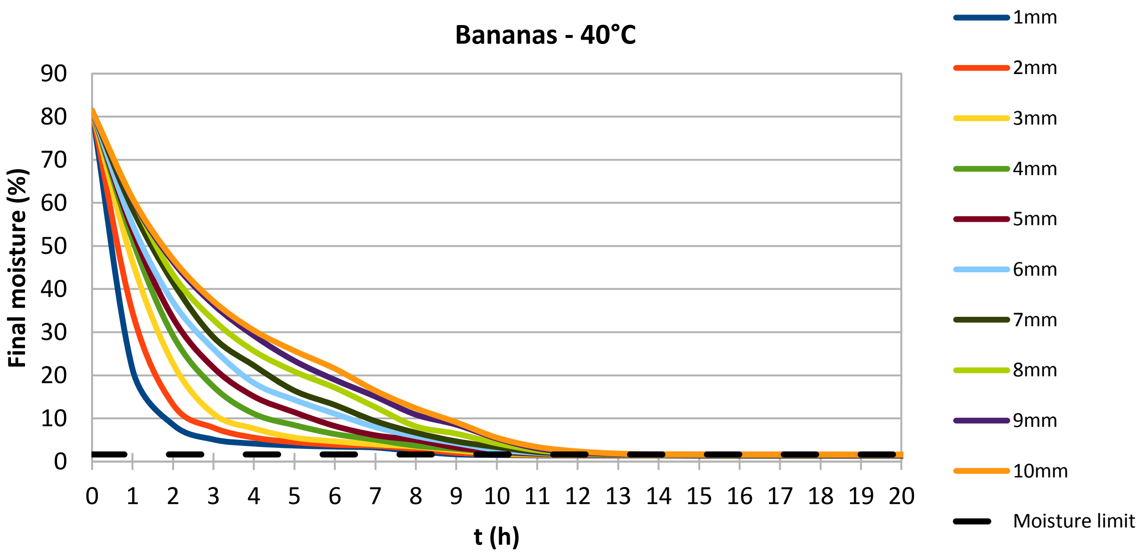

Figure 27. Results for bananas at 40°C.

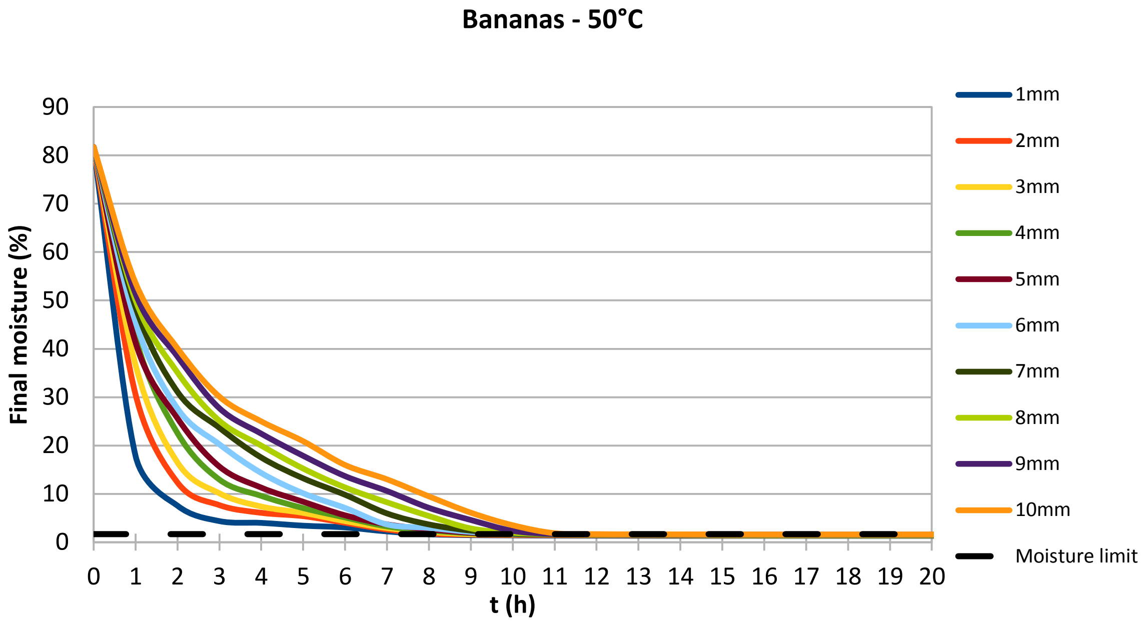

Figure 28. Results for bananas at 50°C.

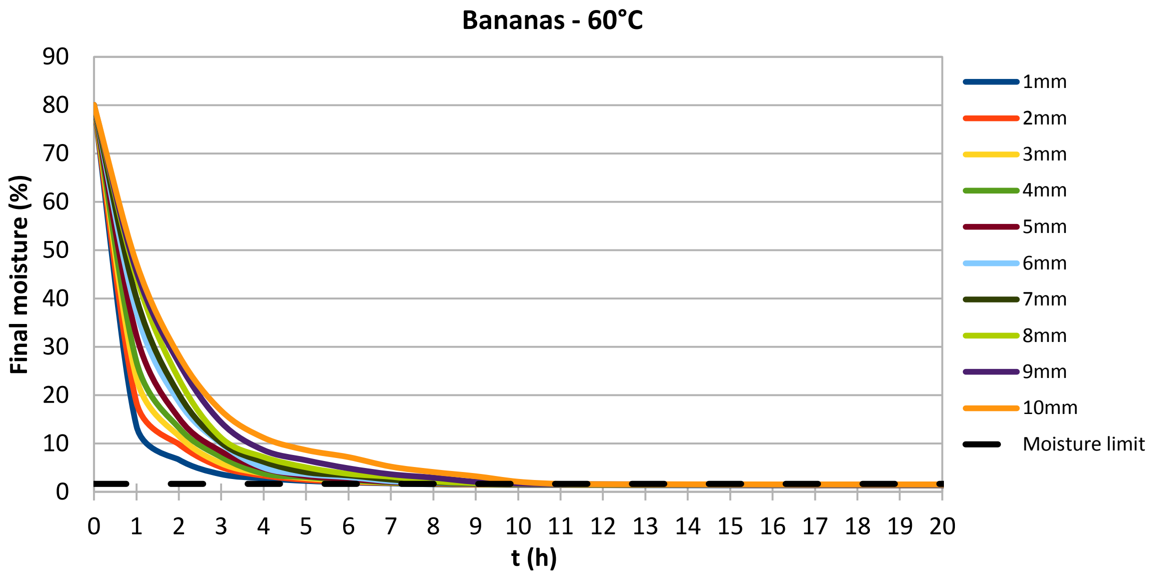

Figure 29. Results for bananas at 60°C.

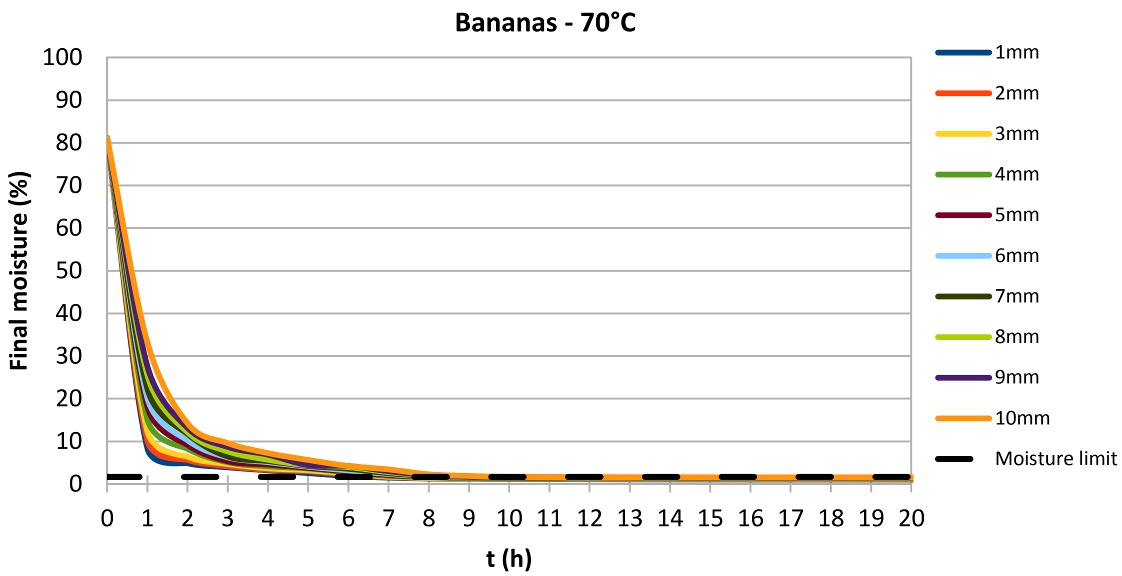

Figure 30. Results for bananas at 70°C.

Comparing the results of bananas with the ones obtained with potatoes and tomatoes, it can be seen that all three present the same tendences and thickness and temperature behaviour. However, for the same thickness and temperature conditions, bananas need higher drying times than potatoes to reach the moisture limit. As in the case of potatoes and tomatoes, the results for some thicknesses (1, 5 and 10mm) have been plotted across temperatures below:

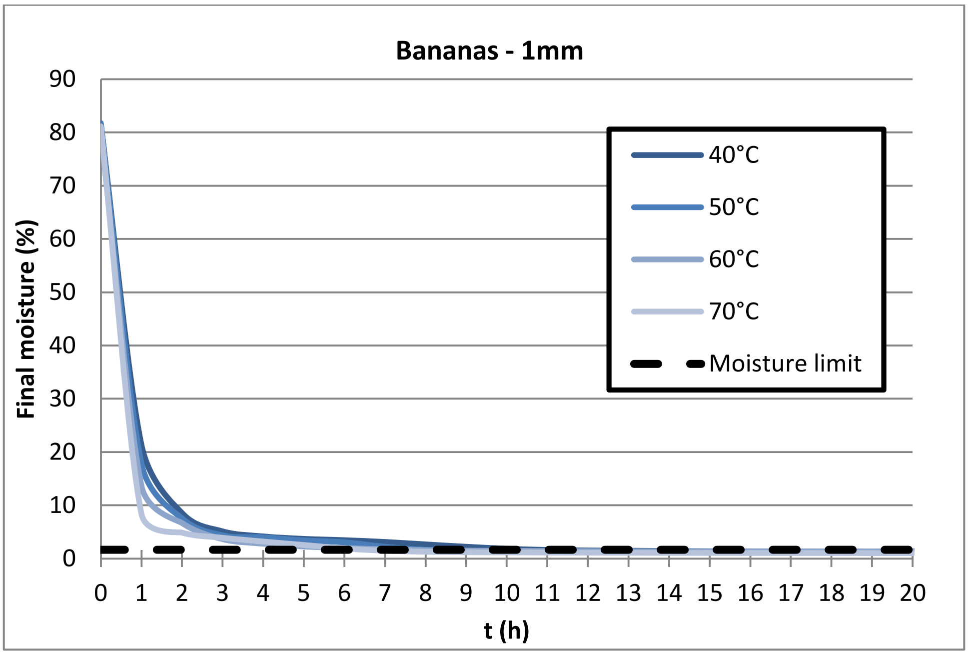

Figure 31. Results for bananas with thickness of 1 mm.

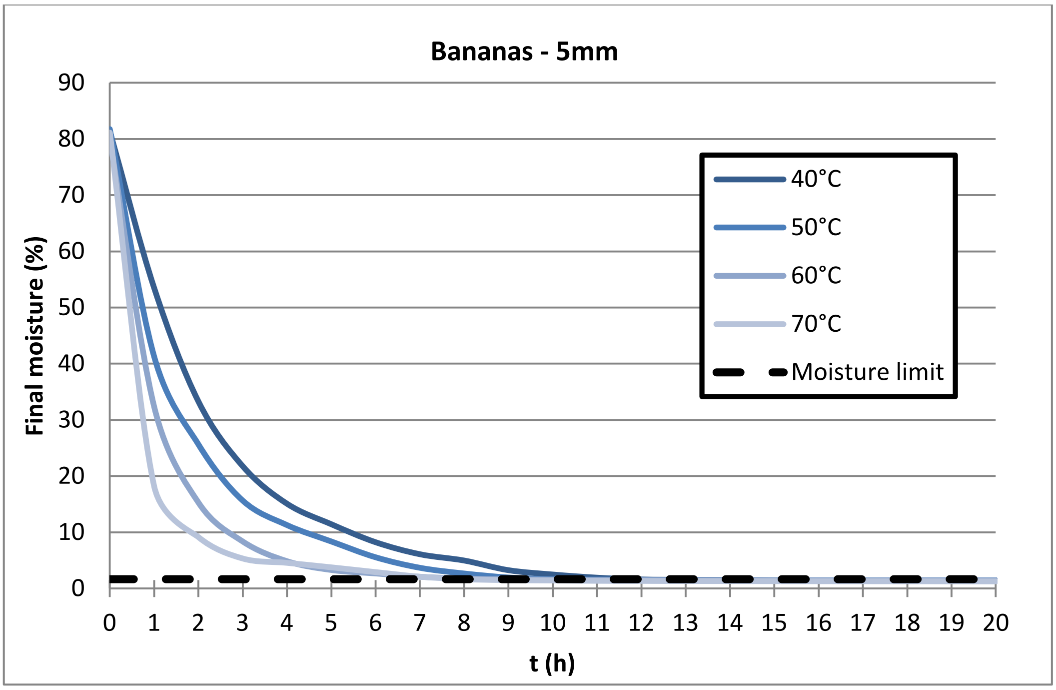

Figure 32. Results for bananas with thickness of 5 mm.

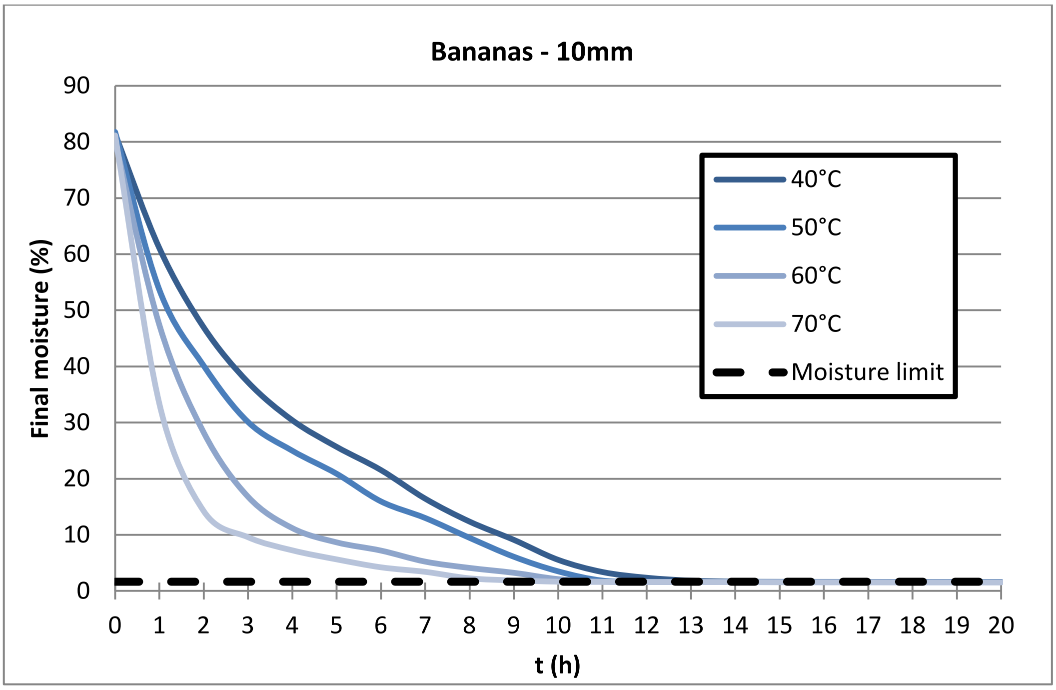

Figure 33. Results for bananas with thickness of 10 mm.

Comparing all graphic of all products, it can be seen that bananas present the same temperature behaviour as potatoes and tomatoes. More specifically, the set of curves is wider when the thickness increase.

4.4 Considerations about the results

Comparing all the results of the three products, it can be determined that, whereas tomatoes and bananas have similar drying rates, this rate is higher for potatoes. It must be said that both potatoes and bananas have similar initial moisture contents (roughly 80%) whereas tomatoes one is about 94%. As a consequence, less time is needed for potatoes to achieve the moisture limit. Referring to it, tomatoes and bananas present similar moisture limits whereas potatoes one is a little bit higher. This can be explained since tomatoes and bananas present acidity and a high content of sugar, respectively. For this reason, it is necessary to dry them longer to be able to grind them. It must be said that both initial moisture content and moisture limit were determined empirically.

On the one hand, initial moisture content was calculated for each experiment as the average of the initial moisture contents of all foods used in the mentioned experiment. On the other hand, moisture limit was determined by taking for each food the lowest final moisture content from which the food was grindable. More specifically, these limits were 6,29, 1,41 and 1,65 for potatoes, tomatoes and bananas, respectively. However, they are just estimations obtained of the experiments but they can be used to determine the optimal drying conditions (thickness, temperature and time of drying) for each product.

It must also be remarked that some results were not considered because they had anormal drying rates and were out of the rest of the results tendences. These anomalies corresponded with the littlest samples, namely the ones with inital low weights (less than roughly 0.4 g). Due to its low weight, they were dried at higher rates and consequently, presented lower drying times. For this reason, their results were removed in order not to misrepresent the solutions.

5 OPTIMUM DRYING CONDITIONS

As mentioned before, optimum drying conditions are the best conditions of thickness, temperature and drying time among the grindable possibilities. These possibilities are found below the moisture limit of each product. In order to see them clearly, the graphics above have been zoomed as follows.

5.1 Optimum conditions for potatoes

The grindable possibilities for potatoes can be seen for each temperature in the following graphics:

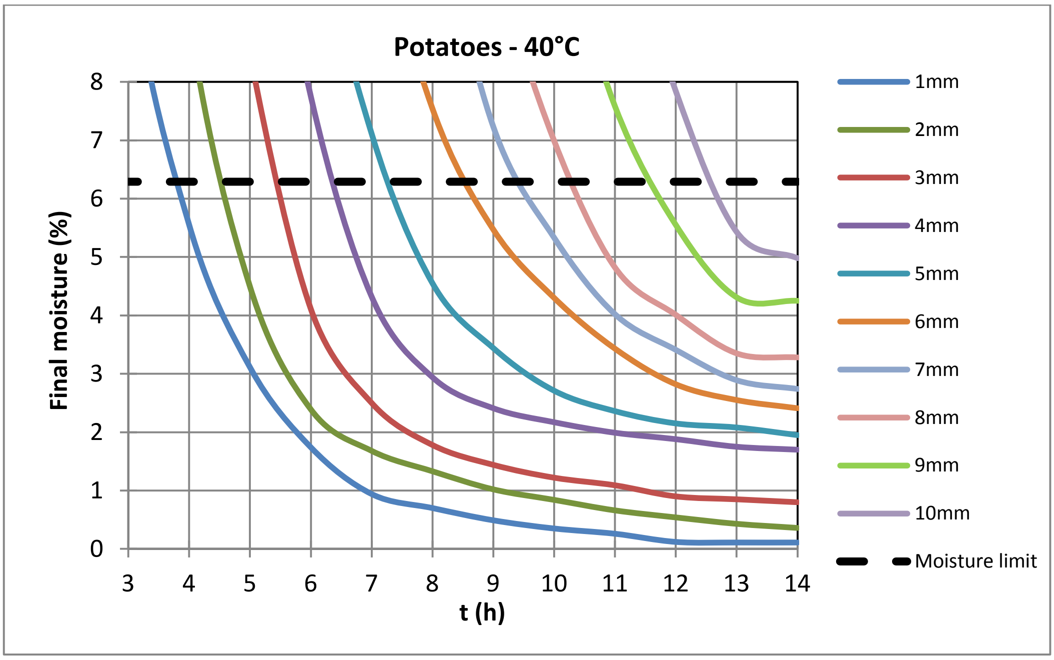

Figure 34. Zoomed results for potatoes at 40°C.

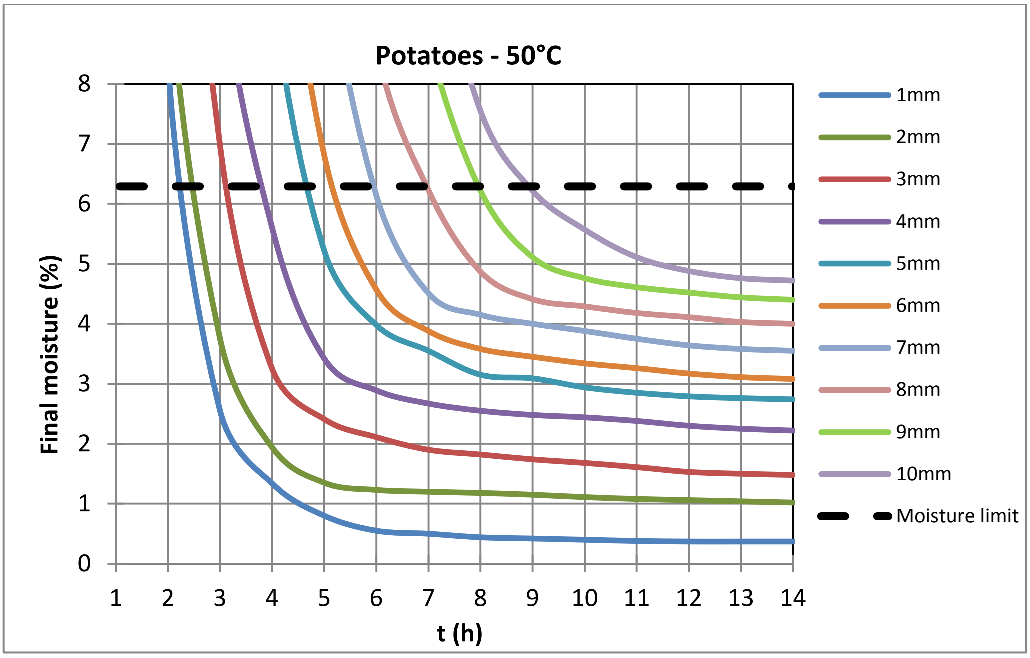

Figure 35. Zoomed results for potatoes at 50°C.

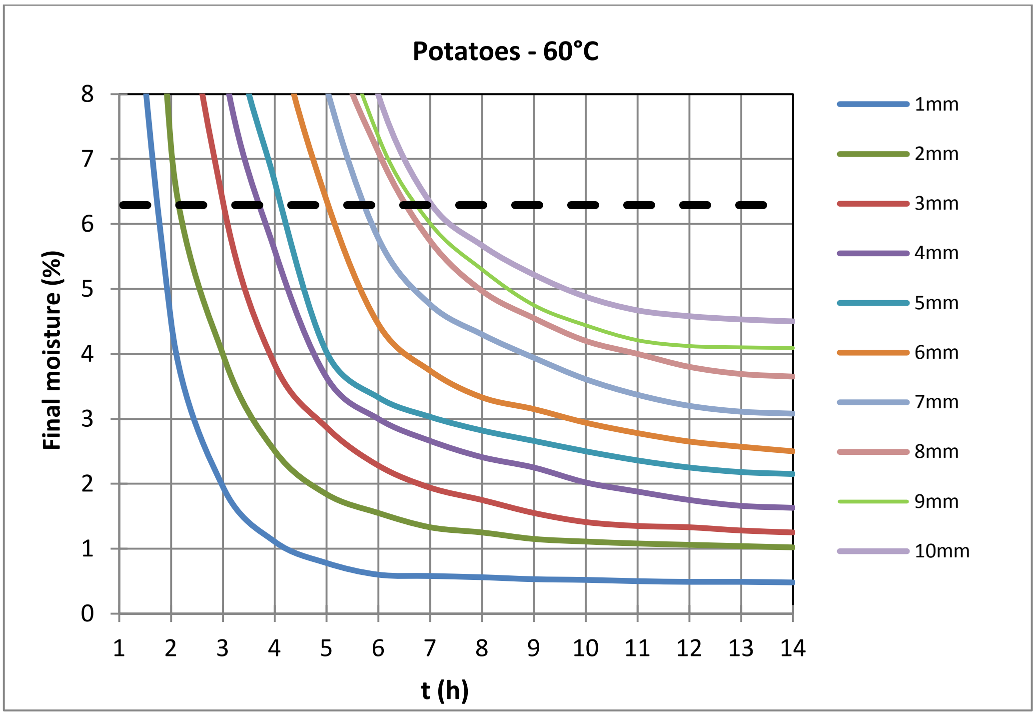

Figure 36. Zoomed results for potatoes at 60°C.

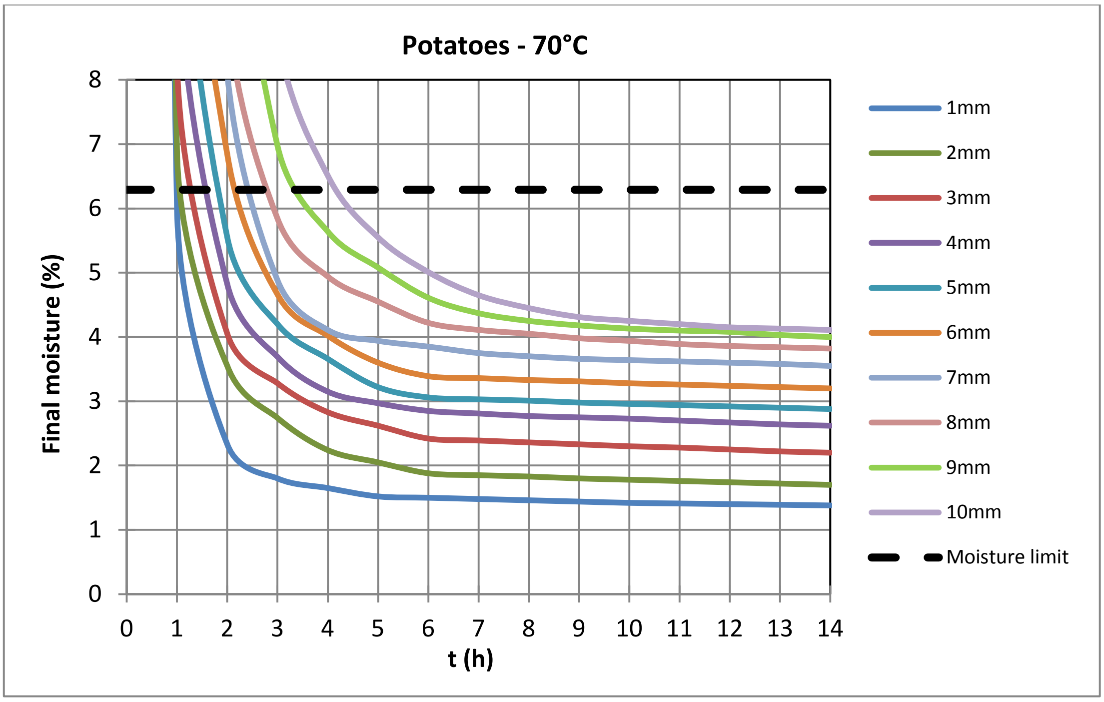

Figure 37. Zoomed results for potatoes at 70°C.

The grindable possibilities to cover all thicknesses have been gathered from the graphics above in the next summary table:

Table 2. Summary of the drying conditions for potatoes

TEMPERATURE (°C)	DRYING TIME RANGE (h)
40	4 – 13
50	3 – 9
60	2 – 8
70	1 – 5

As seen in the table above, the lower the temperature is, the wider the drying time range is to cover all thicknesses. In order to choose the best drying conditions, there are some factors about thickness that must be considered. For instance, it must be said that dried samples with thicknesses from 7 mm and above were harder to grind. Another factor is that fruits and vegetables are usually sliced with average thicknesses between 3 and 5 mm. This is because it is really difficult to get 1 and 2 mm thicknesses when foods are cut manually. Since lower thicknesses involve lower drying times, it is important to separate the results in thoses cases where thinner slices are possible. Considering these new ranges of thicknesses, the new drying time ranges obtained are shown in the following table:

Table 3. Summary of the drying conditions for potatoes considering thicknesses

TEMPERATURE (°C)	DRYING TIME RANGE (h) Thickness: 1 – 6 mm	DRYING TIME RANGE (h) Thickness: 3 – 6 mm
40	4 – 9	6 – 9
50	3 – 6	4 – 6
60	2 – 6	3 – 6
70	1 – 3	2 – 3

As seen in the table above, higher temperatures present thinner and lower drying time ranges. In this case, the optimum drying conditions depend on the possibility of getting slices with thicknesses of 1 or 2 mm. If the cutting techniques are good enough to get these thicknesses, the optimal conditions would be working with thicknesses of 1 - 2mm, at a temperature of 70°C during 2 h. It must be said that at this temperature and this drying time, slices with thicknesses of 3, 4 and 5 mm will also be possible. However, it must be remarked that the thinner the slice, the easier to grind. Otherwise, when 1 and 2 mm thicknesses are not possible, the optimal conditions are working with thicknesses of 3 - 4mm, at a temperature of 70°C during 3 h. With these conditions, slices with thicknesses of 5, 6, 7 and 8 mm will also be dried adequately for grinding.

5.2 Optimum conditions for tomatoes

The grindable possibilities for tomatoes can be seen for each temperature in the following graphics:

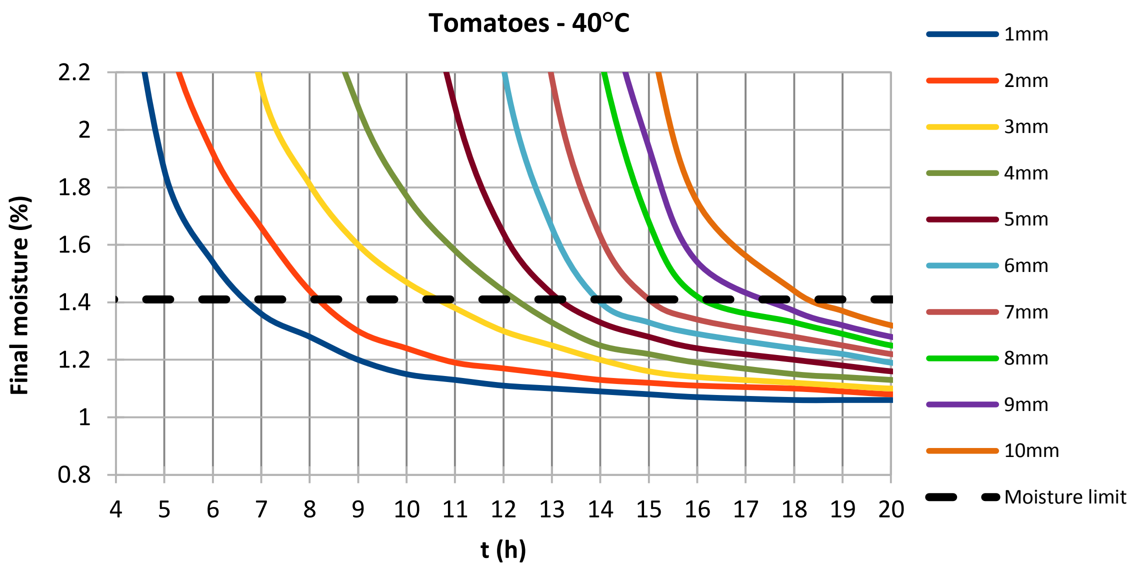

Figure 38. Zoomed results for tomatoes at 40°C.

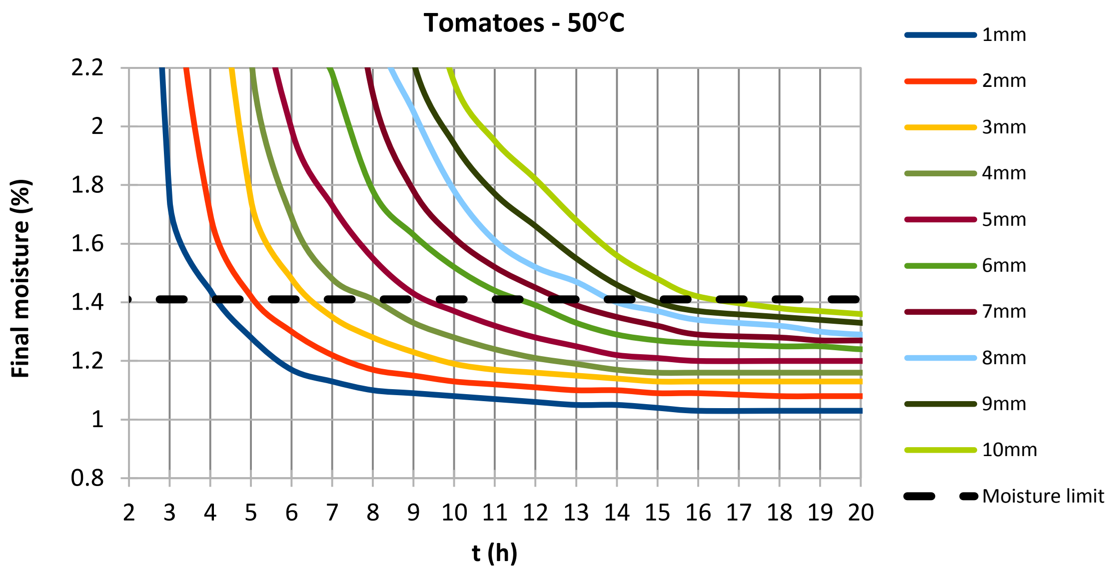

Figure 39. Zoomed results for tomatoes at 50°C.

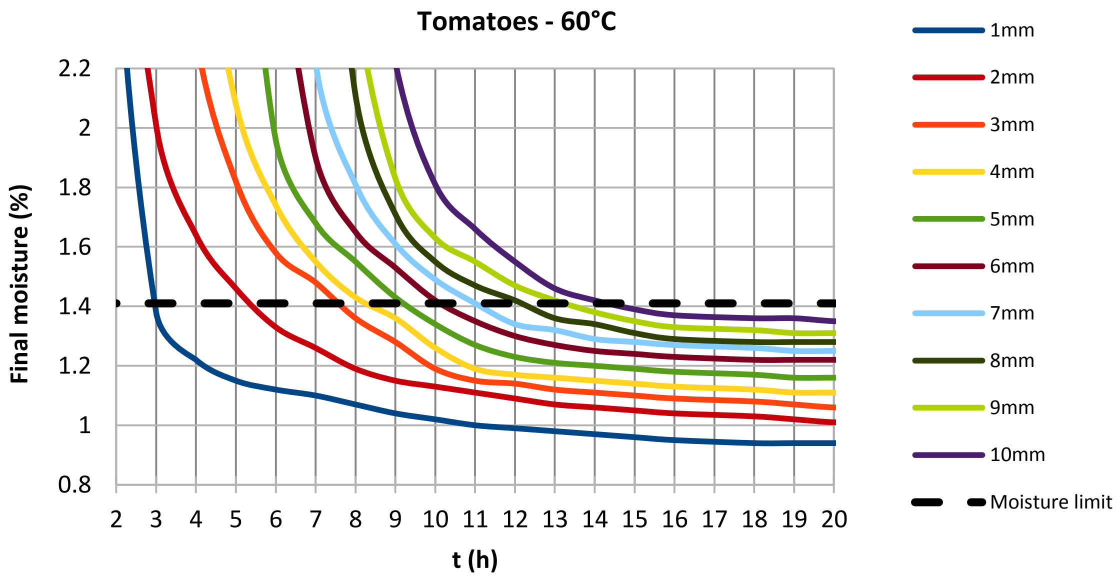

Figure 40. Zoomed results for tomatoes at 60°C.

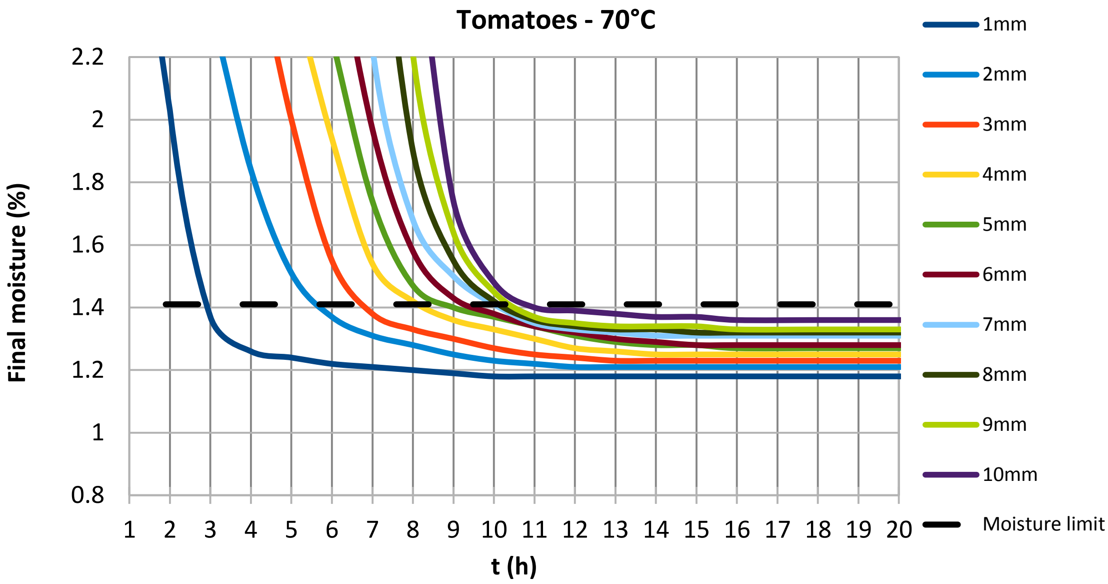

Figure 41. Zoomed results for tomatoes at 70°C.

Similarly to potatoes, the grindable possibilities to cover all thicknesses have been gathered from the graphics above in the next summary table:

Table 4. Summary of the drying conditions for tomatoes

TEMPERATURE (°C)	DRYING TIME RANGE (h)
40	7 – 19
50	5 – 18
60	3 – 15
70	3 – 11

As seen in the table above and as it happened with potatoes, the lower the temperature is, the wider the drying time range is to cover all thicknesses. Albeit different as with potatoes, there are some factors about thickness that must be considered to choose the best conditions. For instance, it must be said that thin samples were really difficult to remove from the tray even when dried. This is due to the high initial moisture content of tomatoes and their juiciness. For this reason, it is not recommended to use samples with thicknesses of 1 and 2 mm. Moreover, as it happened with potatoes, dried samples with thicknesses from 7 mm and above are harder to grind. Considering these new ranges of thicknesses, the new drying time ranges obtained are shown in the following table:

Table 5. Summary of the drying conditions for tomatoes considering thicknesses.

TEMPERATURE (°C)	DRYING TIME RANGE (h) Thickness: 3 – 6 mm
40	11 – 14
50	7 – 12
60	7 – 11
70	7 – 11

As opposed to potatoes, higher temperatures don't have huge differences between their drying time ranges. It must be said that higher temperatures present higher drying rates and consequently, they should have thinner drying time ranges. However, for the thickness range of interest, the differences between all ranges are not really significant, specially for 50, 60 and 70°C. For this reason, optimum drying conditions for tomatoes would be working 3 - 4mm, at a temperature of 50°C during 7 h. The temperature selected is 50°C since at 60 and 70°C it is necessery the same drying time in order to achieve the moisture level.

5.3 Optimum conditions for bananas

The grindable possibilities for bananas can be seen for each temperature in the following graphics:

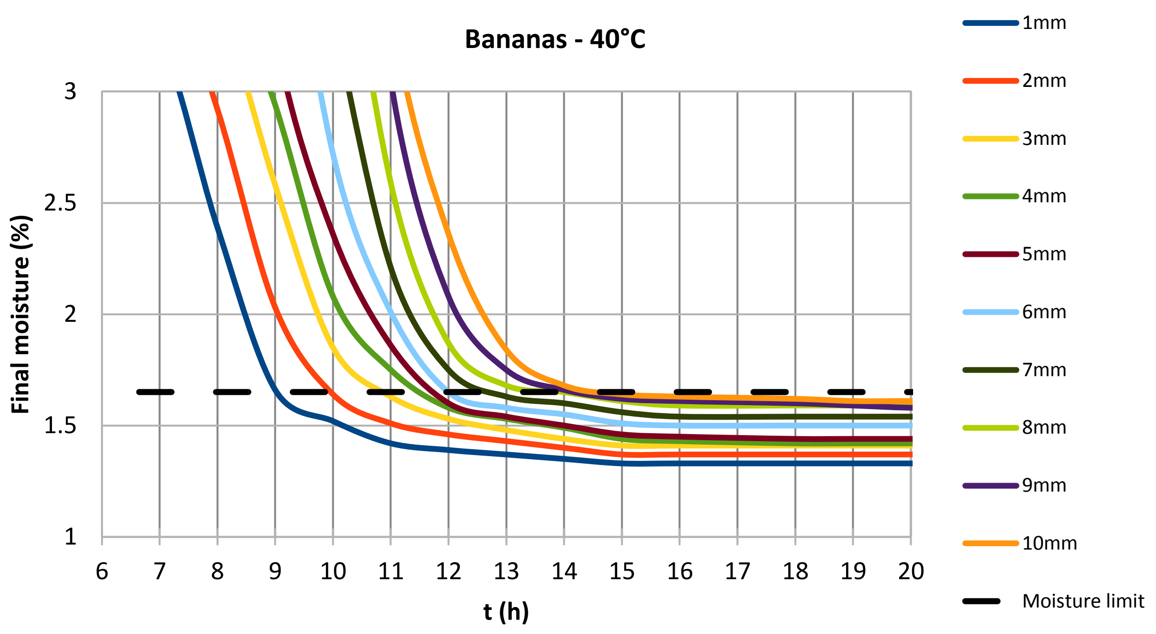

Figure 42. Zoomed results for bananas at 40°C.

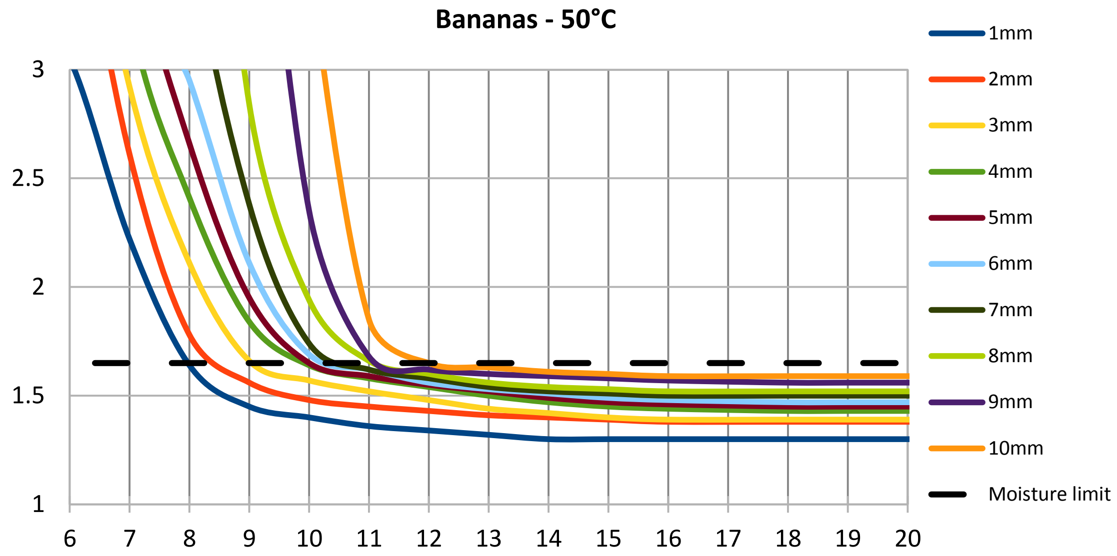

Figure 43. Zoomed results for bananas at 50°C.

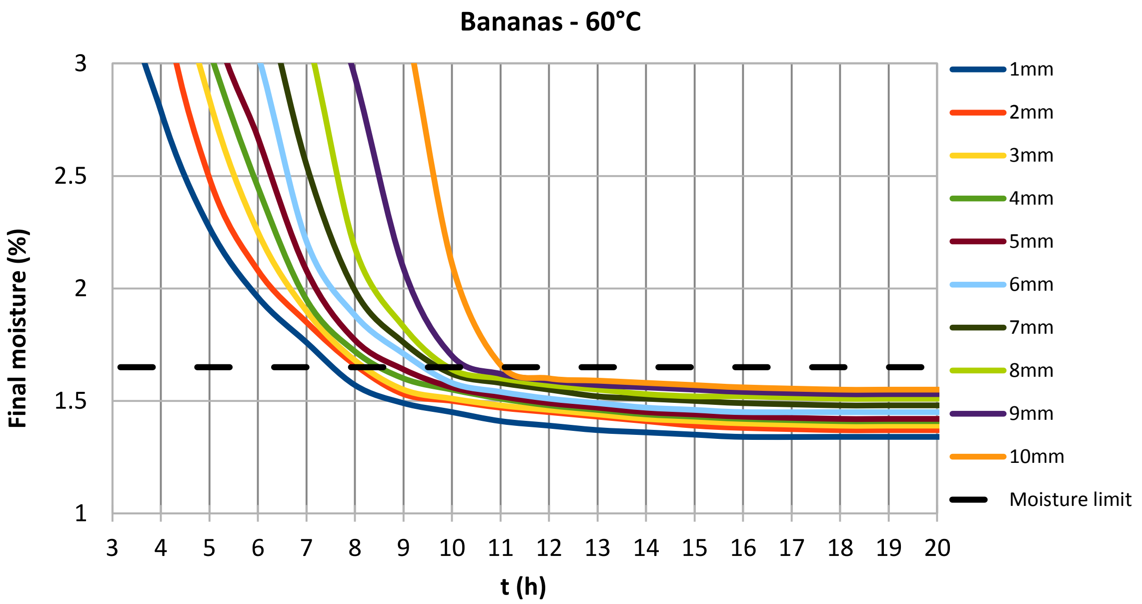

Figure 44. Zoomed results for bananas at 60°C.

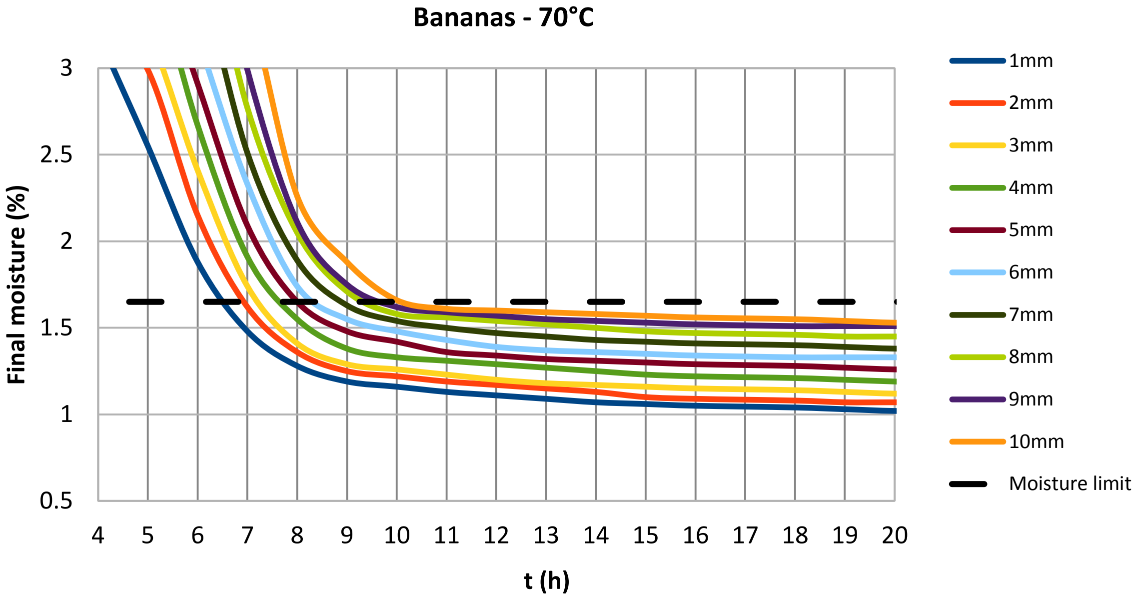

Figure 45. Zoomed results for bananas at 70°C.

Similarly to potatoes and tomatoes, the grindable possibilities to cover all thicknesses have been gathered from the graphics above in the next summary table:

Table 6. Summary of the drying conditions for bananas.

TEMPERATURE (°C)	DRYING TIME RANGE (h)
40	9 – 15
50	8 – 12
60	8 – 11
70	7 – 10

As seen in the table above and as it happened with tomatoes, there are no significant differences between drying time ranges across temperatures even though the higher ones present higher drying rates and thus, thinner drying time ranges. Moreover, there are some factors about thickness that must be considered to choose the best conditions. For instance, it must be said that as it happened with tomatoes, thin samples were really difficult to remove from the tray even when dried. For this reason, as with tomatoes, it is not recommendable to use samples with thicknesses of 1 and 2 mm. Considering these new ranges of thicknesses, the new drying time ranges obtained are shown in the following table:

Table 7. Summary of the drying conditions for bananas considering thicknesses

TEMPERATURE (°C)	DRYING TIME RANGE (h) Thickness: 3 – 10 mm
40	11 – 15
50	9 – 12
60	8 – 11
70	7 – 10

It can be seen in the table above that there are no significant differences in the drying time ranges considering the new ranges of thicknesses. Similarly with tomatoes, these ranges are quite similar except for the results at 40°C. Considering this, optimum drying conditions for bananas would be slices of 3 - 4mm with a temperature of 70°C during 7-8 h.

To sum up, there is a summary table below with the optimum drying conditions for each product:

Table 8. Summary of the drying conditions for each product

FOOD	THICKNESS (mm)	TEMPERATURE (°C)	DRYING TIME (h)
Potatoes	1-2	70	2
Tomatoes	3 - 4	50	7
Bananas	3 - 4	70	7 – 8

6 CONCLUSIONS

In conlusion, world's population is increasing annually, thereby increasing world's food demand such as fruit and vegetables one. In order to achieve this increase and diminish hunger in the process, there are several solutions that can be taken. One of them is increasing fruit and vegetables production, which may involve significant negative environmental effects such as groundwater pollution, soil erosion and a loss in biodiversity. For this reason, it is important to take more sustainable solutions such as a decrease of post-harvest losses by drying and powdering afterwards fruit and vegetables. This solution not only reduces food loss but also takes profit of all food that is thrown away for not meeting appearence standards. In order not to create more food loss during the drying process, it is important to know the best drying conditions, which have been determined in this study (table 8). It has been seen that the higher the temperature and the lower the thickness of the slices, the better is the drying process. However, in some cases when the food has high initial moisture content (like tomatoes) or sugar content (like bananas), really thin slices are not adequate since they get sticky in the drying tray. This is the reason too why both tomatoes and bananas need higher drying times than potatoes.

7 ACRONYMS AND VARIABLES

7.1 Acronyms

CRED	Centre for Research on the Epidemiology of Disasters
DALYs	Disability-adjusted life years
FAO	Department of Food and Agriculture of the United Nations
FSC	Food Supply Chain
FiBL	Forschungsinstitut für biologischen Landbau (Research Institut of Organic Agriculture)
GHGs	Greenhouse gases
ha	hectarees
IFOAM	International Federation of Organic Movements
MDGs	Millenium Development Goals
OECD	Organization for Economic Cooperation and Development
UN	United Nations
USDA	United States Department of Agriculture
SIK	Swedish Institute for Food and Biotechnology
SOFI	The State of Food Insecurity in the World
WHO	World Health Organization

7.2 Variables and sub-indices

Variables

h	Moisture content (%)
m	Mass (g)
t	Time of drying (h)
T	Temperature of drying (°C)

Sub-indices

0	Initial
dry	Part that is not water
f	Final
H_2O	Water

8 BIBLIOGRAPHY

[1] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. FAO Statistical Yearbook 2013: World Food and Agriculture.
(Available in: http://www.fao.org/docrep/018/i3107e/i3107e.PDF. Consulted in: 16 August 2014).

[2] UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS/POPULATION DIVISION. World population to 2300.
(Available in: http://www.un.org/en/development/desa/population/publications/pdf/trends/WorldPop2300final.pdf. Consulted in: 16 August 2014).

[3] L. STECK, Theodore. Human population explosion.
(Available in: http://www.eoearth.org/view/article/153596/. Consulted in: 10 July 2014)

[4] WHO. Definition of MDGs [on line].
(Available in: http://www.who.int/mediacentre/factsheets/fs290/en/. Consulted in: 14 September 2014).

[5] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Rome Declaration on Food Security and World Food Summit Plan of Action. Restrieved 26 October 2013.
(Available in: http://www.fao.org/docrep/003/w3613e/w3613e00.htm. Consulted in: 21 August 2014).

[6] USDA Food and Nutrition Service. Guide to Measuring Household Food Security. Retrieved 1 November 2013.
(Available in: http://www.fns.usda.gov/sites/default/files/FSGuide_0.pdf. Consulted in: 21 August 2014).

[7] FAO. The State of Food Insecurity in the World 2014.
(Available in: The State of Food Insecurity in the World 2014. Consulted in: 22 August 2014).

[8] KINDLEBERGER, Charles P. Economic Laws and Economic History. USA, 1997.

[9] International Centre for Trade and Sustainable Development [on line].
(Available in: http://es.ictsd.org. Consulted in: 28 August 2014).

[10] FAO. Global food losses and food waste.
(Available in: http://www.fao.org/docrep/014/mb060e/mb060e.pdf. Consulted in: 7 September 2014).

[11] FAO, OECD. Agricultural Outlook 2012-2021.
(Available in: http://www.oecd.org/site/oecd-faoagriculturaloutlook/publication.htm. Consulted in: 27 July 2014).

[12] FiBL AND IFOAM. The World of Organic Agriculture 2013: Statistics and emerging trends 2014.
(Available in: https://www.fibl.org/fileadmin/documents/shop/1636-organic-world-2014.pdf. Consulted in: 12 September 2014).

[13] FAO. Food waste with sustainable systems
(Available in:
http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-8_EN.pdf. Consulted in: 7 September 2014).

[14] TRISTRAM, Stuart. Waste: uncovering the global food scandal paperback. First American Edition 2009.