Departamento de Engenharia Química e Biológica

Effect of Pre-treatments and Post-treatments on Drying Products

Dissertação apresentada para a obtenção do grau de Mestre em Processos Químicos e Biológicos

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Dedicated to my beloved grandmother, Isaura Maria Palma.

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RESUMO

O processo de liofilização aplicado a vegetais e frutas permite que estes sejam detentores de elevada qualidade em termos de atributos como a cor, o teor nutricional, volume, reidratação cinética, prevenção da deterioração durante o armazenamento, entre outros, quando comparados com alimentos que foram submetidos apenas à secagem convencional com ar quente. No entanto, estudos científicos mostraram a eficácia de tratamentos aplicados antes e depois da secagem relativamente aos atributos dos alimentos, melhorando a sua qualidade.

Deste modo, o objetivo da presente tese focou-se em adquirir uma vasta panóplia de estudos científicos para demonstrar que a secagem convencional conjuntamente com pré e pós-tratamentos pode aproximar-se, ou até, superar a qualidade de alimentos liofilizados. A qualidade dos alimentos passa pela sua avaliação em termos de atributos como a inativação enzimática, a estabilidade do produto durante o armazenamento, a secagem, a reidratação cinética, a cor, o teor nutricional, o volume ou formato e ainda a sua textura e estrutura celular.

Relativamente aos pré-tratamentos foram abordados os seguintes: branqueamento com água, branqueamento com vapor, ultrassom, congelação, alta pressão (high pressure - HP) e a desidratação osmótica. O pré-tratamento denominado de pulsos elétricos de elevada frequência (high electric pulsed field - HELP) também foi estudado mas os atributos alimentares não foram explicitados.

O branqueamento com água e com vapor mostrou ser adequado no que respeita a inativação enzimática de forma a prevenir o escurecimento enzimático preservando a qualidade do produto durante longos períodos de armazenamento.

Em relação ao ultrassom os resultados publicados demonstraram que este pré-tratamento é eficaz para diminuir o tempo de secagem, melhorar a reidratação cinética e reter a cor do alimento. Por outro lado, estudos demonstraram que o ultrassom permite a perda de açúcares e, em alguns casos, pode levar ao rompimento celular.

Para a congelação existiram algumas controvérsias para chegar a uma conclusão global consistente em relação aos atributos alimentares, uma vez que, cada alimento demonstra resultados diferentes quando é submetido à congelação. Para além disso, a congelação comporta um vasto leque de variáveis que podem comprometer o estudo correto deste pré-tratamento. No entanto, para os casos científicos estudados, a congelação melhorou a reidratação cinética e a cor dos alimentos.

O pré-tratamento de alta pressão (high pressure) mostrou ser eficaz no tocante à inativação enzimática, melhorando a estabilidade dos alimentos quando armazenados. Para além de ter melhorado a performance de reidratação. No entanto, para outros atributos, quando o pré-tratamento de alta pressão era aplicado foram encontrados resultados divergentes

dependendo do alimento utilizado. A desidratação osmótica tem sido muito utilizada em tecnologia alimentar de forma a incorporar um soluto desejado em solução no interior da estrutura celular de alimentos (melhoramento do seu teor nutricional). Para além disso, a desidratação osmótica permite que os tempos de secagem sejam reduzidos e que a impregnação de solutos durante a osmose reforce a estrutura celular dos tecidos.

No caso de pós-tratamentos foram estudadas duas tecnologias, das quais, do inglês o puffing e do francês a tecnologia détente instantanée contrôlée (DIC) indicadas na literatura científica como tratamentos adequados para o melhoramento de diversos atributos alimentares quando aplicados em combinação com a secagem convencional. Ambas as tecnologias são semelhantes onde o produto alimentar é submetido a um estágio de alta pressão e o processo pode fazer uso de diferentes meios de aquecimento como o CO_2, o vapor, o ar e o N_2. No entanto, existe uma diferença significativa relacionada com o último estágio de ambos os tratamentos o que posteriormente pode influenciar a qualidade do produto final obtido. O puffing e o DIC são bastante utilizados para expandir os tecidos celulares melhorando o volume das amostras dos alimentos, melhorando a reidratação cinética, entre outros atributos.

A eficiência de tais pré e pós-tratamentos está dependente do estado em que vegetais e frutas se encontram. Desta forma, variáveis tais como a estrutura celular, variedade, origem, estado do alimento (fresco, maduro, cru), condições de colheita, são decisivos e cruciais aquando a aplicação de um ou mais tratamentos.

Pôde concluir-se, como se verificou na literatura científica, que a aplicação de pré-tratamentos e de pós-tratamentos associados à secagem convencional têm como objetivo a obtenção de produtos desidratados de qualidade semelhante aos produtos liofilizados.

Devido a razões de confidencialidade, por parte da empresa Unilever R&D Vlaardingen, a parte experimental, resultados e discussão da presente Tese de Mestrado não será divulgada.

Palavras-chave: Liofilização, Secagem convectiva, Pré-tratamentos, Pós-tratamentos, Atributo alimentar.

ABSTRACT

Freeze drying technology can give good quality attributes of vegetables and fruits in terms of color, nutrition, volume, rehydration kinetics, stability during storage, among others, when compared with solely air dried ones. However, published scientific works showed that treatments applied before and after air dehydration are effective in food attributes, improving its quality.

Therefore, the hypothesis of the present thesis was focus in a vast research of scientific work that showed the possibility to apply a pre-treatment and a post-treatment to food products combined with conventional air drying aiming being close, or even better, to the quality that a freeze dried product can give. Such attributes are the enzymatic inactivation, stability during storage, drying and rehydration kinetics, color, nutrition, volume and texture/structure.

With regard to pre-treatments, the ones studied along the present work were: water blanching, steam blanching, ultrasound, freezing, high pressure and osmotic dehydration. High electric pulsed field was also studied but the food attributes were not explained on detailed.

Basically, water and steam blanching showed to be adequate to inactivate enzymes in order to prevent enzymatic browning and preserve the product quality during long storage periods.

With regard to ultrasound pre-treatment the published results pointed that ultrasound is an effective pre-treatment to reduce further drying times, improve rehydration kinetics and color retention. On the other hand, studies showed that ultrasound allow sugars losses and, in some cases, can lead to cell disruption.

For freezing pre-treatment an overall conclusion was difficult to draw for some food attributes, since, each fruit or vegetable is unique and freezing comprises a lot of variables. However, for the studied cases, freezing showed to be a pre-treatment able to enhance rehydration kinetics and color attributes.

High pressure pre-treatment showed to inactivate enzymes improving storage stability of food and showed to have a positive performance in terms of rehydration. For other attributes, when high pressure technology was applied, the literature showed divergent results according with the crops used.

Finally, osmotic dehydration has been widely used in food processing to incorporate a desired salt or sugar present in aqueous solution into the cellular structure of food matrix (improvement of nutrition attribute). Moreover, osmotic dehydration lead to shorter drying times and the impregnation of solutes during osmose allow cellular strengthens of food. In case of post-treatments, puffing and a new technology denominated as instant controlled pressure drop (DIC) were reported in the literature as treatments able to improve diverse

food attributes. Basically, both technologies are similar where the product is submitted to a high pressure step and the process can make use of different heating mediums such as CO_2, steam, air and N_2. However, there exist a significant difference related with the final stage of both which can comprise the quality of the final product. On the other hand, puffing and DIC are used to expand cellular tissues improving the volume of food samples, helping in rehydration kinetics as posterior procedure, among others.

The effectiveness of such pre and/or post-treatments is dependent on the state of the vegetables and fruits used which are also dependent of its cellular structure, variety, origin, state (fresh, ripe, raw), harvesting conditions, etc.

In conclusion, as it was seen in the open literature, the application of pre-treatments and post-treatments coupled with a conventional air dehydration aim to give dehydrated food products with similar quality of freeze dried ones.

Along the present Master thesis the experimental data was removed due to confidential reasons of the company Unilever R&D Vlaardingen.

Keywords: Freeze Drying, Air Drying, Pre-treatments, Post-treatments, Food attribute.

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GLOSSARY

POD- Peroxidase enzyme

LOX- Lipoxygenase enzyme

PPO- Polyphenoloxidase enzyme

PME- Pectin methyl esterease enzyme

PE- Pectinestererase enzyme

Polyacetylenes: FaOH-Falcarinol; FaDOH-Falcarindiol; FaDOAc- Falcarindiol-3-acetate

AscA- Ascorbic acid

FD- Freeze drying

HP- High pressure

OD- Osmotic dehydration

HELP- High electric pulse field

MW-AD – Microwave assisted air drying

SHS – Super heating system

DIC - Détente Instantanée Contrôlée / Instant Controlled Pressure Drop

ΔE or TCD- Total color difference

Firmness - (Newton units)

RR- Rehydration ratio

MC- Moisture content

D_{eff}- Water diffusivity (m^2/s)

NI- Non indicated

Chapter 1 Introduction

1. INTRODUCTION

Freeze drying is a dehydration procedure where the frozen water contained into the cellular structure of the product is removed by sublimation. This method avoids microbial degradation and sustains the primary cellular structure of the product preserving its shape and volume. For this reason, freeze dried food is known as food of excellent quality compared with air dried (Ratti, 2001). However, this technology has the drawback of being an expensive process. This fact is due to the several stages required during a freeze drying process, which are: freezing, vacuum, sublimation and condensation (Ratti, 2001). According to the author, and to have a perception of all the separately costs of each freeze drying stage, freezing takes 4% of all costs while vacuum and condensation stages around 25% each, sublimation takes the highest percentage of 45% (Ratti, 2001).

Air dehydration is one of the oldest drying technologies addressed to reduce costs but with a lower product quality. The lower product quality associated with air drying is intrinsically related to modifications of porosity that occur along the process due to heat and moisture mass transfer. In fact, the water that filled the intracellular cavities was evaporated and substituted by air, the product could experience drastic contractions and compressions. Thus, these porosity changes during air drying process lead to volumetric shrinkage of vegetables and fruits (Marquez, et al., 2011; Mayor, et al., 2004). Since air drying causes all of these changes in food products, the aim of the project was focus in the enhancement of all the attributes of air dried products. Attributes such as nutrition, color, volume, texture, stability during storage (enzymatic inactivation), drying and rehydration kinetics will dictate the product quality.

Therefore, by searching other procedures in published scientific work applied along air drying, as main process, it was possible to show published results that pointed out an improvement of food quality. In the open literature, the authors mainly reported the application of pre and/or post-treatments in order to enhance several attributes of vegetables and fruits.

Thus, the project it was carried out with the intention to verify in scientific published data if the hypothesis of:

"*The application of a pre-treatment combined with a post-treatment to air dehydration could enhance food quality aiming being close, or even better, to the quality that a freeze dried product can give*"

it will be possible.

Thus, in order to select adequate pre and post-treatments that could promote higher quality of food it was necessary to make a detailed research in order to find some recourses used in other researches to be addressed to air drying processes. Essentially, pre-treatments are commonly used before the first air drying step as water blanching, steam blanching,

ultrasound, freezing, high pressure, high electric pulsed field and osmotic dehydration, while post-treatments as puffing and instant controlled pressure drop (DIC) are applied after the first drying stage as it will be explained later along this thesis.

Chapter 2 Literature Review

2. LITERATURE REVIEW

2.1. Pre-treatments

The application of a pre-treatment to air drying technology is widely used and presented in scientific work. Thus, in order to make an evaluation and finally conclude which treatment is more appropriated in the enhancement of a particular attribute, a pre-treatments selection was made to be studied. These pre-treatments were identified during the literature survey, where most of the cases air drying is indicate as being coupled to them.

The pre-treatments studied and presented along this report are:

- Water blanching
- Steam blanching
- Ultrasound
- Freezing
- High Pressure
- Osmotic dehydration
- High Electric Pulsed Field
- Additional pre-treatments – Paprika and tomato

With the exception for the High Electric Pulsed Field, each pre-treatment chapter is presented considering the effects on several food attributes such as: drying kinetics, rehydration kinetics, visual aspect which comprises color and volume attributes, nutrition, texture and stability during storage (enzymatic inactivation). For that reason, the pre-treatment chapters are divided in sub-sections, each one corresponding to a food attribute discussion.

Moreover, different paprika and tomato varieties were introduced and studied individually in order to verify the most used pre-treatments applied to these crops. Red paprika and tomato were chosen since these crops are commonly used worldwide, being widely studied by the scientific community giving rise to a significant amount of published work available.

In order to be more clearly for the reader to find an overall conclusion of each scientific work is presented in table format the main findings and conclusions of each study in the section APPENDIX 1 LITERATURE REVIEW – ATTRIBUTE TABLES.

2.1.1. Blanching

General considerations

Blanching is a cooking method that could be applied to all kind of vegetables and fruits and it is widely studied in food processing technology. Blanching can be applied directly to the product using a hot water bath or steam vapor. Both methods have several and different effects on vegetables and fruit attributes. In addition to cooking, blanching can be also considered as a preservation method. In general blanching as a pre-treatment lie between the sample preparation and subsequent operations, such as, dehydration or freezing.

Regarding the elimination of micro-organisms, blanching is essential before methods as freezing or conventional drying since these methods are not efficient in reducing significantly the micro-organisms of food (Fellows, 2000). In addition to this safety aspect, it is important to ensure a reasonable blanching step of certain vegetables and fruits to avoid modifications of the product during long periods of storage. Indeed, some deterioration such as discoloration resulting from enzymatic activity could occur during storage (Fellows, 2000). Therefore, one of the main aims of blanching is deactivation of certain enzymes.

As mentioned, blanching is a cooking method and can be applied to food products in two ways: blanching by hot water or blanching by steam. In the present chapter, blanching by hot water and by steam will be described. The blanching pre-treatment is depicted for several crops in Table 10 and Table 11 (designated by attribute tables).

2.1.1.1. Water blanching

Blanching by hot water consists basically in retaining the product in a water bath with a known ratio (product to water) during a certain time and temperature. In Figure 1 are illustrated elementary steps of blanching by hot water.

Figure 1- Blanching by hot water: 1- Cooking step with a define temperature, time and ratio (water:product); 2-Final cooling step. Adapted from **(© 2014 Martha Stewart Living Omnimedia, Inc. All rights reserved.)**

To ensure the homogeneity of the temperature during blanching a steering device could be required. Furthermore, and in some specific cases, known as osmotic drying process, salts and/or sugars are also added during blanching step. Although most of the times boiling water is used, it is reported that blanching water temperature ranged from 70 °C to 100 °C (Fellows, 2000). The periods, reported in the literature, during which the blanching operation should occur lies between 20 s and 60 min (Chinprahast, et al., 2013; Aguero, et al., 2008). The majority of the authors report the temperature and the time whereas few mention the ratio between water and product. When this ratio is indicated it varies considerably in the literature. For instance, **(i)** Mukherjee, et al. (2007) applied a ratio of 0.13 $g_{potatos}/g_{water}$ while **(ii)** Leeratanarak, et al. (2006) for the same crop used 0.015 $g_{potatos}/g_{water}$. For a hot water blanching of carrots **(iii)** Gonçalves, et al. (2010) used a 0.0083 $g_{carrots}/g_{water}$ while **(iv)** Gamboa-Santos, et al. (2013a) used a ratio of 0.2 $g_{carrots}/g_{water}$.

It is also reported that blanching should be stopped immediately to avoid any overcooking. Therefore, after blanching process the product should be cooled down by ice water bath or by cooling water for a certain period of time. Fante, et al. (2012) cooled garlic in an ice bath during 3 min, Kowalska, et al. (2008) used cooling water at 10°C during 5 s for pumpkin while Doymaz (2008) conducted a study where leek slices were cooled in tap water at room temperature for 3 min.

Another aspect to be considered is the ratio between surface area to volume of food pieces. Furthermore, the variety of the crop it is relevant and also the mechanical methods used before blanching such as cutting, peeling and slicing. All these parameters should be considered when investigating the effect of blanching on food products (Fellows, 2000). At lab scale, the process of blanching with hot water is discontinuous. However, at large or industrial scales, the process can be continuous. In the attribute Table 10 included in the section LITERATURE REVIEW – ATTRIBUTE TABLES are detailed all the water blanching parameters found in the literature.

2.1.1.2. Steam blanching

Blanching can also be performed with steam, in this case, the hot water is replaced by steam as a heating medium. At large scale steam blanchers can be described as a simple tunnel with conveyor belt. The steam vapor is injected within the tunnel and comes in contact with the product transported by the conveyor belt. This type of equipment is mainly used for food products with a considerable large surface area. According with the literature, steam blanching is performed in a range of 96 to 100°C (Fante, et al., 2012; Maharaj, et al., 1996), generally at atmospheric pressure as indicated in Table 11. The times, during which steam blanching is performed lies between 1 and 10 min (Fante, et al., 2013; Llano, et al., 2003).

Also for steam blanching is applied a final cooling step to avoid overcooking of food, **(i)** Fante, et al. (2012) applied an ice bath during 3 min to garlic heads while **(ii)** Llano, et al.

(2003) used an ice bath at 7°C to kiwifruits. In Table 11 is detailed all the data concerned with the mentioned studies.

In addition, a different steam blanching method was performed by Sotome, et al. (2009) since the authors applied different conditions compared with conventional steam blanching.

Thus, superheated steam and superheated steam with water microdroplets were applied to potato tubers. In this case, the steam temperature was 115°C for both methods and the time required was longer than the usual time (11 - 16 min). In Table 11 all these parameters can be seen on detail (Sotome, et al., 2009). In Figure 2 is depicted the super heating system with microdroplets used in this study. Water **(3)** is fed to the copper pipe **(2)** at high pressure of 0.2 to 0.4 MPa. The heating panel **(1)** provides enough heat to evaporate water and also to maintain a constant temperature inside the chamber where the product will be placed. As a consequence, vapor starts to be formed inside the pipe **(4)**. At the end, steam vapor and the hot water microdroplets **(6)** are spread out from the nozzle **(5)** to the product **(7)**.

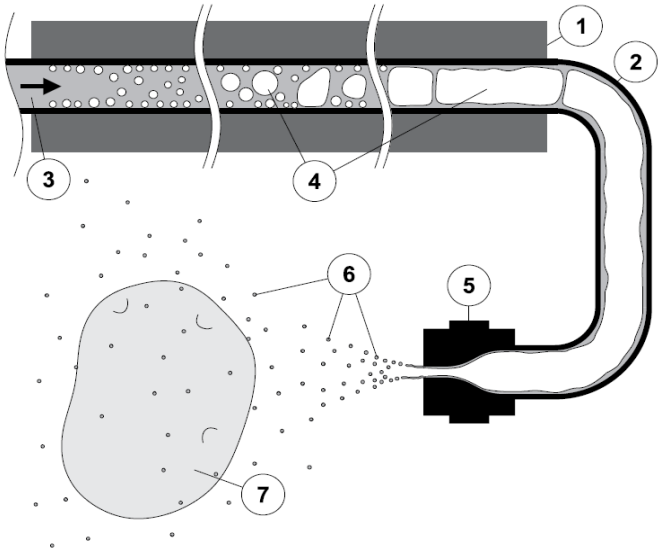

Figure 2- Super heating steam with hot water microdroplets applied to food products: **1**- Heating plate; **2**- Cooper pipe; **3**- Feeding water; **4**- Steam formation; **5**- Nozzle; **6**-Water microdroplets; **7**- Food piece.
Adapted from **(Sotome, et al., 2009).**

In comparison to blanching with hot water, steam blanching has the advantage to minimize losses resulted from leaching. Therefore, the wastes from steam operation are lower compared with the wastes of a hot water blancher. However, there are some limitations related to conventional steam blanchers when compared with hot water blanchers.

For a steam blanching operation there is always a lack of heating uniformity in all edges of food pieces. Thus, it is not convenient if the product is placed in stack on the conveyor belt because the steam vapor will not surround the product pieces in uniform way. During the

steam blanching occurs some mass loss from the food, also there is limited cleaning of the product (Fellows, 2000).

The development and improvement of blanching equipments has been aimed to minimize loss of solid substances within the product and increase the yield of blanched food. The yield of blanched food products is considered as the ratio between the weight of the product after being processed and the weight before it (Fellows, 2000).

Attributes of blanched foods

After blanching being applied it is important to understand the later effects of this pre-treatment on foods. Some attributes related to the blanched foods have been studied and reported in the literature. As an overview, the following attributes will be considered: (i) nutrition (vitamins, ascorbic acid, nutrients and sugars); (ii) color (β-carotene and chlorophyll retention); (iii) rehydration kinetics; (iv) drying kinetics; (v) texture and structure; (vi) stability during storage (enzymatic inactivation). Furthermore, in Table 10 and Table 11 are explained on detail all the blanching methods used to fruits and vegetables with the respective attributes.

In the following sections, each attribute will be discussed according to the results reported in the open literature. The aim is to summarize the published data in order to be able to draw some conclusions which will be used as a guideline for the next steps of this project.

Nutrition (vitamins, ascorbic acid, nutrients, sugars)

Vegetables and fruits have high amounts of vitamins with different functionalities for human health. The aim of blanching is to retain the maximum content of vitamins for the consumer. However, blanching by hot water promotes the loss of vitamins contained in the food by a leaching mechanism which consists in liberation of vitamins to the water bath (Fellows, 2000). The vitamin loss during blanching step is dependent on the blanching conditions: time-temperature and final cooling step. In general, the product will lose much less vitamins when short time and high temperatures are used. However, the ratio of water to product, size of the pieces and the variety of the crop will also dictate the vitamin loss of blanched food (Fellows, 2000).

Fante, et al. (2012) studied sugars losses for garlic when submitted to blanching treatments at 80 and 90 °C (Table 10). The control garlic samples had an initial inulin, glucose and fructose contents in dry weight basis of 56.62%, 2.37% and 2.23%, respectively. Losses by leaching could explained a total reduction of 44% for inulin and around 42% for both glucose and fructose, when garlic was submitted to a water blanching treatment at 90°C during 4 min. Also, a blanching at 80°C for 6 min conducted to a reduction of 45% of inulin, 32% of

glucose and 31% of fructose compared with the mentioned controls. The authors concluded that dissolution of reducing sugars in water increased for higher blanching temperatures due to leaching and diffusion processes. Beyond leaching losses of inulin, the authors reported that inulinase enzyme remained active even in reduced percentage for both blanching conditions mentioned above. Thus, inulinase may caused a depolymerization of inulin sugar which lead to higher inulin losses in water blanched garlic (Fante, et al., 2012).

The same authors also applied a steam blanching to garlic at 100°C during 4 min that lead to 7% of inulin losses while fructose and glucose were enhanced in 24% and 28%, respectively. For the steam blanching conditions presented, an inulin hydrolysis by residual inulinase (18.05%) could promote a relevant increase in glucose and fructose sugars since inulin consists in a polymeric chain of fructose and glucose molecules, as it will be explained. Thus, since in steam blanching there is no significant leaching losses, the percentage of these two monosaccharides was enhanced (Fante, et al., 2012).

In Figure 3 are depicted glucose and fructose molecules and the arrangement of both consists in the inulin molecule. Thus, inulin is a polymeric sugar composed by fructose and sucrose (glucose and fructose) as a terminal in the chain. It is known that in plant tissues inulin consists in shorter fructose chains that allow a higher solubility in water. However, inulin hydrolysis can be conducted by enzymes (inulinase) or even under acidic conditions, such as hydrogen chloride solutions (Bagsvaerd, 1981). According to the literature, inulinase enzyme can be a cause of sugar hydrolysis.

Fante, et al. (2013) also studied sugar losses in yacon roots after a steam blanching treatment at 100°C during 4 min (Table 11). The raw yacon roots have an initial percentage of 6.94% of inulin, 50.68% of fructose and 26.93% of glucose in dry mass (Scher, et al., 2009). After steam blanching inulin was reduced around 31%, fructose about 16%, while glucose losses were more drastic, around 40%.

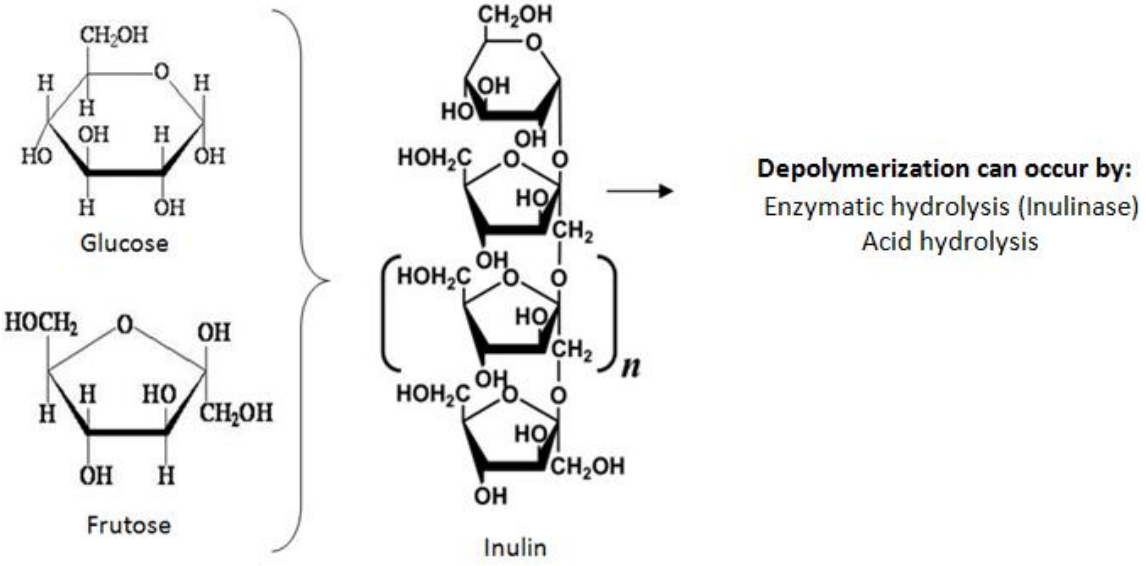

Figure 3 - Representation of reducing sugars: Glucose and Fructose **(Cat, 2009)** and Inulin molecule **(Ueno, et al., 2011)**.

In the study of Gamboa-Santos, et al. (2013b) carrots were blanched in different ways and conditions (Table 1 shows the main results of the present study in carbohydrate retention after air drying being applied. Also in attribute Table 10 and Table 11 can be seen all the blanching methods and procedures). The authors concluded that carrots blanched by hot water retained less amount of three carbohydrates (fructose, glucose and sucrose) compared to steam blanching. As can be seen in Table 1, steam blanching samples even for different shapes (minced or sliced) maintained the same amount of carbohydrates as freeze dried samples (≈ 590 mg/g dry matter). However, all the other water blanching treatments retained less carbohydrates due to leaching.

Table 1- Effect of different blanching pre-treatments on carbohydrate retention after air drying. Adapted from: **(Gamboa-Santos, et al., 2013b)**

		Carbohydrates (mg/g dry matter)			
Carrot treatment	**Carrot geometry**	**Fructose**	**Glucose**	**Sucrose**	**Retention (%)**
Freeze Drying	-	67.27	73.99	449.50	100
Steam (98°C, 2 min)	Minced	67.26	73.97	449.05	99.9
Steam (98°C, 2 min)	Sliced	67.19	73.90	448.65	99.8
Water (98°C, 1 min)	Minced	41.15	46.05	377.58	78.7
Water (98°C, 1 min)	Sliced	57.39	62.63	409.36	89.6
Water (95°C, 5 min)	Minced	31.13	34.81	283.20	59.1
Water (95°C, 5 min)	Sliced	39.00	41.80	349.53	72.8
Water (60°C, 40 min)	Minced	34.37	42.00	311.33	65.6

Mukherjee, et al. (2007) performed a blanching treatment by three different techniques to potato cubes. The aim of this research was to study solids, sugars and ascorbic acid losses after different blanching techniques being applied to the crop. According to an inactivation of 90% of peroxidase on potato cubes an optimum time of blanching was determined for all the pre-treatments. The authors found that a steam treatment at 97°C during an optimum time of 112 s retained around 97.73% of solids (Mukherjee, et al., 2007).

Another blanching treatment was carried out in a whirling bed that consists in the use of a saturated mixture of steam and air as a heating medium in a cylindrical column with partial restriction in gas admission at the column bottom by fixing semi-cylindrical wedge on the distribution plate. A solid loss of 3.70% was reached for the whirling bed at 80°C during a optimum time of 136 s. For the whirling bed conditions of 85°C and 93 s the percentage of solid losses was 3.45%. Although, a blanching treatment conducted by hot water (93°C for a optimum time of 165 s) and a blanching treatment of 100°C for 129 s showed higher solid losses of 10.14% and 11.59%, respectively. In respect to the conventional heat treatments, it is important to notice that blanching by steam decreases solid losses about 9.32% compared to hot water at 100°C. The authors clarify that the solid losses by the whirling bed were not significantly higher when compared to steam blanching. However, these losses can be explained by a high turbulence of the vegetable inside the whirling bed which conducts to mechanical collapsing. The water treatment lead to higher percentages of solid losses for potato cubes which is due to dissolution of the solids in water (leaching). According to Fante, et al. (2012) and Mukherjee, et al. (2007) the leaching effects are fundamental to explain losses within the vegetable during water blanching.

Regarding to ascorbic acid and sugar retention, Mukherjee, et al. (2007) also found that the whirling bed at 85°C and 93 s retained 88.20% of ascorbic acid and 81.63% of reducing sugars on potato cubes. The mentioned percentages were the maximum retentions compared to all the other blanching treatments. The methods and main findings done by the authors (Mukherjee, et al., 2007) are described in Table 10 and Table 11.

However, from the present study can be conclude that in terms of solids, ascorbic acid and reducing sugars retention, the whirling bed treatment used is the best technique to be applied to potato cubes.

The research of Bahceci, et al. (2005) was based in the effect of water blanching on green beans with the purpose of ascorbic acid retention during frozen storage in polyethylene bags at -18°C during 1 year (Table 10). The ascorbic acid content was measured month by month. After 6 months of green beans storage the ascorbic acid content was measured in unblanched and blanched samples at 70°C for 2 min and 90°C during 3 min. The authors found an ascorbic acid loss of 93.65% for unblanched samples but the blanching conditions of 70°C for 2min conduct to 86.21% of ascorbic acid losses. On the other hand, water blanching at 90°C during 3 min lead to lower losses (68.64%).Also the ascorbic acid half-lifes

were improved during storage. In comparison with unblanched samples (1.89 months of half-life) a water blanching at 70°C for 2 min gave a half-life of 2.15 months and blanching at 90°C during 3 min gave an even better half-life of ascorbic acid, 3.48 months (Bahceci, et al., 2005). After 6 months of frozen storage at -18°C, the green beans submitted to water blanching treatment at 90°C for 3 min presented the highest retention and half-life of ascorbic acid (Bahceci, et al., 2005).

The combination of different time-temperature for 90% of peroxidase inactivation was also performed with the aim of studying ascorbic acid retention of butternut squash (Aguero, et al., 2008). That research showed that blanching at lower temperatures during longer periods of time result in higher losses of ascorbic acid (Table 10). For instance, a blanching treatment at 65°C during 20.5 min resulted in 76% of ascorbic acid loss and for a temperature of 70°C during a blanching period of 18.9 min the acid loss was reduced to 70.4%. Moreover, for blanching conditions of 90°C and 8 s the ascorbic acid loss was 27.7%. The authors conclude that the loss of ascorbic acid is function of blanching time and temperature, but the dependence seems to be stronger with the time of the blanching process.

Vina, et al. (2007) applied a blanching treatment at 100°C during 4 min to Brussels sprouts that resulted in reducing the losses about 24% of ascorbic acid in comparison to non-blanched samples (see Table 10). Although, a treatment conducted in two steps: hot water at 50°C for 5 min followed by boiling water during 3 min allowed the losses reduction of ascorbic acid around 19% when compared to non-blanched. According to Aguero, et al. (2008) the loss of ascorbic acid on butternut squash is intrinsically related to long periods of blanching; the ascorbic acid losses increased with higher blanching times. On the other hand, Vina, et al. (2007) suggested a treatment conducted in two steps in order to reduce the ascorbic acid losses of Brussels sprouts.

Conventional blanching treatments as blanching by hot water and blanching by steam were adopted prior to an air drying method to carrots (*D. carota L. var. Nantesa*) with the purpose of studying vitamin C retention (Gamboa-Santos, et al., 2013a). The authors also introduced an ultrasound probe during the blanching treatment. All the blanching methods of this study are resumed in Table 10 and Table 11.

Sliced carrot samples with a pre-treatment of blanching by hot water at 98˚C during 1 min retained 85% of vitamin C. Although, when blanching time increased from 1 min to 5 min with a slightly temperature decrease to 95°C, sliced carrots retained lower content of vitamin C, about 37.5%. From this data it can be conclude that by increasing the water blanching time, vitamin C retention was much lower and drops abruptly to 37.5%.

The blanching operation was also performed with minced carrot with hot water at 60˚C for 40 min and the vitamin C loss was in the order of 99% (Gamboa-Santos, et al., 2013a). In this case, the vitamin C retention in carrots was even lower only about 1%, the authors explained this fact based on the carrot shape (minced samples) with higher specific area that allows a

greater loss of vitamin C. Although, a steam treatment carried out at 98˚C during 2 min to carrot slices permits high retention percentage (about 81.2%) for vitamin C. In Table 2 are described the results of the study conducted by Gamboa-Santos, et al. (2013a) where the geometry of the carrot samples are specified. A drastic reduction of vitamin C retention to 0.7% on minced carrots was attained when a ultrasound probe was used in the treatment (60°C for 10 min), also for sliced carrots this kind of treatment at 70°C during 15 min retained around 4% of vitamin C (Gamboa-Santos, et al., 2013a). These results can also be seen later in Ultrasound pre-treatment in the section 2.1.2. By the presented results, the authors tried to explain that some modifications on blanching conditions allow the retention or the loss of vitamin C. Conditions such as blanching method (hot water, steam or ultrasound); blanching operation conditions (time and temperature); samples geometry (sliced or minced) were decisive on vitamin C retention.

Table 2 – Effect of different conventional blanching treatments on vitamin C retention of carrots (Control: raw carrots). Adapted from **(Gamboa-Santos, et al., 2013a)**.

Blanching conditions	Carrot geometry	Vitamin C Retention (%)
Raw material		100
Steam (98˚C, 2min)	Sliced	81.20
Boiling water (98˚C, 1min)	Sliced	85.00
Hot water (95˚C, 5min)	Sliced	37.05
Hot water (60˚C, 40min)	Minced	1.30

After blanching and ultrasound pre-treatments all the samples were dried in a tray drier with a hot air stream (46°C and 4.9 m/s). When those samples were subjected to the dehydration step the vitamin C losses increased due to the heating medium. The results regarding to this additional drying step can be seen in Table 3.

Table 3 – Effect of blanching followed by drying on vitamin C retention of carrots. Adapted from: **(Gamboa-Santos, et al., 2013a)**.

Blanching conditions	Drying time (h)	Carrot geometry	Vitamin C Retention (%)
Steam (98˚C, 2 min)	9	Sliced	40.2
Boiling water (98˚C, 1 min)	9	Sliced	52.8
Hot water (95˚C, 5 min)	9	Sliced	20.6
Hot water (60˚C, 40 min)	7	Minced	-

Color (β-Carotene, chlorophyll retention)

Apart from attributes such as taste and texture, color of fruits and vegetables is one of the most important attributes for the consumers. A food that present an adequate aspect to the consumer is always preferred compared with an off-color food. By heating vegetables and fruits, color modifications always take place and these changes occur by losing pigments within the food. Also these pigments can be chemically modified by pH variations or oxidation during storage periods. Indeed, blanching by hot water can be performed in solutions of sodium carbonate or calcium oxide with the purpose of chlorophyll and color protection of vegetables (Fellows, 2000).

In Figure 4 it can be seen the color parameters *a**, *b** and *L** of a CIE color scale which is used for color measurements of objects (Inc., 2012). Concerning to the present study, color measurements of vegetables or fruits samples can be determined by parameters such as: *L** which indicate whiteness, lightness or luminosity and varies from 0 (dark) to 100 (white), *a** a parameter which varies from greenness (-60) to redness (+60) and *b** referred of blueness (-60) to yellowness (+60) (Fante, et al., 2012). Also, from these parameters is possible to calculate the *ΔE* value which indicate the total color difference between *a**, *b** and *L** parameters. Thus, *ΔE* gives the color variation between the initial sample (standard) and the sample to be analyzed (Inc., 2012).

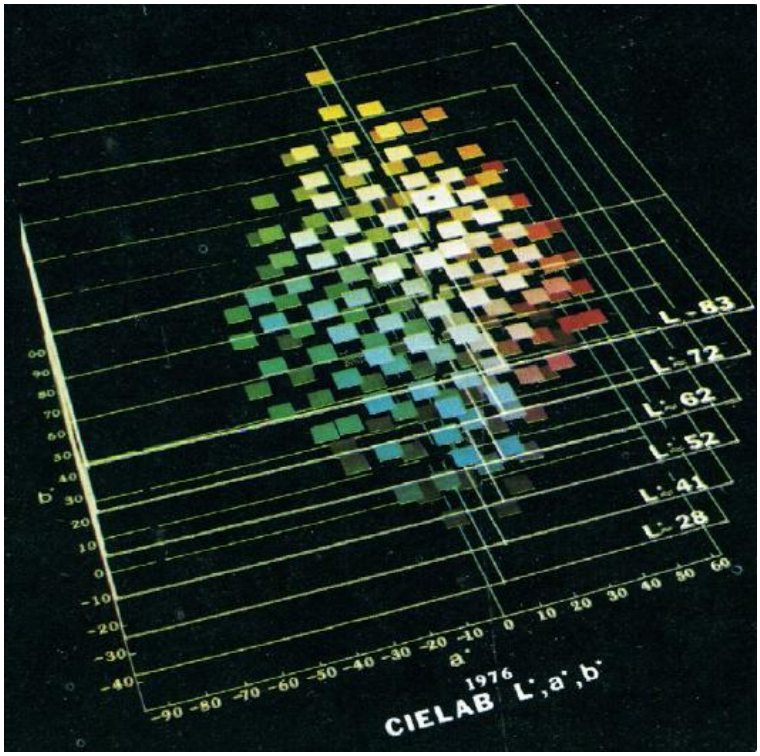

Figure 4 – CIE scale color measurements showing (*L**, *a** and *b**) color parameters **(Inc., 2012)**.

Along this section will be reported and discuss color variations of *L**, *a** and *b**. However, it is important to notice that an individual variation of these parameters may be not detected by the final consumer.

For this reason, the total color variation (*ΔE)* must be always calculated in order to identify the real color changes of samples.

A hot water blanching pre-treatment was applied by Koca, et al. (2007) to carrot slices. The authors conclude that blanching by hot water (90°C, 7 min) applied to carrots, prior conventional air drying, enhances β-carotene retention during storage at different temperatures (27-57 °C). The dehydration method was performed in an air drier with an air stream at 60±5°C, velocity of 1.5 m/s and relative humidity in the range of 6 to 10%. After drying being applied, blanched carrots lost 69% of β-carotene during storage period while unblanched lost 86%. However, as β-carotene oxidation is related with changes at color level of carrots during storage period, Koca, et al. (2007) showed that blanched carrots after dehydration step presented higher values of redness (*a**) and yellowness (*b**) in comparison with unblanched carrots. Thus, in this study, blanching pre-treatment prior to the dehydration step enhances color and carotenoid retention of carrots during storage period. The main results found by Koca, et al. (2007) are indicated on attribute Table 10.

The research of Rawson, et al. (2012) was based in carotenoid and color changes determination after water blanching being applied during 3 min at 80°C to carrot discs. The results pointed for a slightly decrease in carotenoid compounds when blanching is applied to carrots, around 5% compared with samples submitted directly to air drying. According to this small carotenoid reduction, and since color deterioration is related with the loss of this compound, *ΔE* showed also a slightly variation (around 6) compared to the control situation. Also, the retention of falcarindiol (FaDOH), falcarinol (FaOH) and falcarindiol-3-acetate (FaDOAc) was reduced in 23.7, 2.9 and 11.5% respectively, compared with control samples (air dried). Also, the study was performed using ultrasound pre-treatments (Rawson, et al., 2012). The main methods and results can be seen in Table 10 of the section LITERATURE REVIEW – ATTRIBUTE TABLES and will be also described during the section 2.1.2 of the Ultrasound chapter.

Also, blanching by hot water was performed at different temperatures (75 to 95°C) without any further drying step by Gonçalves, et al. (2007) to pumpkin (*Cucurbita maxima L.*) with the aim of study color characteristics in the vegetable. After the pre-treatment, pumpkin lost color properties, such as redness and yellowness, and as a consequence the samples became darker and less bright.

Chinprahast, et al. (2013) studied the effect of color changes after blanching (90°C, 60 s) being applied to gooseberries fruits. The authors showed that the blanching conditions used did not affect the color, represented by *ΔE*, of blanched gooseberries compared with the fruit berries that were not blanched. This fact means that gooseberries fruits maintained the

natural color. Fante, et al. (2012) reported that blanching treatment at 90°C, or even at 80°C, during 10 min enhances the *L** value of garlic samples which became lighter. For fresh garlic *L** = 62.55, however when garlic samples were submitted to water blanching at 90°C during 10 min, *L** increased to 65.91. Similar results were found for a water blanching at 80°C for 10 min, which present *L** of 64.24. For higher water blanching temperatures garlic *lightness* showed to be improved (Fante, et al., 2012). On the other hand, a steam treatment at 100°C and 1 atm during 10 min gave the better *lightness* result to a final *L** value of 67.07. This means that for steam blanching the garlic heads developed a lighter color compared to fresh and hot water treatments. Concerning to *a** and *b** parameters, the sample garlic controls presented values of *a** and *b** equal to -3.45 and 21.61, respectively, and after blanching (80°C, 10 min) the *a** value was -4.22 and *b** 12.72 (Fante, et al., 2012). A blanching at 90°C during 10 min resulted in lower values of these two parameters (*a** = - 4.78 and *b** = 9.13) which could be explained by a loss of color with an increasing in blanching temperature. For steam blanching at 100°C during 10 min the values of *a** (-4.91) and *b** (7.91) were lower when compared with the other treatments and with controls (fresh garlic). With regard to color variation (*ΔE*), after steam blanching at 100°C during 10 min *ΔE*=14.76*,* while for the same 10 min, the total color difference *ΔE* was less pronounced when water blanching at 90°C and 80°C showed values around 13.24 and 9.32, respectively. From this study can be concluded that steam blanching is the most adequate method to increase *lightness* (Fante, et al., 2012). On the other hand, steam method gave the higher color difference and the greenest and bluest garlic samples compared to controls and water treatments (Fante, et al., 2012). The main results of this study are also depicted in attribute Table 10 and Table 11 in the section LITERATURE REVIEW – ATTRIBUTE TABLES.

Fante, et al. (2013) also applied blanching by steam followed by a dehydration step to yacon roots. Color parameters were studied when the steam blanching at 100°C and 1 atm was performed. The authors reported that during steam blanching an increasing in total color difference (*ΔE)* of yacon roots is evident when compared with the original sample. This fact point that steam blanching allows losses of color attributes with blanching time when compared with controls. For the same steam blanching conditions referred above, a total color difference after 1, 2 and 4 min was marked of 2.55, 11.13 and 13.03, respectively. However, when the blanching time of yacon roots was increased for 6, 8 and 10 min the *ΔE* show slightly increases, maintaining the *ΔE* value around 13.31. Concerning the color parameters *L**, *a** and *b** the yacon roots show an increase in whiteness, yellowness (less blueness) and greenness (less redness) compared with controls (Fante, et al., 2013).

Sotome, et al. (2009) concluded that a superheated systems with or without water microdroplets applied to potatoes allowed color losses when compared with control samples. In Table 11 can be seen the different heating methods. The research made by Vina, et al. (2007) includes five different pre-treatments applied to Brussels sprouts. However, besides normal blanching treatments they also introduced combined treatments, one after

the other, as it will be mentioned. The authors applied a normal blanching at 100°C for 1, 3 and 4 min. The fourth pre-treatment was performed with water (50°C, 5 min) followed by boiling water during 3 min. The last treatment was carried out in a microwave (700 W, 5 min) followed by blanching at 100°C during 2 min. The results shown that lightness (*L**) decreased for all blanched samples when compared to the control. Also, the fourth mentioned treatment gave lower total chlorophyll content, a loss of 27% compared with unblanched samples. In addition, blanching at 100°C during 4 min resulted in a reduction of 11% of total chlorophyll content, while the microwave treatment allowed chlorophyll retention of 92% compared with controls (100% of chlorophyll retention) (Vina, et al., 2007). On the other hand, blanching conditions at 100°C for 1 and 3 min avoid chlorophyll losses. Thus, in accordance with these results, the authors suppose that longer immersion water periods lead to higher chlorophyll losses but they did not observed modifications in flavonoid content for all blanched Brussels sprouts (Vina, et al., 2007). The main results and blanching methods of Vina, et al. (2007) are described in Table 10.

Bahceci, et al. (2005) studied losses of chlorophylls *a* and *b* in green beans after hot water blanching followed by a frozen storage period of 12 months at -18°C. The chlorophylls content *a* and *b* was measured monthly. After the storage period, the unblanched green beans presented chlorophyll *a* and *b* half-life of 7.32 and 13.11 months, respectively. A blanching treatment at 70°C for 2 min did not improve half-life of chlorophylls *a* and *b* which were 5.05 and 10.09, respectively (Bahceci, et al., 2005). However, blanching conditions at 90°C during 3 min enhanced half-life of chlorophyll *a* and *b* to 8.26 and 16.70 months, respectively. The chlorophyll degradation (see Table 10) is also detected by an increasing in pheophytins compounds and as a consequence the green beans lost color (Bahceci, et al., 2005). The authors referred a progressive formation of pheophytins during the period of frozen storage in addition to the formation observed during blanching (Bahceci, et al., 2005).

Llano, et al. (2003) studied the color losses of kiwifruit when a steam blanching was applied (see Table 11). The authors concluded that steam blanching of kiwifruit lead to color losses after 5 min of treatment. They also pointed a cell disruption and possible chlorophylls (*a* and *b*) degradation into pheophytin which could lead to browning colors.

Chlorophyll as a pigment is widely found in green vegetables and fruits being known to have anti carcinogenic properties. In Figure 5 is illustrated the molecular structure of chlorophyll *a* and *b*, which consists in a phorphyrin ring chelating a magnesium ion. The lost of magnesium in the porphyrin ring allow the formation of pheopytins as derivatives (Hsu, et al., 2013) as can be seen in Figure 5. This lose of magnesium is mainly due to two factors: heat or acidic environments (low pH) (De Ancos, et al., 2012). Thus, chlorophylls degradation result in pheophytin pigments which promote browning colors of food. This evidence is in accordance with the research made by Bahceci, et al. (2005) and Llano, et al. (2003).

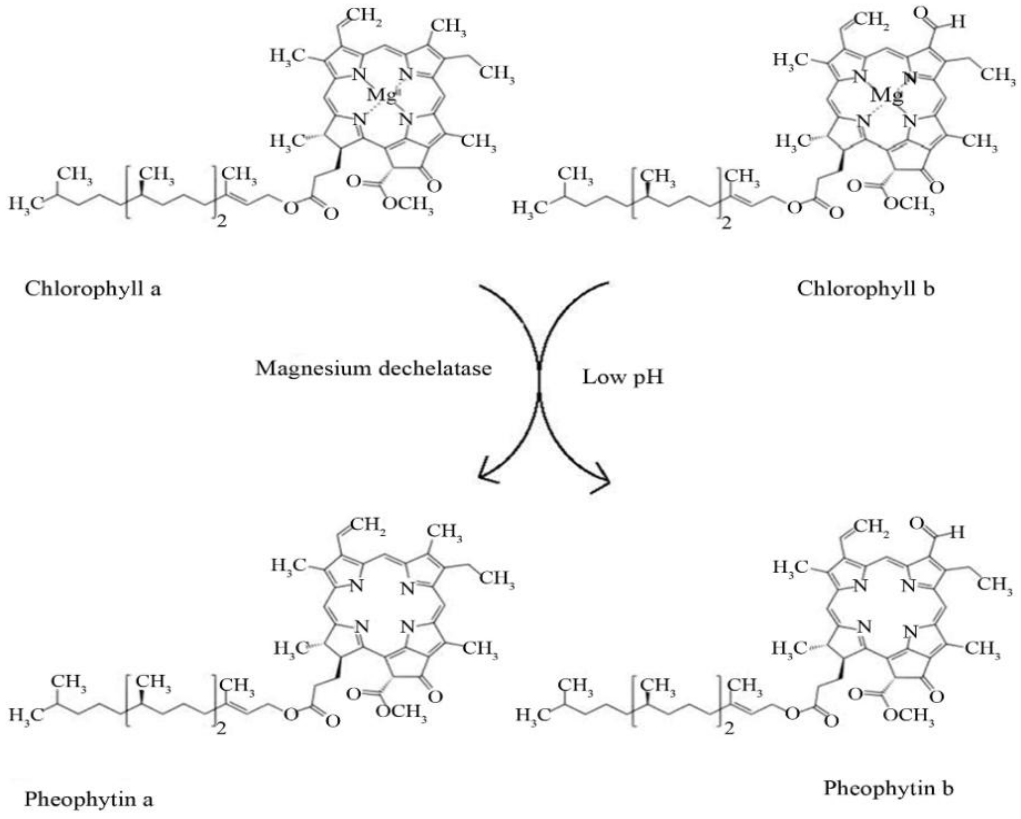

Figure 5 - Chlorophyll degradation into pheophytins **(Hsu, et al., 2013).**

Pheophytins *a* and *b* as sub products of chlorophyll degradation can be also degraded by heat into pyropheophytins by losing the CH_3CO_2H group or the phytol chain which result in pheophorbides *a* and *b*, respectively. Both pyropheophytins and pheophorbides enhance brown/grey color of vegetables or fruits as is illustrated in Figure 6 where is depicted the processes of chlorophyll degradation and the effect in color. However, chlorophylls can also be degraded by chlorophyllase enzyme by losing the phytol chain converting chlorophylls in chlorophyllide (De Ancos, et al., 2012). In this case, as it can be seen by Figure 6, the blue-green/yellow-green color is maintained in chlorophyllide.

However, the loss of Mg^{2+} by chlorophyllide converts the molecule into pheophorbide form improving again brownish colors. On the other hand, a source of heat promotes the formation of pyropheophorbide *a* and *b* by the loss of CH_3CO_2H. As mentioned before, pyropheophorbides can be formed also from pyropheophytins if these compounds experienced a loss of phytol chains (De Ancos, et al., 2012).

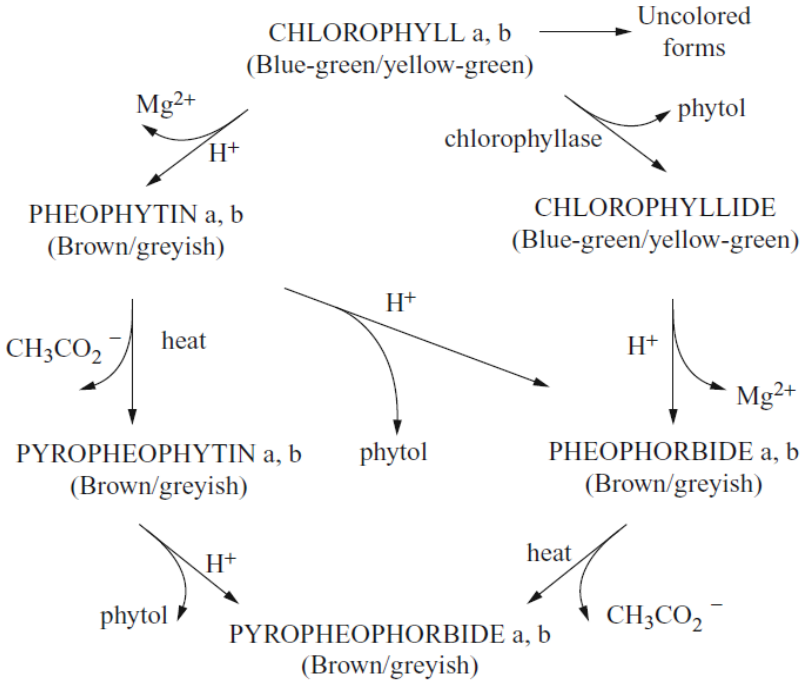

Figure 6- Chlorophyll degradation with the correspondent color losses attributes **(De Ancos, et al., 2012)**.

Gu, et al. (2013) applied a blanching pre-treatment to green pepper berries prior to a sun drying step. It was reported that blanching affects oxidation of phenolic pigments which turned berries darker. Although, resinoids compounds were also responsible for an increasing darkness. After 2 h of sun drying a blanching pre-treatment at 100°C lead to darker berries compared with samples blanched just at 80 or 90 °C. The study also shown that increasing the blanching temperature with a longer dehydration step enhances berries darkness (Gu, et al., 2013).

Gonçalves, et al. (2010) reported that carrot blanched at 90°C during 1 min retained 80% of initial phenolic compounds. In that research, for a good carrot quality a balance was made to ensure a good phenolic retention and also color properties. In conclusion, phenolic components were less retained for lower blanching temperatures and longer times (Gonçalves, et al., 2010). Carrot color was also affected and this was shown by a decreasing of *L**, *a** and *b** values for higher temperatures and shorter blanching times. For example, the percentage variation for 90°C and 1.4 min of blanching conditions in relation to the reference raw sample were *L** = 5.1%, *a** = 33.3%, *b** = 25.8% (Gonçalves, et al., 2010). The authors conclude that samples became darker and the redness parameter was the more affected. The detailed blanching measurements and main findings are presented in Table 10.

In Table 4 is represented some natural food, such as fruits and leaves, with the respective pigments. According to the pigment contained in the fruit or in the leaves different classifications (high; moderate; low) for the stability of the pigment to heat, light, oxygen

and pH changes are indicated in the Table 4 and is also referred if the pigment is water or oil soluble.

Table 4 – Naturally occurring pigments in foods. Adapted from: **(Fellows, 2000)**.

Pigment	Typical source	Oil or water soluble	Stability to the following			
			Heat	Light	Oxygen	pH change
Anthocyanins	Fruits	Water soluble	High	High	High	Low
Betalaines	Beetroot	Water soluble	Moderate	High	High	High
Carotenes	Leaves	Oil soluble	Moderate to Low	Low	Low	High
Chlorophylls	Leaves	Water soluble	High	High	High	Low
Polyphenols	Tea leaf	Water soluble	High	High	High	High
Xanthophylls	Fruits	Water soluble	Moderate	High	High	Low

In order to finish this section devoted to the effect of the blanching pretreatment on color attributes of food, some main conclusions of the studies mentioned will be emphasized.

The main conclusions will focus the aspects for blanching as the only method and also for the combination of blanching with further dehydration. In summary, Koca, et al. (2007) by introducing a conventional dehydration step after blanching improved color and carotenoid retention of carrots during storage period. Gu, et al. (2013) also used a further drying step (sun drying) and concluded that an increasing in blanching temperature with an extended sun drying period resulted in darker berries.

In the research of Gonçalves, et al. (2007) and Gonçalves, et al. (2010) pumpkin and carrot slices lost color after blanching being applied, however for Chinprahast, et al. (2013) blanching did not affect the color of gooseberries. Fante, et al. (2012) reported that a^* and b^* color parameters of garlic decreased when the blanching time is increased but the lightness (L^*) was enhanced by the blanching conditions applied.

On the other hand, Vina, et al. (2007) reported that lightness (L^*) of Brussels sprouts decreased for all the blanching conditions used when compared to the raw material.

According to Bahceci, et al. (2005), hot water blanching at 90°C during 3 min enhanced half-life of chlorophylls *a* and *b* at storage periods of 8.26 and 16.70 months.

Regarding to steam blanching, the color retention was also affected by steam conditions used to treat fruits and vegetables. Llano, et al. (2003) concluded that steam blanching of kiwifruit lead to chlorophylls losses which improve the development of browning colors. Fante, et al. (2013) reported that steam blanching resulted color losses in yacon roots samples during the treatment time when compared with raw material controls. Sotome, et al. (2009) concluded also that steam blanching performed to potatoes allowed color losses when compared with control samples.

Rehydration kinetics

In the present section the rehydration capacity of foods after a blanching pre-treatment and a further drying step will be discussed using published scientific studies.

Doymaz (2008) studied the effect of blanching by hot water on the rehydration kinetics of leek slices with different thicknesses. It was found that rehydration capacity is improved when a blanching pre-treatment at 70˚C for 3 min is applied to leek slices prior to a hot air drying process at 50°C (air velocity of 2.5 m/s). Besides the blanching pre-treatment increasing rehydration capacity, the water temperature of rehydration method is an important factor, since high water temperatures (around 80°C) improved the rehydration capacity of leek pieces (Doymaz, 2008). The main measurements, results and consequences of blanching are described in Table 10.

Jambrak, et al. (2007) investigated the rehydration capacity of button mushrooms, Brussels sprouts and cauliflower after a blanching pre-treatment by hot water at 80°C for 3 min, by the use of a ultrasound probe with a frequency of 20 kHz and also a ultrasound bath at 40 kHz during 3 and 10 min. After these treatments a conventional air drying was applied (see Table 10). Beyond the conventional air drying, freeze drying was also performed at -45°C, during 3h as reference of a drying technology. For the three studied vegetables the applied blanching conditions (80°C, 3 min), previously of a conventional air drying, did not result in higher rehydration capacities compared with controls and ultrasound treatments (Jambrak, et al., 2007). Freeze drying technology helped the rehydration capacity for all the samples, however using a ultrasound bath at 40 kHz during 3 min also enhanced the rehydration capacity of mushrooms (Jambrak, et al., 2007). After 12 and 15 min of rehydration of mushrooms, the samples treated with ultrasound bath (40 kHz, 3min) had similar rehydration capacity as freeze dried mushroom, around 4.3 $g_{moisture}/g_{dry\ matter}$. Similar results occurred for cauliflower. After 12 min of rehydration the samples submitted to the ultrasound treatment with the probe at 20 kHz for 3 min indicate 5 $g_{moisture}/g_{dry\ matter}$ while freeze drying samples shown a slightly increase in the moisture content around 5.5 $g_{moisture}/g_{dry\ matter}$ (Jambrak, et al., 2007).

However, rehydration capacities for Brussels sprouts where even lower in comparison with mushrooms and cauliflower (Jambrak, et al., 2007). The authors explained that a different shape and a compact configuration of the vegetable own gave lower rehydration capacities. From this study can be conclude that probe or bath ultrasound pre-treatments enhanced rehydration kinetics of mushrooms and cauliflower which were closed to the rehydration behavior of freeze dried samples (Jambrak, et al., 2007). Doymaz (2010) studied the rehydration kinetics of red apples (*Malus domestica*) after two different treatments followed by a dehydration step. A blanching treatment by hot water at 70°C for 2 min was applied to the fruit and also a treatment with a 0.5% citric acid solution during a period of 2 min at ambient temperature. The drying process was performed in an air drier (55 - 75°C) with a constant air velocity of 2 m/s. After a drying step with air at 65°C, the results showed that

the blanched samples presented higher rehydration ratios compared with citric acid pretreated samples and controls. The rehydration ratio was defined as the ratio between the weight of rehydrated apples (g) and the weight of dried apples (g). A rehydration kinetics at 30°C after 6 h gave a rehydration ratio of blanched apples around 4.5 while for citric acid treatment and controls the ratio was similar, around 4 (Doymaz, 2010). However, the rehydration kinetics performed at 65°C gave better rehydration ratios compared to the one performed at 30°C. After 6 h of rehydration in a water bath of 65°C, the rehydration ratio of blanched apples was 5 while for samples treated with citric acid was around 4.5 and for controls about 4. In this study the observations indicate that rehydration is improved by blanching but also by increasing the rehydration temperature (Doymaz, 2010). The blanching methods, results and consequences on the rehydration kinetics are described in Table 10 (Doymaz, 2010).

Rehydration kinetics was applied by Gamboa-Santos, et al. (2013b) to carrot samples of two different shapes (minced and sliced) previously dried with hot air. The rehydration technique was performed at ambient temperature with a carrot to water ratio of 0.02 g/g and during 24 h. The best rehydration ratios were obtain for sliced carrots blanched at 95°C for 5 min which showed a maximum rehydration ratio of 15 that is higher when compared to freeze dried samples used as a control that showed 6.4 (Gamboa-Santos, et al., 2013b). Also, by the results presented can be seen that boiling water and steam blanching treatments gave the lowest rehydration ratios compared with control and water blanching at lower temperatures and longer times (Gamboa-Santos, et al., 2013b). The main results of the Gamboa-Santos, et al. (2013b) study are presented in Table 5 but also in the section LITERATURE REVIEW – ATTRIBUTE TABLES. In addition, this study will be reported in the section 2.1.2 devoted to Ultrasound chapter.

Table 5- Rehydration ratios of pretreated carrots (expressed in mass after rehydration by mass of initial carrots) after air drying. Adapted from **(Gamboa-Santos, et al., 2013b)**.

Carrot treatment	Carrot geometry	Rehydration Ratios
Freeze Drying	-	6.4
Steam (98°C, 2 min)	Minced	5.5
Steam (98°C, 2 min)	Sliced	4.3
Boiling water (98°C, 1 min)	Minced	5.1
Boiling water (98°C, 1 min)	Sliced	5.5
Water (95°C, 5 min)	Minced	14.5
Water (95°C, 5 min)	Sliced	15.0
Water (60°C, 40 min)	Minced	13.5

Rehydration kinetics was also performed after blanching pre-treatments and subsequent drying in the study of Gamboa-Santos, et al. (2013a) with the purpose of study the sensory quality of carrots. Thus, rehydration kinetics was performed in hot water during 10 min with a ratio of 0.03 $g_{carrots}/g_{water}$. The goal of the sensory test was to evaluate mainly texture and

taste of rehydrated carrots in a scale of 8 points – 1 means “like very much” and 8 “dislike very much”. After the assessment, carrots pretreated with steam (Table 11) showed the best sensory evaluation with a score of 3 ± 1.2. However, carrots blanched by water showed lower sensory evaluations (Table 10). The authors related the loss of carrots flavor with a decrease of carbohydrates and volatiles compounds during water blanching (Gamboa-Santos, et al., 2013a).

Previously of an air drying step at 48°C with an air stream velocity of 3.5 m/s and 10% of relative humidity, Mate, et al. (1999) used a blanching pre-treatment by hot water during short and long periods of time applied to potato slices. The authors studied the influence of blanching on rehydration and mechanical properties (strain and stress) of potato slices. They conclude that unblanched samples presented a granular, more porous and firm aspect which lead to quick break. On the other hand, blanching (during short or long time periods) improved the mechanical capacity of potato pieces providing higher strain and stress values at the breaking point (Mate, et al., 1999). Considering this fact, blanching by hot water enhanced pliability and stiffness of potato pieces. In this study, rehydration was applied during 60 min after blanching and dehydration step, however the authors conclude that features for unblanched and blanched potato samples were close. However, when the rehydration of potato slices conducted at 100°C the samples presented better rehydration ratios compared with rehydration ratios obtained for rehydration bath temperature of 70°C (Mate, et al., 1999). Also, in this case, the rehydration temperature affects clearly the rehydration capacity of the product. As it was mentioned before, dried potatoes that were unblanched presented a structure more porous (≈ 15%) compared with blanched samples that showed less porosity, around 5% (Maté, et al., 1998). Although, in this research, unblanched dried potatoes and blanched samples had similar rehydration ratios indicating that the higher porosity for unblanched dried potatoes (≈ 15%) did not conduct to improved rehydration ratios. The results and main conclusions pointed out by the authors in this study are also reported in Table 10 (Mate, et al., 1999).

In conclusion, there is still a boundary between blanching with further drying step and rehydration capacities of the final products. According to the open literature, blanching as a pre-treatment can improve the rehydration ratio of vegetables or fruits, however it was shown by Doymaz (2010) that rehydration temperatures also improve rehydration ratios. Also, in the study done by Mate, et al. (1999) it was not expected that more porous potatoes had similar rehydration ratios compared with less porous potatoes. Thus, additional research is needed in order to have a deeper comprehension about the relation between a blanching pre-treatment and a better rehydration step.

Drying kinetics

In the present section will be presented the results found in the literature regarding to the influence of blanching by hot water of food prior to dehydration steps.

Doymaz (2008) reported that blanched (3 min, in hot water at 70˚C) leek samples dried in shorter periods of time compared with samples not submitted to blanching. Thus, the time of further drying step was reduced by blanching pre-treatment.

Before sun dehydration, Gu, et al. (2013) applied a blanching step to green pepper berries at 100°C for 10 min. The authors reported that after drying, the mentioned blanching conditions increased the weight loss of berries around 10% compared with unblanched samples.

Doymaz (2010) studied the behavior of red apples (*Malus domestica*) in terms of drying kinetics after two different treatments. A blanching treatment was performed to the fruit in a hot water bath at 70°C for 2 min to red apples. The author also studied the influence of a 0.5% citric acid solution during a period of 2 min at ambient temperature. After the mentioned treatments a further drying step was applied to the red apples in a cabinet drier with a range of air temperatures of 55 to 75°C and a constant air velocity of 2 m/s (Doymaz, 2010). The author concluded that the apples immersed in the citric acid solution dried faster compared with blanched and control samples (Doymaz, 2010).

A similar research for button mushrooms, Brussels sprouts and cauliflower was conducted by Jambrak, et al. (2007). All the mentioned vegetables were blanched in hot water at 80°C during 3 min or treated by ultrasound (probe at 20 kHz or bath at 40 kHz) for 3 and 10 min. After these pre-treatments, an additional drying step was applied to treated samples and also to unblanched samples (Jambrak, et al., 2007). A conventional air drying at 60°C with an air velocity of 0.3 m/s was applied. The air temperature of 60°C is commonly used in food drying and the authors adopt the mentioned temperature to prevent vegetable detriment. Freeze drying was also introduced to frozen samples at -45°C and during 3 h. For all the studied vegetables the hot water blanching treatment (80°C, 3 min) did not decreased the drying time compared with ultrasound treatments and controls (Jambrak, et al., 2007). For Brussels sprouts and cauliflower the ultrasound treatment with the probe at 20 kHz during 3 min was the best treatment concerning the reduction in drying time. In Table 10 are described the blanching method and the main findings encountered by Jambrak, et al. (2007). Also, Leeratanarak, et al. (2006) found that applying hot water blanching at 90˚C during 1, 3 and 5 min improves potatoes drying speed when compared to unblanched samples (Table 10). The authors Severini, et al. (2005) clarify that after blanching by hot water as a pre-treatment, potato tissues become more pliable and flexible giving rise to a permeable tissue membrane and as a consequence a faster water elimination (Table 10).

However, as reported by the authors and also by Mate, et al. (1998), if blanching is performed during long periods of time, modifications at cell structure, starch gelatinization

degree and water assimilation during blanching step can occur. For these reasons, there will be higher internal resistance to water diffusion out of the product during the drying step. By heating the product with hot water, the granulated starch on potato cells can be involved in a gelatinization process and lead to a perturbation on moisture diffusivity from the vegetable tissues to the drying air. This is the explanation claimed by Mate, et al. (1998).

During food heating, starch gelatinization phenomena can occur. Starch is a polysaccharide retained in food tissues and is formed by amylose and amylopectin molecules, whose structures are depicted in Figure 7. When starch grains are heated by water the breaking of starch chain occurs and as a consequence starch particles start to swell (**2**), as illustrated in Figure 7. Along the swelling process occurs also amylose losses (**3**) until some granules show a shape deformation named as granule collapsing (**4**). After this step, the gelatinization process occur (Sharpe, 2004).

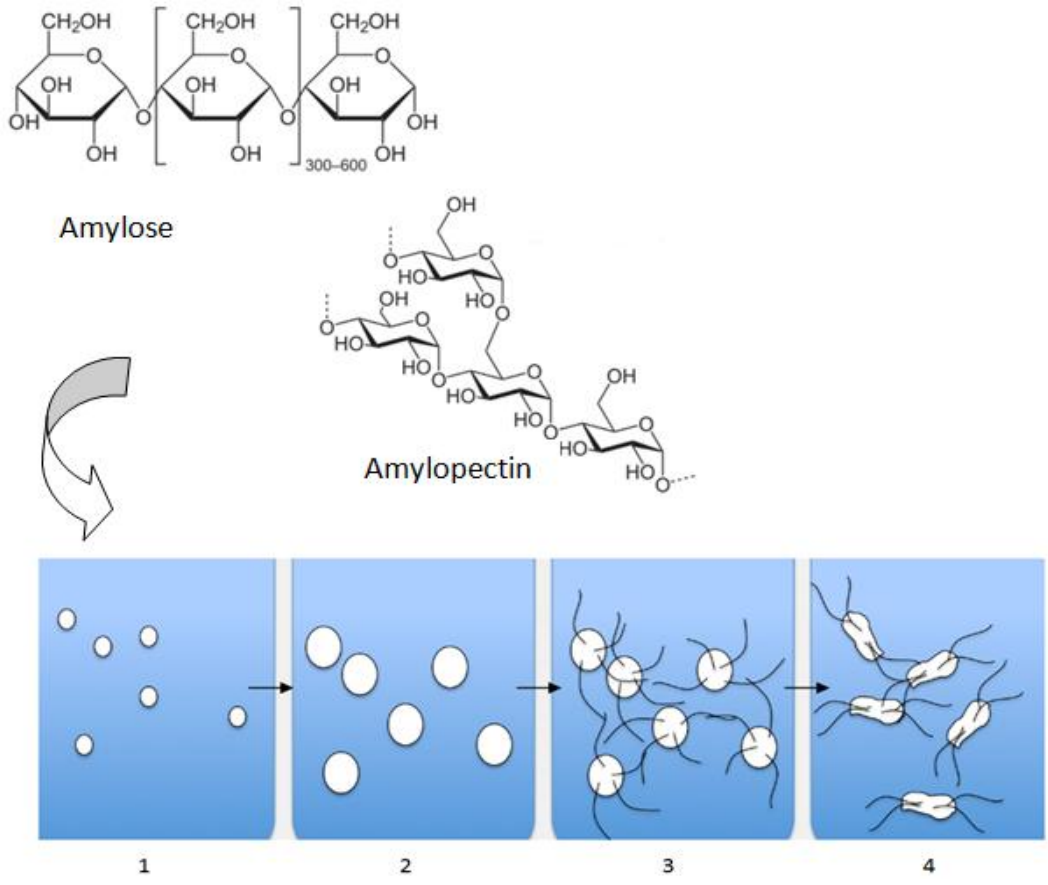

Figure 7- Steps preceding the starch gelatinization process of starch grains in hot water. Adapted from **(GeistScience, 2012)** and **(Duhnam, 2010)**.

Falade, et al. (2007) performed a blanching pre-treatment at 80°C for 5 min and 100°C during 2 min of two types of yam known as white yam (*Dioscorea rotundata Linn*) and water yam (*Dioscorea alata*). After blanching, a dehydration step with hot air (50-80°C) stream

(velocity of 1.5 m/s) was applied to yam slices. The authors conclude that blanching may cause starch gelatinization of yam slices which lead to lower drying rates compared with controls (Falade, et al., 2007). Sotome, et al. (2009) reported that steam treatments known as superheating system and superheating system with water microdroplets enhance also the formation of starch grains which conducted to gelatinization effect on potatoes samples. The blanching methods of this study are described on detail in Table 11 by Sotome, et al. (2009).

In conclusion, blanching improves drying speed for the studied vegetables (Gu, et al., 2013; Doymaz, 2008; Leeratanarak, et al., 2006). However, in the study presented for red apples by Doymaz (2010) a solution of citric acid reduced even more the drying time compared with blanched samples and controls. On the other hand, as it was mentioned, a starch gelatinization effect can occur for long blanching processes which may be responsible for a lower water diffusivity from the food to the drying medium (Falade, et al., 2007).

Texture/structure

Before applying a blanching step to foods it is crucial to know what will be the possible structural changes on the cell tissue. The heat from a blanching step entails changes that could be irreversible on vegetables or fruits. However, when a reasonable time-temperature of blanching is used in the treatment of the product a satisfactory enzymatic inactivation can be attained. Blanching by hot water can remove nutrients, minerals and vitamins from food by leaching or promote starch gelatinization and can also remove gases from the cell tissues. In addition, blanching can avoid undesirable tissue softening and loss of flavor (Fellows, 2000). The Figure 8 illustrates the main exchanges from a vegetal cell during a hot water blanching when used as a pre-treatment.

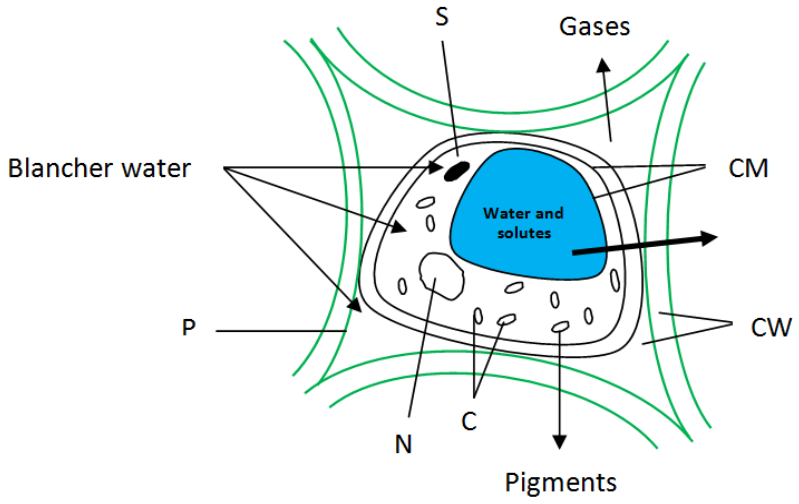

Figure 8 - Effect of blanching on cell tissues. **Adapted from (Fellows, 2000)**. Legend: **S**- Starch gelatinized; **CM**- Cytoplasmic membranes altered; **CW**- Cell walls little altered; **P**- Pectins modified; **N**- Nucleus and Cytoplasmic proteins denatured; **C**- Chloroplasts and chromoplasts distorted.

Food texture is a fundamental attribute regarding to all the mouth-feelings that the product could give to consumers and to the sensory panelist. All the experiences that the product offers are transmitted to the brain through the mouth sensors. These sensors record a "picture" from all the characteristics that the product could give in terms of memory and hearing (Fellows, 2000). In Figure 9 it is illustrated an example of a texture assessment evaluation obtained with three different products: starch gel, gellan gum and xanthan gum (Fellows, 2000).

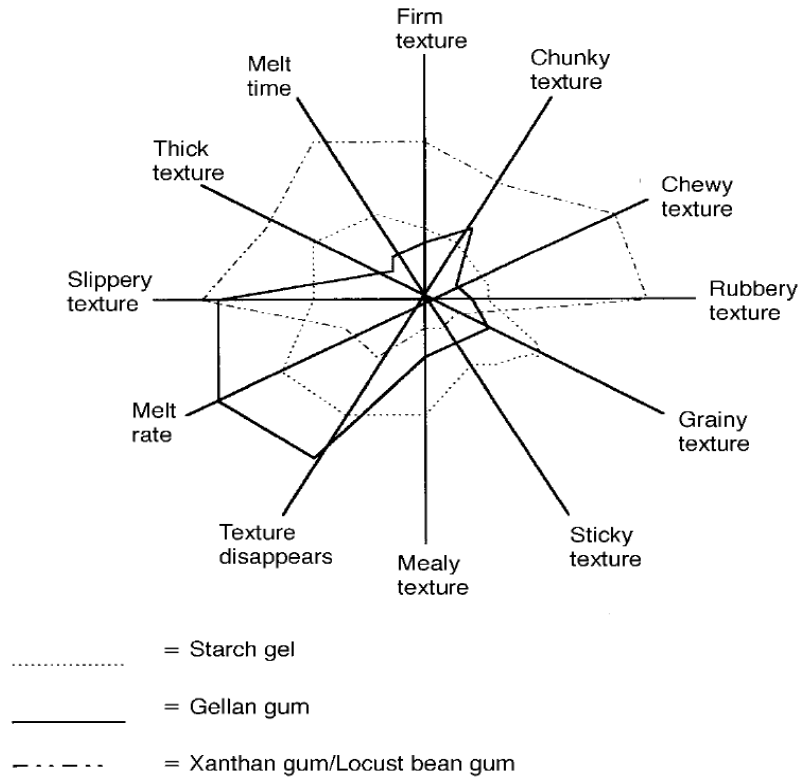

Figure 9 - Texture assessment for starch gel, gellan gum and xanthan gum. **Adapted from (Fellows, 2000)**

A research related to texture changes during blanching pre-treatments of Brussels sprouts was conducted by Vina, et al. (2007). All the blanching treatments turned the vegetable more pliable which lead to lower values of firmness which is based on the force required to push/penetrate a plunger of a specified size into the pulp of the legume or fruit up to a specific depth (*N*). During the texture characterization of Brussels sprouts the authors obtained the curve force-deformation from which the maximum force, corresponding to a compression of 3 mm, was registered (Vina, et al., 2007). Blanching at 100°C during 1 min decreases maximum force applied to Brussels sprouts around 60% compared with fresh Brussels sprouts (controls). Blanching at 100°C for 3 and 4 min reduced even more firmness of Brussels sprouts about 80% and 86%, respectively, compared with controls. A treatment performed with hot water (50°C, 5 min) followed by boiling water during 3 min gave a

reduction of firmness around 84% for Brussels sprouts. Also a microwave treatment (700 W, 5 min) followed by boiling water blanching (100°C, 2 min) presented 81% of firmness reduction. Thus, firmness loss (*N*) of Brussels sprouts is function of blanching conditions and duration time, and it is observed that for longer blanching periods the loss of material firmness was higher (Vina, et al., 2007). The main results of this study are present in Table 10.

Abu-Ghannam, et al. (2006) reported that blanching of potatoes at higher temperatures and during long periods of time conducted to lower values in terms of firmness. This fact means that the material offers less resistance to be deformed when a certain force is applied. For instance, to perforate a potato sample after a blanching treatment at 100°C during 15 min a maximum force of 7.5 N was enough. However, a higher maximum puncture force around 18 N was needed when applied to a potato sample after blanching at 90°C for 15 min. Also a force of 25 N was required to perforate a potato blanched at 80°C during the same time (see the study of Abu-Ghannam, et al. (2006) in Table 10). Gonçalves, et al. (2007) studied pumpkin texture after blanching by hot water. The authors concluded that the blanched samples became less firm. According to this research, it is important to notice that if 90% of peroxidase was inactivated by blanching conditions, a percentage of pumpkin firmness of just 14% could be reached when compared to fresh samples. The same authors, Gonçalves, et al. (2010) studied texture modifications of carrots during blanching with hot water. The results shown a reduction of about 36% of firmness (*N*) compared with controls for all blanching treatments used to inactivate 90% of peroxidase enzyme. The main results of both researches made with pumpkin and carrots are described in Table 10.

Neri, et al. (2014) introduced four different water blanching conditions to carrots discs before a blast freezing step with the purpose of study cellular changes due to these treatments. The authors conclude that an extended blanching time of 10 min induced cell damage due to pectin losses in comparison with the fresh carrots. The results are presented in more detail in Table 10.

Llano, et al. (2003) introduced a steam blanching at 99.8°C and 1 atm to kiwifruits and concluded that after 3 min of treatment the cell firmness was reduced in about 50% in comparison with the fresh fruit.

A steam blanching treatment applied to fresh potatoes using two different methodologies show that those potatoes samples became breakable (Sotome, et al., 2009). For all heating conditions presented in Table 11 the samples offered less resistance to the force applied to potatoes during texture analysis. The raw potatoes presented a breaking stress around 1.88 MPa while after superheating system with microdroplets being applied during 11 min the breaking stress decreased to around 1.14 N/cm^2. The superheating system for the same time gave a similar reduction of breaking stress (1.06 MPa). However, when these two heating methods were carried out during an extended time of 16 min the samples lost more

resistance (Sotome, et al., 2009). For superheating system with microdroplets the breaking stress measured was around 0.63 MPa while for the superheating system the value obtained was about 0.56 MPa. The superheating system performed with microdroplets resulted in better resistance of breaking stress of the potatoes samples but not very significantly. However, an increase in heating time for both steam treatments enhanced the pliability of potatoes samples (Sotome, et al., 2009). In attribute Table 11 are detailed all the blanching procedures. In conclusion, all the blanching treatments applied to different crops reduced the firmness of the cell tissues (Neri, et al., 2014; Gonçalves, et al., 2010; Sotome, et al., 2009; Gonçalves, et al., 2007; Vina, et al., 2007; Abu-Ghannam, et al., 2006; Llano, et al., 2003).

Stability during storage

Blanching by water is mainly use for enzymatic inactivation of food products. The heat from water ceases enzymatic activity that otherwise could cause food deterioration during storage period. Some enzymes contained in natural food are peroxidase (POD), catalase, lipoxygenase (LOX), polyphenoloxidase (LOX), polygalacturonase and chlorophyllase. It is known that peroxidase and catalase do not affect the product during storage. However, these enzymes are known as indicator enzymes because they are heating resistant which means they are the latest ones to be inactive in food matrix. Thus, if the food presents a low activity of these enzymes it is expected that other enzymes, less heat resistant, will remain inactive. Almost all the vegetables need to be blanched in order to inactivate enzymes and to achieve a better quality during storage period. Beside this fact, a proper blanching method should always be carried on because nutritional and sensory changes could occur if blanching step is not applied. On the other hand, if under-blanching conditions were used during the treatment it could conduct to cell tissue disruption, enzymes and substrates mixing but do not cause enzymatic inactivation (Fellows, 2000).

Enzyme inactivation is recommended even for storage in frozen conditions of vegetables and blanching by hot water can be understood as a suitable method for this purpose. In accordance with Bahceci, et al. (2005) an inactivation around 90% of peroxidase enzyme in vegetables is crucial to avoid losses of attributes during frozen storage. In their research the authors studied the effect of green beans blanching on the quality conservation during frozen storage (Bahceci, et al., 2005). The effect of hot water blanching was evaluated by the authors measuring the inactivation of peroxidase and lipoxygenase activity. No drying further step was applied in the research (Bahceci, et al., 2005). A blanching water temperature of 70°C and an immersion time of 2 min was sufficient to inactivate around 90% of lipoxygenase in green beans. Although, peroxidase as a heat resistant enzyme presents the same percentage of inactivation for higher water blanching temperature and treatment duration of 90°C and 3 min. Also, for this research it was important to detect if the mentioned enzymes could recover their enzymatic activity during frozen storage. However,

no reactivation was detected during frozen storage for both enzymes, which may indicate a good efficiency of blanching pre-treatment to green beans. Peroxidase activation was reduced in 90% also by Lee, et al. (1988) after blanching being applied to beans at 82˚C during 3.5 min. The authors conclude that the pre-treatment improved the vegetable characteristics during frozen storage (Lee, et al., 1988). Barrett, et al. (1995) presented different blanching conditions for totally inactivation of peroxidase of green beans (93.3˚C and 2 min).

Aguero, et al. (2008) applied a blanching treatment to butternut squash (*C.moschata* Duch) without any further drying step. The authors inactivate peroxidase in the totality with blanching temperatures of 80, 85 and 90 °C during short periods of time. The authors also reported that peroxidase activity is dependent on the variety of food product and the enzyme activity also depends on pre and post harvest aspects.

The research made by Mukherjee, et al. (2007) was performed with three different techniques of blanching as a heating treatment on potato cubes. The authors described a blanching by hot water at 93 and 100°C during several minutes and a blanching by steam was also applied at 97°C for a optimum time of 112 s. Although, the authors introduced a new technique called whirling bed (briefly described before) that uses a saturated stream of steam and air at 80 to 85°C with a velocity of 3.5 to 4 m/s. All the referred pre-treatments were able to inactivate peroxidase enzyme (Mukherjee, et al., 2007). The present blanching conditions are described on detail in Table 10 and Table 11.

Blanching by hot water was performed without any further drying step by Gonçalves, et al. (2007) to pumpkin (*Cucurbita maxima L.*). The authors reported that the higher the blanching temperature is, a greater peroxidase inactivation could be attained in the vegetable. In this research, peroxidase was inactivated in pumpkin slices during hot water blanching after 5.8 min at 90°C and after 3.9 min at 95°C (see attribute Table 10). The same authors studied also peroxidase inactivation in carrots during blanching with hot water without further drying steps.

Gonçalves, et al (2010) conjugated several temperatures and times in the blanching treatment in order to obtain 90% of peroxidase inactivation and concluded that for higher temperatures, the time needed is not so high for enzyme inactivation in carrots. For instance, for 90% of POD inactivation, 70°C could be applied during 25 min. On the other hand, if the water reaches 85°C the time is reduced for 2.8 min. Although in this research, peroxidase was inactive in carrots submitted to treatments of blanching hot water performed at 90°C and 2 min.

Also Leeratanarak, et al. (2006) studied the effect of blanching by hot water at 90°C during several minutes on potatoes slices prior to principal drying steps. It was reported that the heat from hot water could dominate totally the activity of peroxidase even if 1 min is using

during the blanching process. This effect conducted to a prevention of enzymatic browning on potato samples that were blanched (Leeratanarak, et al., 2006).

According to Koca, et al. (2007), carrots blanched by hot water prior to drying step presented less alterations concerning with enzymatic browning during storage period at 57°C. Chinprahast, et al. (2013) reported that peroxidase could be inactivated by a water bath at 90°C during 60 s for gooseberries fruits. The results and blanching methods used by the authors are described in Table 10.

According to Ismail, et al. (2006) blanching treatment at 100°C during 6 min inactivate peroxidase enzyme of chilli puree, while blanching with boiling water for 1 min cease the enzymatic activity of lipoxygenase. Once again, it can be seen that peroxidase is more resistant to heat compared with lipoxygenase enzyme.

Abu-Ghannam, et al. (2006) reported that pectinmethylesterease enzyme is inactivated for different blanching conditions applied to potatoes. The enzyme remains inactive for a water temperature of 75°C during 10 min or even for 80 or 90°C during 5 min. Llano, et al. (2003) inactivated peroxidase and pectinmethylesterease of kiwifruit with steam blanching at 99.8°C and 1 atm during 8 min (see Table 11).

Fante, et al. (2012) performed a treatment of blanching by steam at 100°C and 1 atm during different periods of time to garlic heads without further drying step (Table 11). The best condition for peroxidase, polyphenoloxidase and inulinase inactivation was steam blanching at 90°C during 4 min. Fante, et al. (2013) concluded that a steam blanching treatment during 4 min was the most adequate to inactivate 84.62% of peroxidase and 83.76% of polyphenoloxidase of yacon roots (Table 11). Sotome, et al. (2009) performed a steam blanching treatment applied to potatoes by two different technologies known as superheating system and superheating system with water microdroplets. The heating methods conditions are presented on detailed in Table 11.

Both steam technologies used were able to inactivate polyphenoloxidase after 11 min of treatment. Peroxidase, as a heat resistant enzyme, was also inactive after 16 min for both pre-treatments mentioned above (Sotome, et al., 2009) .

Polyphenoloxidase was mainly inactivated in green pepper berries for blanching at 100°C during 10 min (Gu, et al., 2013). Fante, et al. (2012) reported that a blanching pre-treatment (90°C, 4 min) to garlic (*Allium sativum L.)* resulted in a inactivation of 91.96% of peroxidase, 89.79% of polyphenoloxidase and 78.51% of inulinase. The same authors reported an inactivation for the same enzymes during 6 min for a water temperature of 80°C. For these blanching conditions 89.77% 77.40% and 74.66% of peroxidase, polyphenoloxidase and inulinase inactivation was attained, respectively (Fante, et al., 2012). In contrary to the expected, polyphenoloxidase and inulinase showed to be more heat resistant compared with peroxidase. In conclusion, different blanching conditions of water temperature and time can be conjugated with the aim of enzymatic inactivation of food. Also, according with

the literature, in order to inactivate enzymes conventional blanching conditions (temperature and time) are dependent on the vegetable sort. It is also relevant to refer that 90% of peroxidase inactivation ensures a reasonable blanching procedure and avoid food deterioration during storage.

Conclusions

In conclusion, blanching by hot water and by steam can be applied to fruits and vegetables mainly for enzymatic inactivation. However, enzymatic inactivation should not be understood as a food attribute (not directly) since the goals of this procedure are: prevention of enzymatic browning and preservation of product quality during storage period. The first objective is intrinsically related with further color deterioration when certain enzymes are present.

Color and nutrition are the principal attributes studied in the literature to evaluate the performance of both conventional blanching methods. However, in some cases, blanching by hot water improves color parameters (potatoes from Leeratanarak, et al. (2006); green beans from the study of Bahceci, et al. (2005)) but in other researches it was observed color losses (pepper berries from Gu, et al. (2013); garlic heads from the study of Fante, et al. (2012); carrots from Rawson, et al. (2011), Gonçalves, et al. (2010) and Koca, et al (2007); Brussels sprouts from the research of Vina, et al. (2007); pumpkin of Gonçalves, et al. (2007)).

For all cases studied, steam blanching enhances color losses, Fante, et al. (2013), Sotome, et al. (2009) and Llano, et al. (2003). Regarding to nutrition attribute, hot water blanching allows sugar and solid leaching which reduce sugars content of blanched samples. In the study of Gamboa-Santos, et al. (2013a) blanching by water intensified vitamin C losses while steam blanching improved vitamin C retention.

Concerning to texture attribute all the researches pointed for firmness loss of food tissues after blanching. Rehydration capacity of mushrooms and cauliflower was improved using ultrasound pre-treatments which show similar rehydration capacity as freeze dried samples (Jambrak, et al., 2007).

Regarding to drying, some blanching pre-treatments reduced the drying time of samples. On the other hand, some authors explained that the cause for longer drying times may be due to starch gelatinization of food tissues (Falade, et al., 2007).

2.1.2. Ultrasound

General considerations

Ultrasound technology can be applied in different areas such as medicine, chemistry, and food technology. The ultrasonic equipment emits an acoustic sound wave which propagates in a certain medium (gas, liquid or solid) with high frequency and intensity (W/m^2) above the limits of human hearing (Chemat, et al., 2011). As it is depicted in Figure 10, sound waves at frequencies below the human hearing (20 Hz) are considered as infrasound while ultrasound is described by frequencies above 20 kHz. The simple principle of ultrasound is based on a longitudinal wave that crosses the medium and reaches the product. After, the vibrational wave echoes back and is transformed into an electrical signal while the interpretation of this signal can be performed.

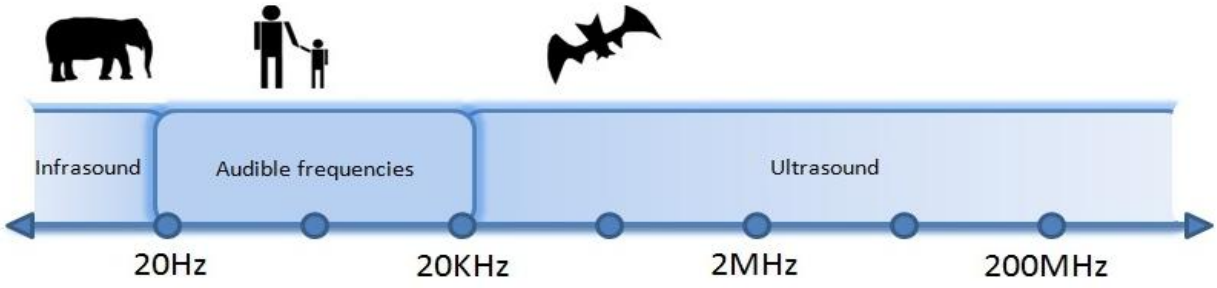

Figure 10- Sound wave frequencies. **Adapted from (Igel).**

Ultrasound conducted with high frequencies above 100 kHz and intensities not higher than 1 W/cm^2 is widely used in assessment of food quality during processing, however the body tissue is not penetrated by the sound waves (non invasive analysis). It is used in vegetables, fruits, dairies, cereals, gels, among others products (Chemat, et al., 2011).

Sound waves of low frequencies between 20 and 500 kHz are denominated by high power ultrasound and the intensities are higher than 1 W/cm^2. The sound waves in the range of these frequencies have a straight influence in mechanical characteristics of food which will be mentioned further in this chapter (Chemat, et al., 2011).

According to the literature the ultrasound probes frequency usually used is about 20 kHz (Gamboa-Santos, et al., 2013a; Jambrak, et al., 2007). For ultrasound baths the frequencies are higher, between 20 kHz and 40 kHz (Rawson, et al., 2012; Jambrak, et al., 2007). The time which ultrasound can be applied lies between 3 to 30 min (Rawson, et al., 2012; Fernandes, et al., 2009c). Thus, if ultrasound is applied to a solution as medium, the ratio between product to water should be also known. For an ultrasound bath Gamboa-Santos, et al. (2013a) used a ratio of 0.21 $g_{carrots}/g_{water}$ while Rawson, et al. (2011) used 0.75 $g_{carrots}/g_{water}$ for the same crop.

Processing and preservation of food by ultrasound

High quality of food can be attained by using emerging technologies such as high pressure, pulsed electrical field (HELP), microwave heating, among others. However, the industrial implementation of these technologies has resulted in increased expenses, disadvantages regarding with processing control and acceptance by the consumers (Chemat, et al., 2011). Ultrasound can replace these food technologies avoiding the constraints mentioned and environmental problems. Therefore, ultrasound can be introduced as a processing or preservation method to food products (Chemat, et al., 2011).

Regarding to processing methods, ultrasound can be used in a wide range of food applications. In the unroll of the present study it is important to summarize some of these food applications such as: **(i)** depolymerization, **(ii)** freezing and crystallization, **(iii)** drying.

Ultrasound enhances depolymerization of macromolecular chains present in solutions. The basis of polymer rupture is due to cavitation process which enhances mechanical or chemical scission of polymeric chains (Chemat, et al., 2011). In Figure 11 is represented the cavitation effect of an ultrasound wave in a liquid medium. If the minimum pressure attained in the rarefaction step is sufficiently low to "break down" the liquid, voids (or cavities) will be created, originating cavitation bubbles. Along the wave propagation consecutive rarefactions and compressions steps occur which generate expansions or contractions of bubbles, respectively (Soria, et al., 2010). For large pressure amplitudes during one cycle (high intensity ultrasound) the bubbles suddenly collapse at the compression step. The energy released produces a shock wave responsible for several cavitation effects.

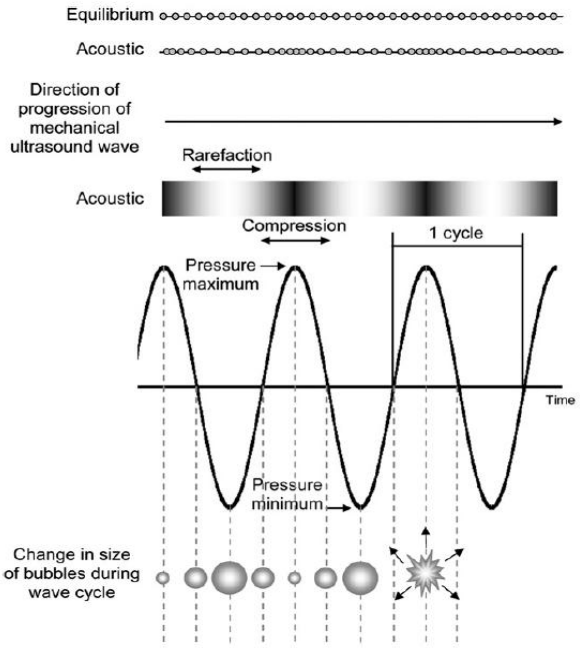

Figure 11 - Ultrasonic cavitation **(Soria, et al., 2010)**.

In Figure 12 is illustrated a mechanical depolymerization phenomenon when gas voids (bubbles) are formed in liquid medium and cause mechanical breakdown of molecules due to the forces generated by the rapid motion of the liquid following the cavitation collapse. On the other hand, cavitation can also generate chemical degradation when hydroxyl radicals are formed by the momentary temperature rise caused by powerful shock waves resulting from bubbles collapse (Chemat, et al., 2011; Czechowska-Biskup, et al., 2005). The starch and chitosan chain scission that occurs by OH^- radicals when ultrasound was applied in water solution at a frequency of 360 kHz can be referred as an example of chemical cavitation. Thus, after ultrasound being applied, a molecular weight reduction was obtained for these saccharides (Czechowska-Biskup, et al., 2005). It is also reported that polymeric degradation is dependent on solution concentration and for lower polymer concentration in solution the degradation rate by ultrasound was higher (Mason, et al., 2002).

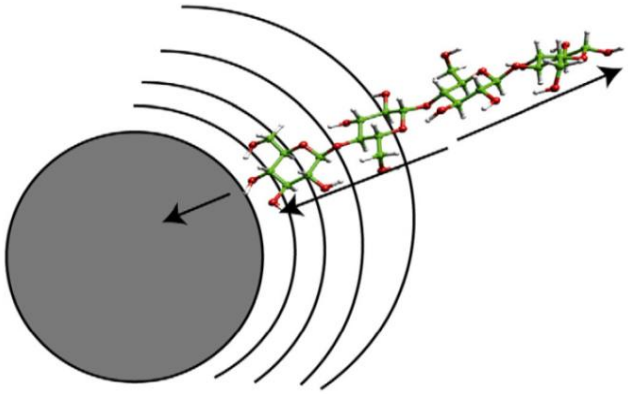

Figure 12 - Molecule depolymerization using ultrasound **(Chemat, et al., 2011)**.

Freezing as a sole method enhances an inconsistent seeding growth of water crystals inside the cells which could lead to a disruption of tissues (Chemat, et al., 2011). However, sonocrystallization can overcome this freezing disadvantage. In the study of Sun, et al. (2003) with potatoes, ultrasound assisted freezing helped uniform growth of crystals and avoided microstructural changes of cell tissue.

Regarding to drying, ultrasound can increase the effective water coefficient (D_{eff}) which conduct to a reduction in drying times (Fernandes, et al., 2008a; Fernandes, et al., 2007b). However, there are other ultrasound applications that will be not explained on detailed but also aid the improvement of processing industrial steps, such as: filtration, defrosting, defoaming, deaeration, cooking, cutting, demoulding, sterilization, pasteurization, emulsification, among others.

Preservation of food is mainly related to maintain a final product free of microorganisms (spores, bacteria) but also the inactivation of enzymes that could enhance modifications at color and flavor attributes (Chemat, et al., 2011).

Attributes of ultrasound foods

Along the present section will be discussed information found in the literature regarding to the impact of ultrasound in some food attributes. The following attributes will be described in different sections: (i) nutrition, (ii) color, (iii) rehydration kinetics, (iv) drying, (v) texture/structure.

Nutrition (vitamins, nutrients, sugars)

Vitamin C retention was studied by Gamboa-Santos, et al. (2013a) after an ultrasound treatment using a probe has been applied to carrots. For all ultrasound conditions applied in the study, vitamin C retention was extremely low. An ultrasound probe at 20 kHz applied to minced carrots at 60°C during 10 min resulted in losses of 99.3% of vitamin C while for the same frequency a remarkable 96.3% of vitamin was lost for sliced carrots at 70°C and 15 min of treatment (Gamboa-Santos, et al., 2013a). The present results are depicted on detail in Table 6. After the treatment with ultrasound probe the samples were subjected to a dehydration method (air drying at 46°C with a velocity of 4.9 m/s). However, vitamin C retention was even lower due to losses of drying temperature (see section 2.1.1 of Blanching chapter).

In Table 6 the results are present for different ultrasound conditions and different carrot geometries.

Table 6 - Effect of ultrasound treatments on vitamin C retention of carrots.
Adapted from: (Gamboa-Santos, et al., 2013a).

Ultrasound conditions	Carrot geometry	Vitamin C Retention (%)
Raw material		100
US probe (60°C, 10 min)	Minced	0.7
US probe (70°C, 15 min)	Sliced	3.7

The explanation for an abruptly vitamin C loss during ultrasound treatments is regarding to a possible development of microchanels in the carrots structure (voids) during cavitation. These voids promote the migration of soluble solids retained within the product, such as vitamins (Mothibe, et al., 2011).

An ultrasonic bath at 25 kHz was used in the treatment performed to Banana *cv Pacovan* during 10, 20 and 30 min in the study carried out by Azoubel, et al. (2010). The results of this study showed water increasing to the cells and a decrease in soluble solid due to concentration gradients promoting the mass transfer of solids (as sugar) from the fruit to exterior medium and the mass transfer of water in the opposite direction. The research

conducted by Fernandes, et al. (2007b) to banana *cv Nanica* shows also that after ultrasonic bath under the same conditions the samples lost sugar but gained water. The same results were found for melon fruit (Fernandes, et al., 2008a) and for pineapple (Fernandes, et al., 2009c).

Gamboa-Santos, et al. (2013b) studied the influence of ultrasound probe treatments with distilled water as heating medium at 60 and 70°C applied to sliced and minced carrots previously to an air drying method. In comparison with control samples (freeze dried) ultrasound of minced samples retained higher content of total carbohydrates (71.63%) when compared to sliced carrots (63.15%). The losses of carbohydrates in sonicated samples were close to the ones observed in samples treated with hot water (see Blanching chapter). However, steam blanching maintained the same carbohydrates content compared with freeze dried samples but hot water blanching allows carbohydrate losses due to leaching as mentioned in Blanching chapter. In Table 7 is depicted carbohydrates retention obtained by Gamboa-Santos, et al. (2013b) after ultrasound followed by dehydration step.

Table 7 - Carbohydrates retention after ultrasound and drying step.
Adapted from (Gamboa-Santos, et al., 2013b).

		Carbohydrates (mg/g dry matter)		
Carrot treatment	**Carrot geometry**	**Fructose**	**Glucose**	**Sucrose**
Freeze Drying	-	67.27	73.99	449.50
US (60°C, 10 min)	Minced	39.27	40.88	343.04
US (70°C, 15 min)	Sliced	31.76	35.42	333.88

Color (phytochemicals, phenolics)

Polyacetylenes and carotenoids are a group of phytochemicals present in vegetables. The most common polyacetylenes are: falcarinol, falcarindiol and falcarindiol 3-acetate. These polyacetylenes are known to have particular characteristics to prevent multiplication of defect cells. For instance, falcarinol shows a cytotoxic activity to cancer cells, leukemia and mouse melanoma (Aguilo-Aguayo, et al., 2014).

The aim of Rawson, et al. (2011) research was to study the influence of ultrasound followed by two drying methods on color and polyacetylene compounds of carrots. Thus, Rawson and coauthors applied an ultrasonic bath treatment at 20 kHz during 3 and 10 min with different sound wave amplitudes to sliced carrots (Table 12). After this pre-treatment being applied a dehydration step with hot air at 60°C and 0.3 m/s was performed. Beyond the drying step, a freeze drying technology was also applied (0°C and 0.04 mbar) as a control. The authors concluded that samples submitted to ultrasound followed by freeze drying retained higher content of polyacetylenes but they experienced higher changes of total color difference (ΔE) compared with sonicated samples prior air drying (Rawson, et al., 2012). A pre-treatment

with a ultrasonic probe (20 kHz) immersed in distilled water during 10 and 15 min was performed by Gamboa-Santos, et al. (2013b) to carrot samples (minced and sliced). Beyond ultrasound, blanching by steam and hot water treatments were used (see Blanching chapter). After the three treatments being applied, the samples were subjected to air drying (see attribute Table 12 for the ultrasound and drying conditions). The authors Gamboa-Santos, et al. (2013b) concluded that dehydrated carrot slices submitted to ultrasound treatments retained similar phenolic content when compared with control (freeze dried samples). Carotenoid retention was determined to be higher for sonicated carrot discs followed by freeze drying when compared to air drying (Rawson, et al., 2012).

Rehydration kinetics

An ultrasound probe of 20 kHz frequency and an ultrasound bath at 40 kHz were used in the treatments applied during 3 and 10 min to button mushrooms, Brussels sprouts and cauliflower (Jambrak, et al., 2007). After the ultrasound treatments the three vegetables were submitted to conventional air drying. These samples were compared with untreated and freeze drying samples. The detailed drying conditions are present on Table 12. After these steps, rehydration of the vegetables was performed at 80°C and during a period of 15 min. As it was expected, freeze dried samples gave the best rehydration capacities of all the vegetables studied but the ultrasound pre-treatments followed by conventional drying resulted also in higher rehydration capacities when compared with controls and blanched samples (see Blanching chapter). Between the three vegetables studied, cauliflower shows higher rehydration capacities followed by mushrooms and Brussels sprouts (Jambrak, et al., 2007). The main results of this study obtained for the different crops will be presented in the following paragraphs.

For cauliflower, an ultrasound probe at 20 kHz frequency and during 3 min gave the best rehydration capacity of 5 $g_{moisture}/g_{drymatter}$, which is approximately the rehydration capacity of freeze dried samples (5.5 $g_{moisture}/g_{drymatter}$), after 15 min of rehydration. An ultrasound bath at 40 kHz during 3 min revealed to be the best condition for mushrooms rehydration after 15 min (4.3 $g_{moisture}/g_{dry\ matter}$). This rehydration capacity was very close to the rehydration capacity of freeze dried mushrooms (around 4.4 $g_{moisture}/g_{dry\ matter}$). Although, ultrasound probe at 20 kHz applied during 10 min to mushrooms gave a lower rehydration about 3.9 $g_{moisture}/g_{drymatter}$. On the other hand, Brussels sprouts did not show the same rehydration capacity trend as mushroom and cauliflower. The rehydration capacity of this crop was lower for all the treatments used (ultrasound and blanching) in comparison with mushrooms and cauliflower. A freeze drying treatment applied to Brussels sprouts gave a rehydration capacity of 1.2 $g_{moisture}/g_{drymatter}$ but the highest rehydration capacity obtained for this crop was attained when an ultrasound probe (20 kHz, 3 min) followed by air drying was used, pointed a value of 0.8 $g_{moisture}/g_{drymatter}$ (Jambrak, et al., 2007). From this study can be conclude that ultrasound pre-treatments enhanced the rehydration capacities of

mushrooms and cauliflower which were closed to the ones obtained from freeze drying technology. In the case of Brussels sprouts, the research intrinsically related the different shape of the crop with its lower rehydration capacity (Jambrak, et al., 2007).

Rehydration kinetics of carrots was determined by Gamboa-Santos, et al. (2013b) after ultrasonic probe treatment followed by air drying (see Table 12). Freeze drying technology was used as control with a rehydration ratio equal to 6.4. However, ultrasound pre-treatments gave higher rehydration ratios when compared with freeze dried carrots. The ultrasound probe treatment applied to minced carrots at 60°C during 10 min enhanced the rehydration ratio in 8.6% while the sliced carrots sonicated at 70°C for 15 min improved its rehydration ratio around 20%, compared with freeze drying. On the other hand, blanching treatments at 95°C for 5 min to sliced and minced carrots gave the highest rehydration ratios around 14.5 and 15, respectively compared with freeze dried samples (Gamboa-Santos, et al., 2013b). The results regarding to blanching can be seen on detailed in Blanching chapter, section 2.1.

After an ultrasound probe treatment and a drying step, the carrots rehydration was performed to evaluate sensory quality of the vegetable in terms of texture and taste (Gamboa-Santos, et al., 2013a). Rehydration was applied to carrots in boiling water for 10 min with a ratio of 0.03 $g_{carrots}/g_{water}$. The sensory quality assessment was conducted by panelists that attributed a punctuation in a scale ranging from 1 to 8 points - 1 for “like very much” and 8 for “dislike very much”. The score of 3.2 ± 1 was attributed to carrots obtained from ultrasound pre-treatment at 60°C for 10 min while a worst punctuation of 3.5 ± 1.2 was attributed to samples submitted to an ultrasound treatment at 70°C for 15 min (see Table 12). The same sensory evaluation was performed with samples obtained with water and steam blanching treatments that can be seen in section 2.1.1. of Blanching chapter. Steam blanching treatment permitted the best evaluation score (3 ± 1.2) among all the other treatments (Gamboa-Santos, et al., 2013a).

Drying kinetics

Jambrak, et al. (2007) used different ultrasound conditions to mushrooms, cauliflower and Brussels sprouts before a drying step. The aim of this research was to study the effect of ultrasound pre-treatments performed on drying time. A pre-treatment using an ultrasound probe (20 kHz, 3 min) in the case of Brussels sprouts and cauliflower was the most efficient to reduce the drying time compared with control and water blanched samples. Also, in Table 12 are described the ultrasound treatments conditions and main findings of the study carried out by Jambrak, et al. (2007). For example, when Brussels sprouts are treated with probe during 3 min the drying time was 12.5 h compared with blanching and control samples which were 25 h, until the same final moisture content of 0.4 $g_{water}/g_{dry\ matter}$ being attained. This fact points to a reduction approximately of 50% of drying time. For cauliflower, in terms

of drying time, ultrasound probe for 3 min was the most effective pre-treatment to reduce drying time in comparison with untreated, blanched and sonicated samples. In the case of button mushrooms, no significant differences were obtained to sonicated samples and controls (Jambrak, et al., 2007).

Fernandes, et al. (2008a) performed an ultrasonic bath treatment at a frequency of 25 kHz, intensity of 4870 W/m^2 during 20 and 30 min to melon fruit. After ultrasound treatments, all the melon samples were dried in a forced circulating air oven at 60°C (see Table 12). The aim of this study was to evaluate the influence of the mentioned treatments applied to melon tissue on water diffusivity during drying. The authors concluded that ultrasound enhances the water diffusivity in the fruit samples compared with controls (samples without pre-treatment). The melon samples subjected to air drying without any pre-treatment showed an effective diffusivity of $5x10^{-9}$ m^2/s while after 20 and 30 min of ultrasound treatment values increased to $6.42x10^{-9}$ m^2/s and $6.97x10^{-9}$ m^2/s, respectively. As a consequence, the samples pretreated by ultrasound dried faster than the samples without prior treatment (Fernandes, et al., 2008a). In Table 12 it can be seen the detailed conditions and results for this study.

Regarding to water diffusivity coefficient, dehydrated bananas without ultrasound pre-treatment show lower D_{eff} compared with sonicated samples (Azoubel, et al., 2010). As a consequence, the drying time is reduced when ultrasound is applied as pre-treatment. For example, bananas dehydration at 50˚C and 70˚C took 345 and 111 min, respectively, to attain 25% of moisture (in wet basis), but when bananas were subjected to ultrasound for 20 min the dehydration step is reduced to 207 min at 50˚C and 106 min at 70˚C (Azoubel, et al., 2010). In Table 12 can be seen all the conditions and main findings of this study.

Fernandes, et al. (2009c) submitted pineapple samples to an ultrasonic bath treatment with distilled water and also with sucrose solutions of 30 and 70 °Brix. The water diffusivity coefficient (D_{eff}) during drying was reduced when the ultrasound treatment was applied to the fruit for different conditions. For the pineapple sample controls (dehydrated samples without pre-treatment) a D_{eff} of $8.41x10^{-9}$ m^2/s was determined while for ultrasound in distilled water during 10, 20 and 30 min the water diffusivity coefficients obtained were 9.08×10^{-9} m^2/s, 1.38×10^{-8} m^2/s and 1.22×10^{-8} m^2/s, respectively. As a result, the drying time was reduced compared with control samples. The use of ultrasound in melon tissue enhances the water diffusivity coefficient in 39.3% during the dehydration step while in the case of the pineapple the increase in D_{eff} coefficient was significantly higher (around 64%) (Fernandes, et al., 2008a). Fernandes, et al. (2007b) studied the effect of using an ultrasonic bath in bananas *vs Nanica* with further dehydration and the drying time is reduced in 11% compared with samples without pre-treatment. A research performed with apple cubes dipped in an ultrasonic bath of citric solution followed by a dehydration step was performed by Nowacka, et al. (2012). The authors concluded that when ultrasound was applied to apple samples the drying time was significantly reduced. The dehydration of untreated samples

was performed in 165 min to attain a moisture content of 0.11 $kg_{H2O}/kg_{dry\ solid}$ while with a previous ultrasound treatments of 10, 20 and 30 min the drying times were reduced to 108, 114 and 99 min. The main results of the study are present in Table 12.

Texture/structure (Cell structure)

Ultrasound at high intensities applied to vegetables and fruits lead to enzymatic inactivation but also to cell disruption. In respect to cell structure, during ultrasound treatments can occur intracellular cavitation. The lysis phenomenon of cell using ultrasound is illustrated in Figure 13. The sonic waves facilitate water incorporation into the cell **(1)**, a swelling phenomenon occurs **(2)** which leads to cell collapsing **(3)** (Chemat, et al., 2011).

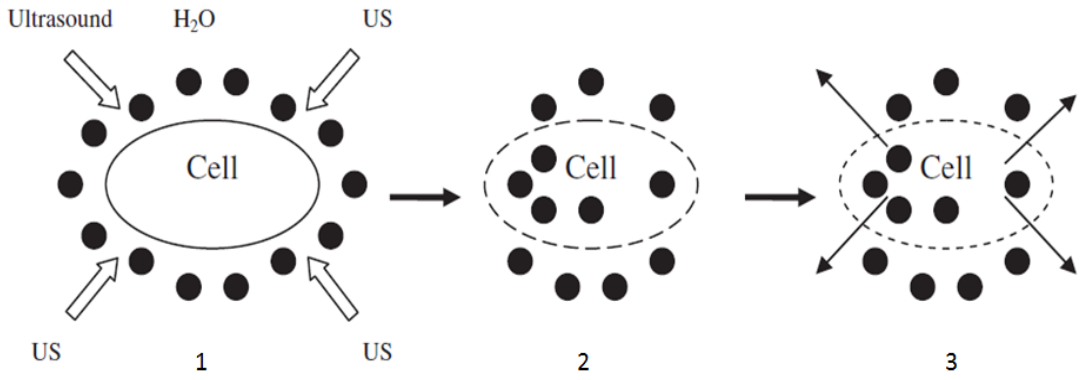

Figure 13 - Effect of ultrasonic waves and consequent cell disruption. **Adapted from (Chemat, et al., 2011).**

Fernandes, et al. (2008a) characterized melon tissue after using an ultrasound bath treatment at 25 kHz during 20 and 30 min. After this treatment two different cell regions were evident in the melon tissues compared with cells observed in the control samples. Some melon cells presented a swollen aspect while others showed thinner form. An increasing in ultrasound time (30 min) also improved the aspect of the swollen cells which expand, however this treatment did not lead to disintegration or cell collapsing.

Samples of apple variety *Idared* were treated in an ultrasound citric acid bath before a drying process being applied (Nowacka, et al., 2012). The dehydrated samples show 60% of shrinkage while all the ultrasound pretreated samples (during 10, 20 and 30 min) presented around 70% of shrinkage. Also, in this research the ultrasound treatment lead to cell damage confirmed by microscopic analysis and an increasing in ultrasound time enhances cell collapsing with structural changes in the tissues (Nowacka, et al., 2012). Regarding to cell disruption, Fernandes, et al. (2009c) show that ultrasound applied to pineapple before a dehydration step also enhanced cell distortion when the duration of treatment is about 30 minutes.

Conclusions

From the bibliographic results presented, some conclusions about the ultrasound pre-treatment effects on nutrition attribute can be emphasized.

The ultrasound enhanced vitamin C losses of carrots Gamboa-Santos, et al. (2013a) and also improved solids/sugar losses of bananas, melon and pineapple, (Azoubel, et al., 2010; Fernandes, et al., 2009c; Fernandes, et al., 2008a; Fernandes, et al., 2007b).

Sugar losses were also found in the research of Gamboa-Santos, et al. (2013b) for carrots.

The research of Rawson, et al. (2011) pointed to a higher retention of polyacetylenes when ultrasound is applied to carrots. Regarding to color attribute, when freeze drying is applied after ultrasound treatments, carrots experienced a higher total color difference.

Concerning to further dehydration steps after ultrasound treatment being applied, the study of Jambrak, et al. (2007) indicated a reduction in drying time of cauliflower and Brussels sprouts. Also the drying time of some fruits such as melon, pineapple, banana (*cv Pacovan* and *Nanica*) and apple was reduced by the application of ultrasound as prior treatment (Nowacka, et al., 2012; Azoubel, et al., 2010; Fernandes, et al., 2009c; Fernandes, et al., 2008a; Fernandes, et al., 2007b).

According to Jambrak, et al. (2007) the use of ultrasound improves posterior rehydration kinetics of the vegetables analyzed. Cauliflower shows the best rehydration capacity, which was close to the rehydration capacity of freeze dried samples (Jambrak, et al., 2007). Also, in the research of ultrasound performed by Gamboa-Santos, et al. (2013b) carrots showed higher rehydration ratios when compared with freeze dried samples.

Ultrasound treatments enhanced dilatation of melon fruit cells, however there was no evidence of disrupted cells in the study carried out by Fernandes, et al. (2008a). On the other hand, Nowacka, et al. (2012) detected cell disruption and an increase in shrinkage during dehydration when ultrasound was applied to apple samples. Cell collapsing was also observed in the study made by Fernandes, et al. (2009c) to pineapple fruit.

In conclusion, ultrasound pre-treatment could be applied mainly to reduce drying time of further drying steps and in structural changes studies of plant cell integrity. The conjunction of ultrasound and further dehydration process showed a reduction in drying time of fruits and vegetables for all the researches mentioned. Ultrasound treatment enhanced cell expansion even that in some cases disruption was observed. In addition, ultrasound enhances sugars and solid losses and gave higher rehydration capacities. Regarding to the results, this technology is not focused in enzymatic inactivation as conventional blanching treatments.

2.1.3. Freezing

General considerations

Freezing of vegetables and fruits is a preservation method of quality attributes such as color, texture and flavor by lowering the temperature of plant cells (De Ancos, et al., 2012). The method minimizes the degradation rate of food by inactivation of microorganisms and avoids also cellular reactions that can occur after harvesting. Beyond this fact, freezing extends the frozen period storage in which the product is preserved (De Ancos, et al., 2012). Cooling food by a freezing method consists in lowering the temperature of the product until the core of the food piece reaches -18°C. In the research of Delgado, et al. (2005), the authors referred that freezing was complete when the central core of strawberries achieved a temperature of -18°C and when -1°C was reached at that location the defrost was observed (thawing). As will be mentioned, the freezing conditions can be changed and normally food can be freeze at slow, fast or very fast rates (Fennema, 1976).

Freezing rate

In this section will be introduced the freezing mechanism for further comprehension of the effect of this technology in food matrixes. The product temperature starts to decrease from the superficial area which is in contact with the freezing atmosphere until the inner matter of the product. This temperature drop propagation depends on the freezing speed which is function of several variables as the freezing methodology, shape, type and initial temperature of the product and packaging procedure (De Ancos, et al., 2012). Before freezing being applied, the product is normally placed in polyethylene bags (Chassagne-Berces, et al., 2010). According to De Ancos, et al. (2012), freezing rate can be slow (1 cm/h), semi-quick (1-5 cm/h), quick (5-10 cm/h) or very quick (10-100 cm/h).

In Figure 14 can be seen a typical chart for food freezing process. Three different freezing rates are depicted and designated by **a)** slow freezing, **b)** fast freezing and **c)** very fast freezing.

In order to have a better understand regarding to further crystallization phenomenon is important to describe in more detail the slow freezing process. In the chart, the period **A-S** is common for the three curves represented by **a)**, **b)** and **c)** and will be described in conjunction. During the referred period the product is cooled down until 0°C but experiences a *supercooling* process when the temperature reaches the **S** point (Figure 14). At this stage the temperature is characterized to be lower than the freezing point of the product (De Ancos, et al., 2012). The freezing point is the "*temperature at which a crystal ice exists in equilibrium with the surrounding liquid water*" according to Fellows (2000). Thus, the **S-B** period is described by a water phase change (liquid to solid). During this period, the latent heat released when water solidification started increases slightly the product temperature until the freezing point (**B**).

After this period, ice is being formed with the decreasing of the freezing temperatures of the product due to the increase of solute concentration in solution (freezing point depression) (**B-C**). At this stage, almost all the water in the plant cells is frozen but there still unfrozen water in some tissue locations with a high in concentration in solute. Thus, the physical properties of the unfrozen fractions will be modified which can lead to enzymatic activity (browning) and redox reactions (De Ancos, et al., 2012). In the stage **C-D** the product temperature decreases deeply with the continuous increasing of solute concentration in the unfrozen parts (De Ancos, et al., 2012).

In comparison with **b)** and **c)** curves the stages **S-B** and **B-C** point are not present. This fact means that the freezing process is so fast that the product temperature decreases well below the freezing point in short times when subjected to these freezing conditions. In the next section, slow and faster freezing modifications at cell level will be explained.

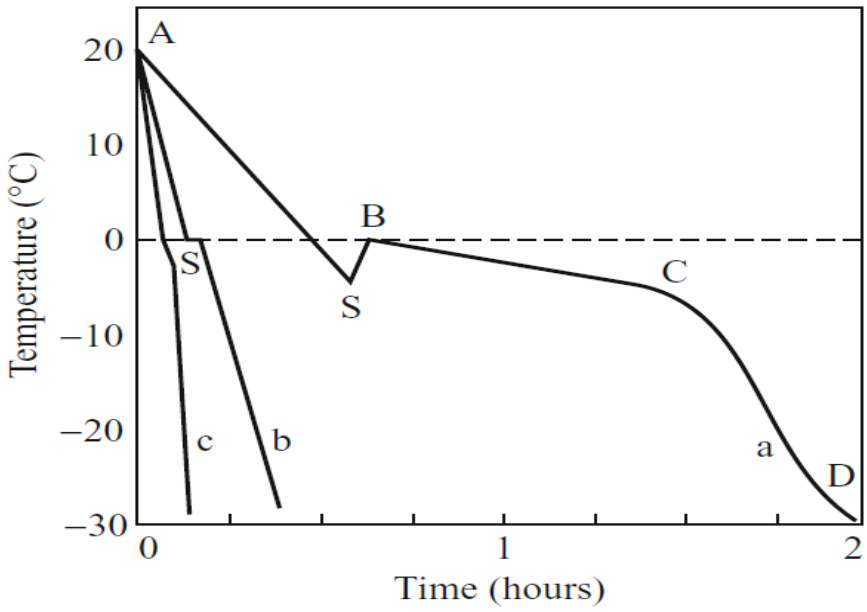

Figure 14- Freezing processes of food at different rates: **a)** slow freezing rate, **b)** fast freezing rate, **c)** very fast freezing rate. **Adapted from (De Ancos, et al., 2012), (Fennema, 1976)**.

Plant cells show similar moisture contents and freezing points (Fellows, 2000). In general, vegetables show a moisture content between 78-92% and respective freezing points of -0.8 to -2.8 °C while in the case of fruits a moisture content of 87-95% is observed with almost the same range of freezing point temperatures (-0.9 to -2.7°C) (Fellows, 2000).

Crystallization and freezing rate

Plant cells can be deformed by freezing and experience injury caused by present solutes, osmosis or modifications at cell structure (De Ancos, et al., 2012). In the freezing

progression, the liquid water undergoes a phase transition and ice crystals start to develop in the tissue. Furthermore, the final structure of the crystals is intrinsically related with freezing rate since this factor will dictate crystals configuration. Thus, the ice crystals can lead to plant cell damage as it will be explain in the next two examples for slow and fast freezing rates (De Ancos, et al., 2012).

The Figure 15 illustrates the development of water crystals during a slow freezing process rate. In the beginning of freezing process, water agglomeration starts to form – *nucleation* stage (**2**) (Fellows, 2000). This is due to water losses from the cell by osmotic pressure (De Ancos, et al., 2012). As the freezing progresses in plant cells (**1**), the amount of water becomes higher and the ice crystal starts to form outside the cells (**3**). Because the freezing process is conducted at slow rate, the water crystals have more time to grow and develop a consistent arrangement. Thus, due to crystals growth, the plant cells will show a structural membrane deformation (**4**) (De Ancos, et al., 2012). As it will be mentioned, this cell damage does not occur with faster freezing rates.

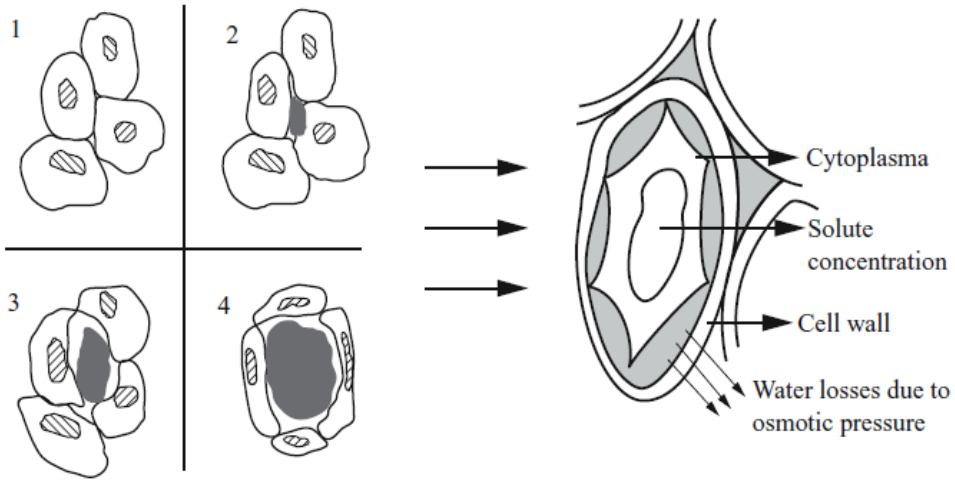

Figure 15- Development of water crystals during slow rate freezing and the effect in plant cells.
(De Ancos, et al., 2012)

For fast freezing rates the time of freezing is not sufficient to allow ice crystals development inside and outside of the plant cells. Thus, the small dimensions of ice crystals formed are mainly intracellular in fast freezing processes as it is depicted in Figure 16. As a consequence, the cells are less deformed compared with slow freezing process (De Ancos, et al., 2012). However, it is important to refer that after a fast freezing rate the storage period can lead to recrystallization which modifies the configuration of ice crystals in terms of size, shape and orientation (Fennema, et al., 1973). This is due to temperature changes along storage which can compromise food quality (De Ancos, et al., 2012). In general, the majority of frozen food experiences migratory recrystallization during changes in frozen storage temperature. This phenomenon consists in the agglomeration of small ice crystals which conduct to a final formation of crystals with higher dimensions (De Ancos, et al., 2012).

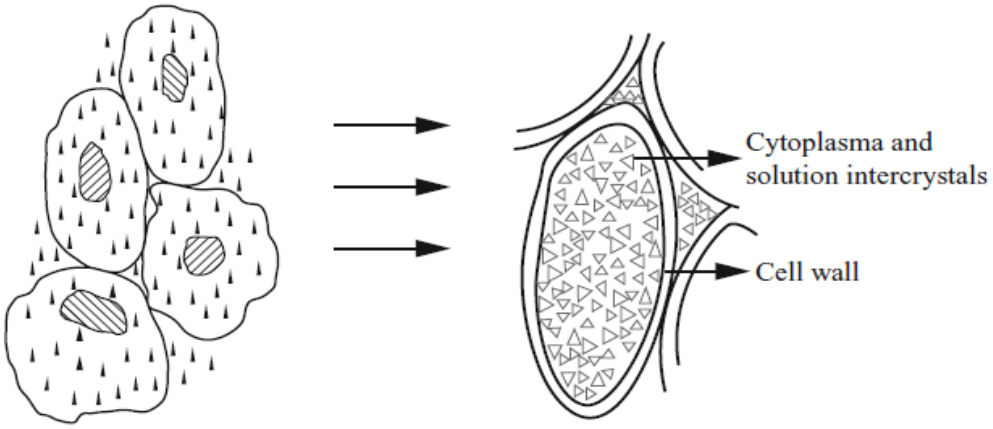

Figure 16- Development of water crystals during fast rate freezing in plant cells.
(De Ancos, et al., 2012).

Solutes and eutectic temperature

In order to understand the role of the solutes inside the food matrix it is important to define eutectic temperature. The food matrix has several solutes that present different solidification temperature points. Thus, the eutectic temperature can be defined as the average of freezing temperatures points of all solutes present (De Ancos, et al., 2012). For this reason, a final eutectic temperature for the product is common used and to obtain a product with a complete formation of ice crystals the eutectic temperature should be reached. In practice, food present in the market is frozen above that temperature which allows the presence of unfrozen water (De Ancos, et al., 2012).

Effect of freezing in food matrix

As it was mentioned before, freezing of vegetables and fruits can lead to plant cell disruption due to the formation of ice crystals. Water in ice state occupies 9% more of volume compared with pure liquid water, this fact lead to volume changes (expansion) in vegetables and fruits after freezing. Although, the volume changes in the plant tissues depends of several aspects as follows: **(i)** moisture content, **(ii)** plant cell configuration, **(iii)** solute concentration, **(iv)** freezing temperature and **(v)** formation of crystals (Fellows, 2000). Also, in the progress of storage, the food experience slightly changes at pigment (chlorophylls), flavor and nutrient level (Fellows, 2000).

In general terms, Figure 17 and Figure 18 represents changes concerned to chlorophylls, color and flavor along storage period at different freezing temperatures for food products (Fellows, 2000). As it can be seen, chlorophyll retention varies according to freezing temperature and period of storage. Chlorophyll degradation is observed along freezing time probably due to rupture of chloroplasts (site in the cell for chlorophyll manufacture and

storage) and consequent pheophytin formation (see explanation in section 2.1.1 of Blanching chapter). However chlorophyll is retained for long periods (greater than 3 months) if freezing is processed at low temperatures. As an example, after 80 days of frozen storage at -7°C chlorophyll retention was around 45% while for the same storage period, chlorophyll retention was around 65% and 80% for freezing at -12°C and -23°C, respectively (Fellows, 2000).

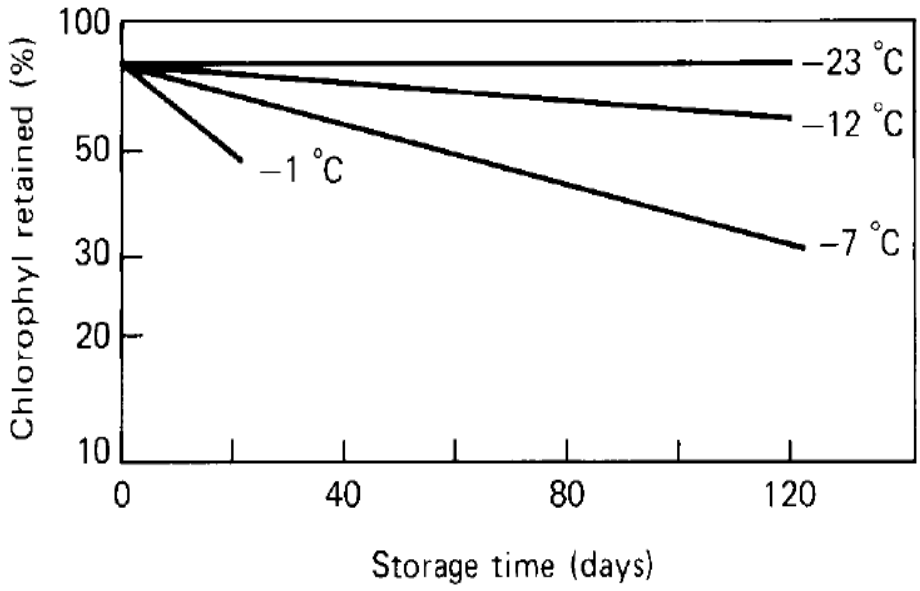

Figure 17- Chlorophyll retention (%) as function of frozen temperature and storage period of food **(Jul, 1984)** and **(Fellows, 2000)**.

Regarding to color and flavor attributes similar conclusions can be drawn. Lower freezing temperatures preserved color and flavor for longer periods of time, as can be seen in Figure 18. When freezing was applied at -9°C the first color changes in the product start to appear after 17 days of storage. On the other hand, for freezing at -12°C and -18°C color modifications were just detected after 1 month and 100 days, respectively. Changes at flavor level are detectable after longer periods when compared with color changes. The first detectable flavor change of food at -9°C was attained after 50 days of storage (the color start changing after 17 days for the same storage conditions). Although, when freezing is used at -12°C and -18°C flavor changes appeared after 100 and 300 days, respectively. From the present attributes, it can be conclude that color is more susceptible of degradation compared with flavor in the progress of frozen storage (Fellows, 2000).

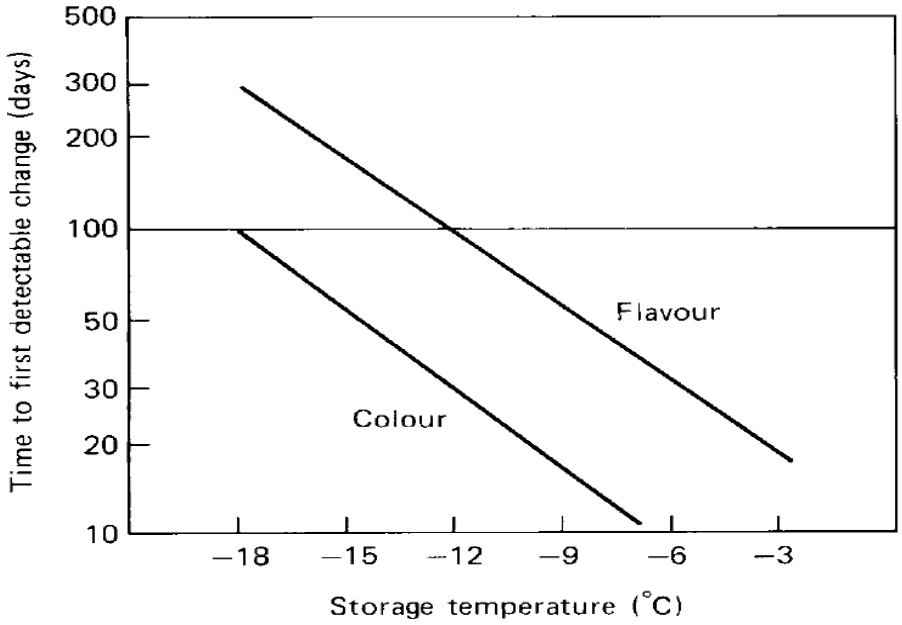

Figure 18- Color and flavor attributes of food as function of storage temperature **(Jul, 1984)** and **(Fellows, 2000)**.

As it was explained in chapter devoted to Blanching pre-treatment, enzymatic inactivation is fundamental for a properly frozen storage period. The presence of certain enzymes such as peroxidase, polyphenoloxidase, catalase and lipoxygenase may enhance modifications of color, flavor, vitamins, among others (De Ancos, et al., 2012). Blanching is widely used before freezing with the purpose of enzymatic inactivation that avoids loss of attributes and deterioration of food during frozen storage (Bahceci, et al., 2005). As an example, Lee, et al. (1988) used hot water blanching to inactivate 90% of peroxidase in beans. The blanching treatment showed a further improvement in the quality of beans during frozen storage.

Freezing equipment

The choice of a freezing method is conditioned by several aspects such as freezing rate recommended, form and size of the food package, product to be processed, batch or continuous process and the production scale (Fellows, 2000). The rate of freezing and the type of refrigerant fluid used also characterize the freezer. In general, there exist two types of freezers (Fellows, 2000):

- Refrigerators cabinets where a cold refrigerant circulates in cycle inside the cabinet. These refrigerators allow the product to freeze by air (air blast freezer), liquid or by surface contact.
- Cryogenic freezers where the product is cooled by a cryogenic fluid such as liquid nitrogen, solid or liquid carbon dioxide or also liquid Freon.

Among the two freezing types, the blast freezers and cryogenic freezers will be considered since these equipments are the most studied in the present chapter.

An air *blast freezer* consists in a quick freezing method where air with a temperature between -30°C and -40°C and velocity between 1.5 and 6 m/s is blown over the product. However, as a disadvantage of these equipments, a defrosting process can be required due to the ice accumulation in the coils of the blast freezer after condensation and freezing of the moisture from air. Furthermore, the low freezing rates allows the growth of large ice crystals inside the product which can comprise its quality (Fellows, 2000).

Cryogenic freezers are described to be a very fast freezing method that provides direct contact of liquefied gases such as nitrogen or carbon dioxide to the food (De Ancos, et al., 2012). The food is freeze rapidly due to low temperatures of the cryogenic refrigerant used which enhances a fast creation of ice crystals. For this reason, cryogenic technology is intended to avoid plant cells deformation, also quality attributes of food are ensured (De Ancos, et al., 2012; Fellows, 2000).

Attributes of freezing foods

In this section will be presented and discussed results found in literature sources of freezing pre-treatment regarding the quality of vegetables and fruits. The attributes will be described in three different subjects: (i) nutrition, (ii) color, (iii) rehydration kinetics and (iv) texture.

Nutrition (vitamins, ascorbic acid, nutrients, sugars)

In the work of Kowalska, et al. (2008), pumpkin was subjected to a freezing process at -18°C during 16 h with further osmotic dehydration during 3 h. The authors studied the water loss and sugars gain during osmotic dehydration in sucrose, glucose and starch syrup solutions. Pumpkin subjected to freezing treatment lost the less amount of water during osmotic dehydration for the three solutions used when compared with blanched and control samples. For example, after 3 h of osmotic dehydration in glucose solution, control samples lost 1.77 $g_{water}/g_{initial\ dry\ mat}$ while frozen samples lost around 40% of this value. On the other hand, samples subjected to water blanching presented a water lost of 1.83 $g_{water}/g_{initial\ dry\ mat.}$. The authors revealed that freezing destroyed the integrity of pumpkin cells when facilitating the osmotic substrate mass transfer compared with blanching. This explains the higher water losses observed for blanching. Regarding to solids gain during osmotic dehydration, frozen samples retained higher amounts of solids compared with blanched and control samples (Maté, et al., 1998). In Table 13 it can be seen all the conditions used and main results of this study.

Blast freezing of tomatoes at -40°C followed by frozen storage at -20°C and -30°C did not show significant reduction of vitamin C content when compared with raw samples

(Lisiewska, et al., 2000). Although, an extended storage period during 1 year for the same storage temperatures mentioned above, improved vitamin C loss of the initial value of 23.6 mg/100g. A frozen storage at -20°C during 1 year resulted in the reduction about 71% (6.8 mg/100g) of raw tomatoes (Lisiewska, et al., 2000). However, frozen storage at lower temperature of -30°C reduced around 45% (12.9 mg/100g) of the initial vitamin C content in raw tomatoes. In conclusion, frozen storage at lower temperatures results in greater vitamin C retention compared with storage at -20°C (Lisiewska, et al., 2000). The main results of the study conducted by Lisiewska, et al. (2000) can be seen in Table 13.

An increase of soluble solids in apples were attained when the fruits were submitted to: **i)** slow freezing at -20°C with a cooling rate of 1°C/min; **ii)** gas nitrogen at -80°C and 8°C/min; **iii)** liquid nitrogen at -196°C in the different fruits studied in any method (Chassagne-Berces, et al., 2010). Among the three methods, freezing applied with liquid nitrogen at -196°C minimize the soluble solids variation (Chassagne-Berces, et al., 2010). In this research, also mangoes were treated by the three different freezing methods but did not show differences regarding to soluble solids when compared with fresh samples as controls (Chassagne-Berces, et al., 2010). The work conducted by Olivera, et al. (2008) point an increase in ascorbic acid when microwave heating is applied to Brussels sprouts prior freezing in comparison with controls (see Table 13).

Color (browning effect, polyacetylenes, carotenes)

Chassagne-Berces, et al. (2010) applied three different freezing conditions to mangoes and apples of different varieties and maturities. The apples and mangoes samples were submitted to freezing methods in a chamber at -20°C, to gas nitrogen at -80°C and also to liquid nitrogen at -196°C. Color parameters were verified after freezing being applied. The study relates the browning effect, especially in apples, because no pre-treatment (e.g. blanching) was applied before freezing to inactivate enzymes (Chassagne-Berces, et al., 2010). In the case of mangoes ΔE=11 while for apples ΔE was around 30 for all the three freezing methods applied. However, *Golden Delicious* apples showed less total color variance in all the three freezing methods comparing to the others apple varieties used (Chassagne-Berces, et al., 2010). The freezing methods and procedures of the present study are explained on detailed in Table 13. In the research of Antal, et al. (2013) was conclude that slow freezing as pre-treatment (0.5°C/min) followed freeze drying of apples (varieties *Jonagold* and *Idared*) kept better the origin color compared to faster freezing pre-treatments. In Table 13 are explained the methods and main conclusions (Antal, et al., 2013). Rawson, et al. (2012) studied the effect of blanching followed by fast and slow freezing methods in the retention of polyacetylenes of carrots slices. After freezing being applied the authors concluded that blast freezing is the best method regarding the retention of polyacetylenes in comparison to slow freezing method. Also, color parameters were studied for slow and blast freezing rates with or without blanching being applied before

them (Rawson, et al., 2012). Thus, slow freezing rate gave a *ΔE*=9.1 while samples previously blanched lost less color *ΔE*=6.6. For blast freezing rate *ΔE*=6.3 but when blanching was applied prior freezing *ΔE*=4.3. Even if there is slightly differences in terms of color parameters it can be conclude that blast freezing kept better the color of carrots compared to slow freezing rates. In addition, in both cases, blanching helped color retention (Rawson, et al., 2012).

Chlorophyll retention of Brussels sprouts was studied by Olivera, et al. (2008) after three different blanching treatments being applied previous to freezing with liquid nitrogen at -35°C. All the prior blanching treatments enhanced chlorophyll losses of sprouts in comparison with unblanched freezing control. Regarding to flavonoid compounds of sprouts, no significant differences were found between the assays (Olivera, et al., 2008). The freezing methods conditions and main findings are presented in Table 13.

In Figure 19 are presented the most common carotenoid pigments of vegetables and fruits. As examples: oranges are rich in β-carotene, β-cryptoxanthin and zeaxanthin; lycopene can be found in tomato, watermelon and papaya; and α-carotene is present in banana and avocado (De Ancos, et al., 2012).

Light exposition, presence of catalysts and high temperatures are the main factors for a modification of *trans* configuration of carotenoids to *cis* which reduce the activity of such pigments (De Ancos, et al., 2012). On the other hand, high temperatures applied to fruits and vegetables before freezing (e.g. blanching) promote enzymatic inactivation that avoids carotenoid degradation.

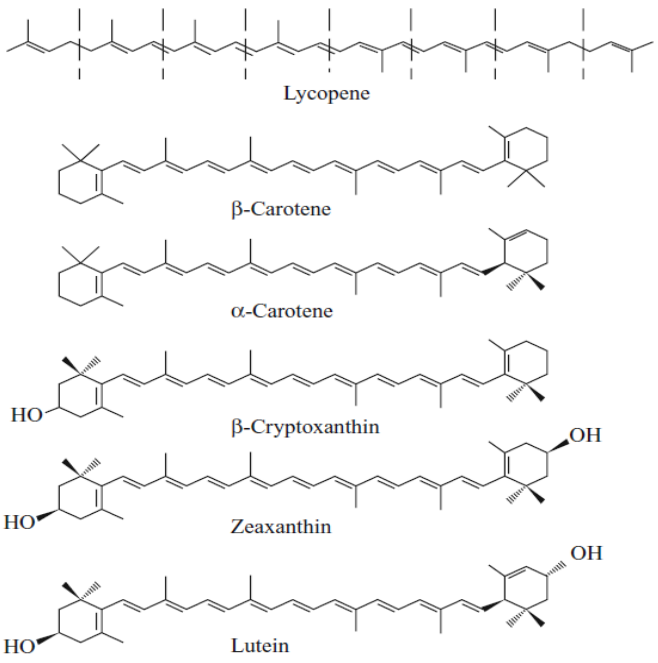

Figure 19- Chemical structure of carotenoids lycopene, β-carotene, α-carotene, β-cryptoxanthin, zeaxanthin and lutein **(De Ancos, et al., 2012)**.

Blast freezing at -40°C was applied to tomato cubes in the study of Lisiewska, et al. (2000). After this freezing stage β-carotene was slightly reduced compared to β-carotene in raw tomato (1.42 mg/100g to a reduction of 1.37mg/100g) (Lisiewska, et al., 2000). Furthermore, the tomatoes were stored during a period of 12 months at different temperatures of -20 and -30°C. After this period, samples that were stored at -20°C and-30°C had a β-carotene reduction about 51% and 32%, respectively for each frozen temperature (Lisiewska, et al., 2000).

Also, lycopene as a carotenoid compound was reduced after 12 months of frozen storage in comparison with fresh tomatoes. A storage at -20°C reduced about 48% of lycopene while a storage temperature of -30°C pointed a lower reduction of 26%. From these results, the authors conclude that frozen storage at lower temperatures preserved β-carotene and lycopene (Lisiewska, et al., 2000).

Rehydration kinetics

In the research conducted by Antal, et al. (2013) rehydration kinetics of two different varieties of apples was performed in distilled water at 25°C. Samples with a mass ratio of 0.008 $g_{prodruct}/g_{water}$ were used with weighing time intervals of 1, 5, 15, 30, 60 and 90 min. These experiments were conducted after samples being frozen at different freezing rates followed by freeze drying (see Table 13).

The authors pointed out that freeze drying samples presented rehydration ratios higher than 4 after 90 min of immersion in water but also those different freezing pre-treatments showed to improve even more the rehydration of sole freeze drying. The best pre-treatment to enhance rehydration kinetics of *Idared* apples it was a freezing process conducted at slow freezing rates (0.5°C/min). After 15 min of rehydration of *Idared* apples the ratio was already 4.50 which is higher than rehydration ratios of sole freeze dried product. Also, at slow freezing rates (0.5°C/min) the *Idared* apples presented a rehydration ratio of 5.23 after 90 min. For the same 90 min of rehydration, the contact plate (2°C/min) and freezing vacuum pre-treatments (3°C/min) gave lower ratios, 4.51 and 4.27, respectively (Antal, et al., 2013).

It is important to notice that the variety of apples *Idared* pre-treated with a freezing process at a freezing rate of 0.5°C/min gave always higher rehydration ratios compared to all the other samples of the same variety and also the *Jonagold* variety (Antal, et al., 2013). This fact shows that rehydration kinetics depends not only on the apple variety but also of the freezing rates applied. In addition to the main conclusions presented, it is important to mention two important factors that can compromise the rehydration behavior. The first factor is that for higher rehydration temperatures it was expected to have higher rehydration performances (the apples rehydration was conducted at 25°C). Another factor is the higher ability of a pre-treated product that underwent slow freezing rate to retain more

water during rehydration, compared to other pre-treatments at fast freezing rates. Slow freezing rate enhance the formation of higher ice crystals causing structural membrane deformation (De Ancos, et al., 2012). The fast freezing rates maintain the primary cell structure which seems not to improve rehydration of the freeze dried apples (Antal, et al., 2013).

As it will be mentioned ahead in the section 2.1.4 devoted to High pressure chapter the research of Estiaghi, et al. (1994) combined several pre-treatments applied to three crops, green beans, carrots and potatoes, before a dehydration stage in a fluidized bed drier (more detail of this study is mentioned in Table 13 and Table 14).

The application of such pre-treatments was carried out in several steps separately and in combination between them to all the three crops (green beans, carrots and potatoes). Drying of untreated crop samples was conducted in a fluidized bed drier and used as control samples. Freezing at -18°C was applied as a pre-treatment before drying and the samples were stored for 24 h and then dried. Blanching was added to freezing as an additional pre-treatment before drying (see blanching conditions for each crop in Table 13 and note that the blanching time is different for potatoes). In addition, high pressure at 600 MPa and 70°C during 15 min was also combined with posterior freezing and drying (Estiaghi, et al., 1994). For this research is important to highlight that the authors did not mentioned the freezing rate at which the crops were frozen but only made reference to a freezing temperature of 18°C (Estiaghi, et al., 1994). After all the samples being dried in the fluidized bed, rehydration was applied in boiling water with a sample mass ratio of 0.052 $g_{dry\ mat}/g_{\ water}$ during 20 min. The water that each sample could absorb was measured and presented in terms of water uptake in $mL_{H_2O}/g_{dry\ mat}$ (Estiaghi, et al., 1994).

After rehydration being applied to green beans the samples that were only dried (the controls) showed a water uptake of 3.4 $mL_{H_2O}/g_{dry\ mat}$ and when freezing is applied as a pre-treatment the water uptake increased around 32%. With a water uptake increase of the same order are the pre-treatments high pressure followed by freezing which showed a percentage about 38% when compared with only dried sample (Estiaghi, et al., 1994). Moreover, if blanching is applied prior freezing to green beans the water uptake was about 73% more compared to controls (Estiaghi, et al., 1994). From these results, it can be concluded that freezing helps the absorption of water by green beans, but blanching or high pressure coupled to freezing gave even better results with regard to water uptake (Estiaghi, et al., 1994). More details of this study can be seen in Table 13. In the case of carrots, all the pre-treatments mentioned increased the water uptake of samples. For the carrot samples used as control a value of 1.6 $mL_{H_2O}/g_{\ dry\ material}$ was attained after being dried in a fluidized bed drier (Estiaghi, et al., 1994). However, if freezing is applied before drying the water uptake doubles (around 3.2 $mL_{H_2O}/g_{\ dry\ material}$) which means an increase of 100% (Estiaghi, et al., 1994). When High pressure was applied before freezing the water uptake increased around 50% compared with the control carrot samples. In this case, high pressure applied in

combination with freezing helped the water incorporation in carrots but freezing as sole pre-treatment gave the best result. Moreover, water blanching used before freezing increased around 38% of water uptake compared with the controls (Estiaghi, et al., 1994).

For potato samples, after rehydration the controls showed a water uptake of 1.7 $mL_{H_2O}/g_{\text{ dry material}}$. However, when freezing is applied as sole pre-treatment the water uptake was reduced around 18% of the value attained with the controls (dried only). On the other hand, blanching applied before freezing enhanced the water uptake of potatoes and showed to be the best procedure among all the others applied and compared with control samples. The water uptake increases in this case was about 117% (3.7 $mL_{H_2O}/g_{\text{ dry material}}$) compared to control. When a high pressure treatment is applied to potatoes before freezing, the water uptake increased around 29% compared to solely dried sample. The detailed conditions and results of this study can be seen in Table 13.

From this research made by Estiaghi, et al. (1994) it could be seen that each crop studied had a different behavior in which concerns of water incorporation into the cellular structure, even if all the pre-treatments applied were done in the same way. According to the research of Estiaghi, et al. (1994), the green beans showed to be the crop with the best water uptake performance during rehydration. In the research conducted by Rhim, et al. (2011) a freezing treatment with different temperature decreasing rates were applied to rice porridge before dehydration by freeze drying. The authors concluded that slow freezing rates during the pre-treatment create bigger ice crystals which perform larger pores after dehydration by freezing. This fact shows that slow freezing rates are more indicated to enhance rehydration ratios after dehydration by freezing compared to faster freezing rates (Rhim, et al., 2011).

In the study of Kompany, et al. (1991) vegetables and fruits that were frozen before being submitted to a vacuum drying process presented higher rehydration capacities compared to air dried ones.

Texture/structure (Cell structure)

The degradation of texture attributes during freezing in liquid N_2 and after frozen storage at -18°C for 8 months applied in Brussels sprouts was studied by Olivera et al. (2008). The authors stated that treatments such as blanching, freezing and frozen storage conditions have a strong impact in texture of several crops. As it is show in Table 13, three different pre-treatments were applied before frozen storage (Olivera, et al., 2008). Texture assessments were performed after all these three treatments being applied to Brussels sprouts. The fresh sample presented a firmness value of 50.3 N (used as reference). Thus, for the first treatment, Brussels sprouts were immersed in water at 50°C for 5 min and after blanched at 100°C during 3 min. From this first treatment, a firmness lost of 83.5% was attained compared to untreated samples (Olivera, et al., 2008). For the second treatment, Brussels sprouts were microwave blanched (700W for 5 min) and also blanched in boiling

water during 2 min. This second treatment showed a firmness reduction of 81.3% of the value of fresh (50.3 N). The third treatment was performed in boiling water for 4 min and showed a reduction of firmness of 86% compared to untreated Brussels sprouts (Olivera, et al., 2008). As it can be seen, firmness is drastically reduced after blanching and microwave treatments being applied. Also, it can be conclude that the three different treatments gave similar firmness reduction of Brussels sprouts (Olivera, et al., 2008).

Succeeding all these blanching treatments, freezing was applied to all Brussels sprouts samples and texture measurements were conducted after a period of storage of 8 months (Olivera, et al., 2008). The firmness reduction of control sample was drastically reduced around 90%, for all the other blanched samples an additional firmness reduction was attained. The authors conclude that blanching prior freezing and further frozen storage reduced significantly texture attributes of Brussels sprouts (Olivera, et al., 2008). Texture measurements were performed in the study of Rawson, et al. (2012) when water blanching and two different freezing processes were applied to carrot discs (slow and blast freezing). In fresh carrots an initial total force of 72.6 kN was registered in the firmness measurement. However, after slow freezing being applied at -20˚C the force required dropped to 39.58 kN. In addition, water blanching was introduced before slow freezing and the force required to perforate these carrot discs was even lower (30.71 kN). In this case, the effect of water blanching promoted lower strength to carrots discs that underwent slow freezing rates (Rawson, et al., 2012). Contradictory results were attained with regard to fast freezing rates (-30˚C) that gave similar results in puncture tests. Thus, both samples blanched and unblanched reached a force around 34 kN during firmness measurements which means that blanching did not gave less hardness to the carrot discs as it happened in the case of slow freezing (Rawson, et al., 2012).

The research of Neri, et al. (2014) was based on the determination of intracellular modifications in carrots after four different blanching conditions being applied (75°C at 3 and 10 min and 90°C at 3 and 10 min) followed by blast freezing at -80°C and storage at -18°C. The tissue of the fresh carrots appeared to be organized as mixture of cells with polyhedral shape (Neri, et al., 2014). After one month of frozen storage of blanched carrots, cell cracking and collapsed areas were identified due to ice crystals formation. The same results were detected when frozen storage was extended for 3 and 8 months.

Pectin is a wall cell structural biopolymer present in vegetables and fruits. A significant reduction of the initial pectin content (0.216 g/100 g) on tomatoes *Micra RS* was determined after blast freezing being applied at -40 C° with consequent storage period at -20°C and -30°C (Lisiewska, et al., 2000). After freezing, pectin was reduced around 32% regarding with the raw sample controls. When the storage period was extended during 1 year the pectin content was drastically reduced in comparison to controls. However, pectin reduction was more pronounced at a storage temperature of -20°C, which presented a decrease of 83%,

while a frozen storage at -30°C reduced 72% of pectin compounds compared with controls (see Table 13).

Two different varieties of apples were submitted to compressive tests after three different freezing pre-treatments followed by freeze drying used as dehydration technology (Antal, et al., 2013). For the *Jonagold* apples variety when a household freezer and a contact plate freezer were used in the pre-treatments gave the higher loss of firmness (N), 30.95% and 32.00%, compared with the raw samples. The vacuum freezing pre-treatment gave the best result, pointing to a loss of 25.47% of firmness compared with the controls (untreated apples of the same variety). Another apple variety *Idared* was also used in the experiments and when the pre-treatment was performed in a household freezer gave a firmness loss of 41.58%, while when the contact plate and the vacuum freezer were used the apple samples presented a higher resistance, showing a firmness loss (N) of 26.30% and 22.61%, respectively (Antal, et al., 2013). Therefore, it can be concluded that for both apple varieties the vacuum freezing applied as a pre-treatment gave more resistance to the freeze dried samples. On the other hand, from the results obtained, it can be concluded that the apple variety and the speed at which freezing is applied during the pre-treatment have a strong influence in the hardness test results (Antal, et al., 2013). In Table 13 can be seen in more detailed the methodology used in the study of Antal, et al. (2013).

Conclusions

During the explanation of the freezing chapter it could be seen that there are a lot of variables compromising the effect of freezing in food attributes such as: freezing rate, variety of food, cellular structure, ice crystals formation, among others. This complex dependency does not make possible an overall conclusion of the chapter since each case is unique and must be studied separately for each substance handled. Thus a briefly conclusion is presented using the attributes studied in the open literature.

In which regards nutrition attribute, the study of Kowalska, et al. (2008) referred that freezing at -18°C during 16 h applied to pumpkin before osmotic dehydration retained more solids compared with blanched and control samples. Freezing with liquid nitrogen (-196°C) applied to apples resulted in a higher soluble solids retention compared to other methods as slow freezing and gas nitrogen (Chassagne-Berces, et al., 2010). On the other hand, in the same research, mangoes had exactly the same freezing treatments but no changes of soluble solids occurred (Chassagne-Berces, et al., 2010). Vitamin C present in tomatoes that were submitted to a blast freeze process at -40°C was retained for longer periods of time during low storage temperatures in the order of -30°C (Lisiewska, et al., 2000).

For color attribute, the research of Antal, et al. (2013) contributed with the observation that slow freezing rates enhanced color retention of two apples varieties compared to freezing at

faster rates. In contradiction to this result, the study of Rawson, et al. (2012) referred that blast freezing showed to retain better the color of carrots compared to slow freezing.

In addition, three different freezing methods applied to apples and mangoes promoted color changes, but between samples obtained from these three freezing methods there was no significant color differences (Chassagne-Berces, et al., 2010).

In the research of Rawson, et al. (2012) blast freezing applied to carrots resulted in better retention of polyacetylenes when compared to slow freezing even if the content of polyacetylenes was reduced during storage. Lower storage temperatures of tomatoes (-30°C during 1 year) promoted higher retention of β-carotene and lycopene according to (Lisiewska, et al., 2000).

In which concerns the texture attribute, the research of Olivera, et al. (2008) pointed that the freezing treatment with liquid N_2 created a drastic reduction of Brussels sprouts firmness. However, there was no significant difference in firmness reduction during storage periods of 2, 4, 6 and 8 months compared with control sample (Olivera, et al., 2008). In the research of Rawson, et al. (2012) carrots that were frozen at slow freezing rates offered more resistance when a certain force was applied compared to carrots that were blast frozen. This fact must be due to the formation of bigger ice crystals during slow freezing which offered more resistance to the force applied (Rawson, et al., 2012). In addition, blanching was applied before freezing at these two different freezing rates. For blanching applied before slow freezing rates the force required to perforate the tissue was lower. However, there was no difference between blast frozen samples that were blanched or unblanched (Rawson, et al., 2012). Also, after 1, 3 and 8 months of frozen storage of blanched blast frozen carrots, cellular disruption was detected due to ice formation (Neri, et al., 2014). In the study of Antal, et al. (2013) vacuum freezing was applied as a pre-treatment to different varieties of apples (*Jonagold* and *Idared*) that were subsequently freeze dried gave rise to a cell structure more strong.

Pectin of tomatoes was reduced in 32% when blast freezing was applied at -40°C (Lisiewska, et al., 2000). Again in this case, lower storage temperatures of tomatoes gave better retention of pectin compounds (Lisiewska, et al., 2000).

Concerning rehydration kinetics, slow freezing rates of 0.5°C/min applied to *Idared* apples gave always higher rehydration ratios compared to all the other freezing pre-treatments and compared also with *Jonagold* apple variety (Antal, et al., 2013). It is important to refer that the freezing pre-treatment carried out at different freezing rates applied to apples was followed by a freeze drying process. However, it can be concluded that apples rehydration kinetics depends on the crop variety but also on pre-freezing rates applied (Antal, et al., 2013). Similar results were attained by Rhim, et al. (2011) in the study of rehydration of rice porridge. The author stated that rehydration ratios of rice porridge were improved after the application of a treatment with slow freezing rates followed by freeze drying.

From the research conducted by Estiaghi et al. (1994) it is important to highlight that freezing enhanced the water uptake of green beans and carrots compared to control samples, and for carrots this increase resulted in doubling the water uptake with respect to controls. However for potatoes, when freezing was used as a pre-treatment reduced the water uptake of samples. The results obtained by the research of Estiaghi, et al. (1994) showed that the water absorption into the cellular tissue of each substance is dependent on its nature (the crop), since all the pre-treatments and final drying stage were applied with the same conditions.

2.1.4. High pressure

General considerations

High pressure is a technology suitable used for a wide range of food products. In industry this method is applied to several products such as fruits, vegetables, juices, seafood, fish and meat products (Norton, et al., 2008). High pressure processes are usually carried out in a pressure range of 100-1000 MPa, during different periods of time. In some cases, temperature conditions can be also modified in the process in a range of -20 to 60 °C (Oey, et al., 2008). Sometimes a liquid medium is required, in the study Pradas, et al. (2012) the liquid medium used was water while for Alvarez-Jubete, et al. (2013) the ethanol-castor oil was the fluid selected.

It is important to highlight that food processing by high pressure is dependent not only of the pressure applied but also the thermal effects associated should be considered (Rastogi, et al., 2007). Rastogi, et al. (2007) explained that the temperature variations due to physical compression/decompression during high pressure treatments is crucial regarding to foodstuff gelling, protein stability and movement of fatty substances from cellular structures. In Figure 20 is represented the pressure and temperature evolution in a non-insulated high pressure vessel (Rastogi, et al., 2007). As a consequence of initial compression from $\mathbf{P_s}$ to $\mathbf{P_1}$ the temperature will also increased. The temperature increase ($\mathbf{T_s}$-$\mathbf{T_1}$) depends on the initial temperature of the product ($\mathbf{T_s}$), the extent of compressibility of the product, but also it specific heat and the pressure ($\mathbf{P_1}$) to be reached during pressurization (Rastogi, et al., 2007). After this period ($\mathbf{t_s}$ to $\mathbf{t_1}$) the product temperature reduced from $\mathbf{T_1}$ to $\mathbf{T_2}$ during the pressure holding time (marked from $\mathbf{t_1}$ to $\mathbf{t_2}$) regarding to heating losses from the high pressure vessel (Rastogi, et al., 2007). Then, the vessel is depressurized and the initial product temperature (or a slightly lower temperature) is established again.

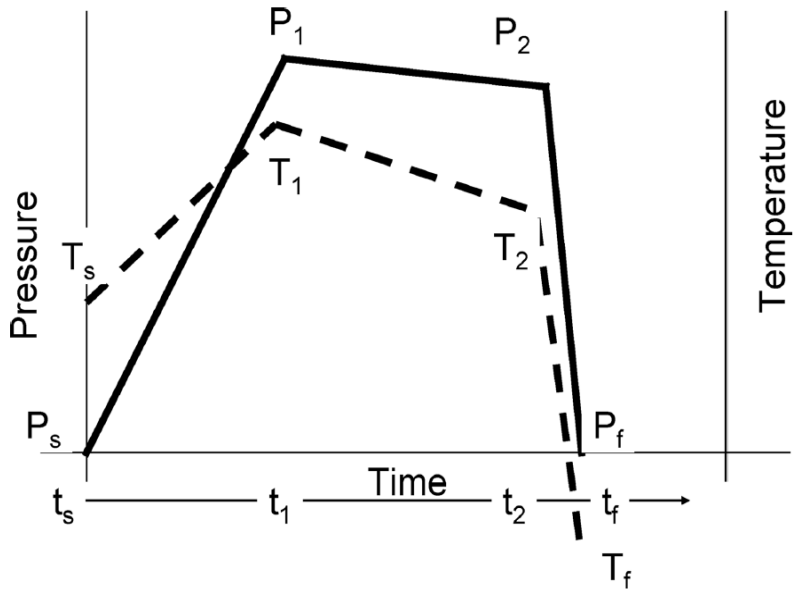

Figure 20 – Pressure and Temperature variation for high pressure treatments **(Rastogi, et al., 2007).**

Among all advantages of high pressure treatments stand out microorganisms elimination, inactivation of enzymes, denaturation of proteins and improvement of shelf life products (Sulaiman, et al., 2013; Pradas, et al., 2012). Some other attributes are present in Table 14 and will be described and discussed in the following sections when high pressure treatments are applied to fruit or vegetables used.

Attributes of high pressure foods

Along the present section will be discussed information found in the literature regarding to the impact of high pressure treatment in some food attributes. The following attributes will be described in different topics: (i) nutrition, (ii) color, (iii) rehydration kinetics, (iv) drying and (v) texture.

Among other attributes, sensory quality tests were performed after high pressure to understand the effect of this treatment in product acceptance by consumers. The study conducted by Pradas, et al. (2012) showed that a high pressure treatment at 400 MPa during 5 min resulted in higher retention of sensory attributes during long periods of storage, improving olives shelf-life (see Table 14). However, untreated samples and the other samples submitted to high pressure treatments (see Table 14 for the treatment conditions) resulted in lower scores of acceptance by trained panelists (Pradas, et al., 2012). The *overall sensory* range scale for olives is from 0 to 7 as it is depicted: **(i)** 7 - 5 perfect or optimal to typical with slight deviations; **(ii)** 4.9 - 3 noticeable deviations to detractions and slight defects; **(iii)** 2.9 - 0 distinct to strong defects (Pradas, et al., 2012). The control olives showed a lower overall quality of 2.1 while a high pressure treatment at 400 MPa for 5 min improved its overall sensory quality to 5.7 after 280 days.

Regarding to odors, the scale is from 0 (disagreeable/unacceptable) to 5 (agreeable). The control samples showed an unacceptable odor while the treatment performed at 400 MPa for 5 min to olives resulted in a 4.5 score (Pradas, et al., 2012). All the other samples submitted to treatments conducted at higher pressures or at the same pressure during more time showed lower scores for this attribute (see Table 14).

Concerning to flavor aspect, the mentioned treatment (400 MPa, during 5 min) showed an *off-flavor* of alpechin while the controls showed *off-flavors* of soapy, zapateria, pit, alpechin, cheese, putrefaction and spicy.

Nutrition (ascorbic acid)

The ascorbic acid content of white cabbage was extremely reduced when pressures of 200-400 MPa were used in the treatment (Alvarez-Jubete, et al., 2013). However, in blanching and high pressure treatment at 600 MPa the ascorbic acid retention is the same. The loss of ascorbic acid for the mentioned treatments compared to control samples was

around 24% while for lower pressures processes (between 200 and 400 MPa) the losses ranged between 80 to 90.6% (Alvarez-Jubete, et al., 2013). The authors explained that higher pressures may induce peroxidase enzyme inactivation which prevents the oxidation of ascorbic acid (Alvarez-Jubete, et al., 2013). The main methods conditions and results are detailed in Table 14.

Color

High pressure treatments applied to white cabbage at pressures of 200 MPa and 600 MPa during 5 min with a temperature range of 20-40°C showed less color variations compared to high pressure at 400 MPa for the same time and temperatures range (Alvarez-Jubete, et al., 2013). High pressure treatment performed to white cabbage at 400 MPa resulted in the higher total color difference ($\Delta E \approx 13$) among all the treatments mentioned above. In addition, water blanching was applied as sole method with a water temperature range between 90 to 95°C during 3 min but almost no differences of ΔE in comparison to all treatments and controls were revealed (Alvarez-Jubete, et al., 2013). Thus, among all the pressure treatments, pressures of 200 and 600 MPa retained more color attributes of white cabbage (Alvarez-Jubete, et al., 2013).

Color parameters of olives were not affected after four different high pressure treatments, the product maintained a regular color compared to controls (Pradas, et al., 2012). The treatment conditions and main findings can be seen in Table 14.

Rehydration kinetics

The research of Estiaghi, et al. (1994) combined several pre-treatments applied to three crops (green beans, carrots and potatoes) before a dehydration stage in a fluidized bed drier. Three sequential steps were applied to the samples in order to evaluate the pre-treatments effect: **i)** drying (control), **ii)** high pressure/drying, **iii)** high pressure/freezing/drying (Estiaghi, et al., 1994). After all these pre-treatments being applied to the three crops the samples were dried in a fluidized bed. Afterwards, rehydration was performed in boiling water with a ratio of 0.052 $g_{\text{dry mat}}/g_{\text{water}}$ during 20 min (Estiaghi, et al., 1994). For green beans and carrots high pressure applied as single pre-treatment did not enhance water uptake of samples. In the case of potatoes, solely bed dried samples showed a water uptake of 1.7 $mL_{H_2O}/g_{\text{dry mat}}$ (control). However, when high pressure is applied before drying of potatoes the water uptake increased to a value that is around 23% than the control value. With regard to high pressure treatments applied prior freezing, it is relevant to notice that freezing helped the incorporation of water for all the three crops, even if for potatoes this increase is not significant (Estiaghi, et al., 1994). The controls samples (only dried) for green beans and carrots showed a water uptake of 3.4 $mL_{H_2O}/g_{\text{dry material}}$ and 1.6 $mL_{H_2O}/g_{\text{dry material}}$, respectively. Thus, high pressure followed freezing increased these water uptake values around 38% for green beans while for carrots the increase was around 50% (Estiaghi, et al.,

1994). In the potatoes case, this enhancement was less pronounced compared to the other crops, the water uptake was improved around 30% compared to controls (Estiaghi, et al., 1994).

As it can be seen, green beans and carrots did not showed an increase in water uptake when high pressure as only pre-treatment was introduced, however potatoes had 23% of water uptake increasing compared to controls. On the other hand, green beans and carrots showed better results regard to water incorporation when high pressure was coupled to freezing, while for potatoes the same happened but in less extent. The attribute Table 14 for the high pressure must be consulted with freezing pre-treatment (Table 13) in order to correlate both studies.

Drying kinetics

In general, high pressure processes applied with pressures higher than 100 MPa to carrots and apples of two different varieties reduced the time of further drying step (Yucel, et al., 2010). The authors pointed a cell permeabilization as a main cause for reduction in drying times. In the case of green beans the drying time was just reduced when pressure treatments at 35°C were applied and when samples were subsequently dried with open air. However, for other high pressure treatments and drying conditions green beans showed higher drying times compared to raw samples control (Yucel, et al., 2010). In Table 14 can be seen in more detailed the study of Yucel, et al. (2010) with all the pressures, temperatures and times values at which the products were exposed.

The drying rate of three different crops in a fluidized bed drier was studied after different pre-treatments being applied (Estiaghi, et al., 1994). The main results of this study can be seen in Table 14 and showed that for green beans high pressure treatments did not enhance drying rates compared to beans that undergo other treatments. However, if freezing is applied before high pressure the beans dried faster compared with sole high pressure treatment. On the other hand, the application of two consecutive treatments before drying, such as blanching and freezing at -18°C, showed to be the best treatment for the improvement of drying rates for this crop (Estiaghi, et al., 1994).
In addition, raw and frozen potatoes attained the higher drying rates compared to the rest of the treatments (Estiaghi, et al., 1994).
The same treatments were applied to carrots but no conclusions can be drawn regarding to drying rates since all treatments showed similar behavior (Estiaghi, et al., 1994). From this study conducted by Estiaghi, et al. (1994) can be concluded that each crop has a different behavior during drying even if the treatments were performed in similar way (Table 14).

Texture/structure (Cell structure)

The study conducted by Pradas, et al. (2012) related three different processes of high pressure performed to olives (Table 14). Previously to experiments set, the olives were maintained during 5 days in water to change their texture and acerbity and after were immersed in a preservation liquid according a traditional recipe. The high pressure method conditions are depicted in Table 14. After 6 months of storage no significant differences were observed in olive firmness (N) independent of the treatment used. However, in the progress of storage and after 1 year the controls and the samples treated at 600 MPa for 5 min experienced higher loss of firmness (40.7% and 39.8% respectively). In contrast, samples treated at 400 MPa for 5 and 10 min showed lower firmness loss about 25.9% and 24.9% (Pradas, et al., 2012). A treatment at higher pressure of 600 MPa during 10 min also resulted in 27.9% of firmness loss. In conclusion, the treatment at 400 MPa for 10 min permits a higher retention of tissue firmness (Pradas, et al., 2012). The authors referred that pectin elimination or retention can be attributed to higher or lower tissue firmness, respectively (Pradas, et al., 2012).

Alvarez-Jubete, et al. (2013) used high pressure treatments to study texture loss in cabbage samples. The control raw samples and blanched cabbage samples showed the same firmness of 120 N/g. The blanching conditions applied did not conduct to texture deterioration of cabbage since these samples maintained the same firmness as controls (see blanching conditions in Table 14). However, treatments at 200 MPa and 20°C resulted in a higher firmness of 148 N/g, followed by the pressure treatment at higher temperature (40°C) with 139 N/g. Alvarez-Jubete, et al. (2013) also showed that the blanching applied did not conduct to texture deterioration of cabbage since these samples maintained the same firmness as controls (see blanching conditions in Table 14). However, the authors explained that the resistance offered by these cabbage samples is dependent of the cultivar, since swede cabbage lost texture attribute when the same blanching conditions were applied (Clariana, et al., 2011).

Conclusions

After the entire high pressure pre-treatment description, some conclusions and remarks can be summarized according with the attributes presented along the section.

In terms of nutrition attributes, high pressure treatments applied to white cabbage reduced drastically ascorbic acid content (Alvarez-Jubete, et al., 2013).

In which concerns color changes, olives color was not modified after several high pressure pre-treatments (Pradas, et al., 2012). The olives kept always its original color compared to controls. In the research of Alvarez-Jubete, et al. (2013) several high pressure pre-treatments were applied to cabbage samples and when the treatment was performed at 200 and 600 MPa the less color variation (ΔE) was observed. High pressure applied as single pre-

treatment did not enhance water uptake of green beans and carrots but helped in 23% the water uptake of potatoes (Estiaghi, et al., 1994). However, during rehydration, green beans and carrots incorporate better the water when high pressure was coupled to freezing, while for potatoes the same happened but not as much compared to the other two crops. Thus, it can be concluded that potato is a crop that presents a better performance during rehydration when high pressure is applied alone than when high pressure is applied before freezing (Estiaghi, et al., 1994). However, the others two crops incorporate more water when high pressure was applied before freezing, and in this case, carrots showed the best performance with 50% of water uptake compared to sole dried sample (Estiaghi, et al., 1994).

For the same high pressure conditions and with regard to further drying periods, in the case of carrots and apples the drying time was shortened but that did not happened in the case of green beans (Yucel, et al., 2010). In this case, the crop variety conditioned more the drying time than the pre-treatment applied (Yucel, et al., 2010). From the research of Estiaghi, et al. (1994) the same conclusions can be drawn since some pre-treatments reduced further drying stages, however each crop used by the authors (green beans, carrots and potatoes) showed different behaviors during drying.

Regarding to texture attribute, olives that underwent to high pressure treatments showed firmness reduction just after 1 year of storage (Pradas, et al., 2012). High pressure treatments applied to white cabbage samples showed to improve firmness, according the research of (Alvarez-Jubete, et al., 2013).

2.1.5. Osmotic dehydration

General considerations

Osmotic dehydration (OD) is widely used and consists in the water removal from food (vegetables, fruits) immersed in aqueous solution of one or more solutes.

In accordance with Rahman (2007), osmotic dehydration results from a mass transfer mechanism where "*The driving force for water removal is the concentration gradient between the solution and the intracellular fluid*". In Figure 21 is schematically represented food and its components immersed in a concentrated solution illustrating solutes, water and food components transfer that occur during osmotic dehydration. By osmotic pressure, the semi permeable cellular membrane lost water, and gain soluble solids contained in the osmotic solution (the concentrated solution).

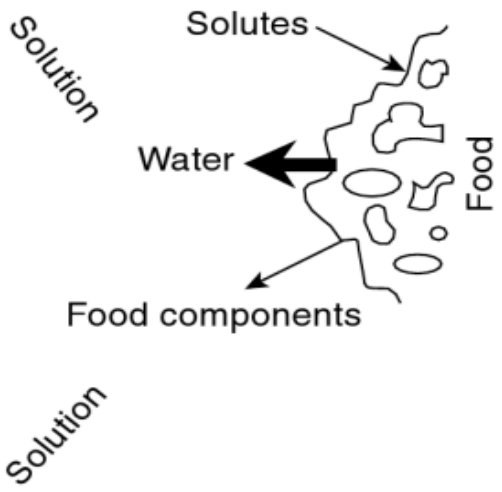

Figure 21- Transport of solutes and water during osmotic process **(Rahman, 2007)**.

According to Rahman (2007), parameters such as the type of osmotic agent, solution concentration, osmotic solution temperature, material geometry and food mass ratio to osmotic solution, are some of the main factors to take in consideration during osmotic dehydration. Several osmotic solutes could be added to the water as solely agents or also in combination with other solutes. The most used solute for vegetables is NaCl while for fruits is sucrose. However, a wide range of osmotic agents are used in the open literature, such as: glucose, fructose, lactose, maltose, dextrose, corn starch syrup, maltodextrin, whey, sorbitol, ascorbic acid, calcium chloride, citric acid, among others (Rahman, 2007).

However, vegetables and fruits obtained from osmotic dehydration still have levels of moisture content that not allow the food to be shelf-life stable. Thus, other processes such as air drying, microwave assisted air drying, freeze or vacuum drying need to be used to

overcome this issue (Rahman, 2007; Garcia, et al., 2007; Debnath, et al., 2004; Rastogi, et al., 2004; Prothon, et al., 2001).

Attributes of osmotic dehydration foods

Along the present section will be presented and discussed information found in the literature regarding to the impact of osmotic dehydration in some food attributes. The following attributes will be described in different items: (i) nutrition, (ii) rehydration kinetics, (iii) drying, (iv) texture and (v) volume.

Nutrition (sugars)

Kowalska, et al. (2001) studied the effect of sugar solutions used as osmotic solutions in apple, pumpkin and carrot. The osmotic dehydration behavior of such crops was different among them and the water loss was 5-10 times greater compared to the absorption of sugar into the cells (Kowalska, et al., 2001). However, apple incorporates more sugar compared to pumpkin and carrot. A more detailed description of the research made by Kowalska, et al. (2001) can be seen in Table 15.

Rehydration kinetics

The research performed by Rastogi, et al. (2004) was focused on rehydration behavior of carrot discs after osmotic dehydration followed by a conventional air drying step applied at 60°C. Osmotic solutions of commercial sugar were used in different concentrations, 0 (water immersion), 5, 10, 20, 40, 60°Brix while the control sample was simply dried. After drying, rehydration experiments were performed during 5h in water at around 25°C with a sample mass ratio of 0.04 g_{carrot}/g_{water}. The results showed that carrot samples which were osmotically dehydrated in sugar solutions of lower concentration, from 0 to 10°Brix, had more ability to absorb water during rehydration and kept more solids compared to samples pre-treated with 20, 40 and 60°Brix sugar solutions (Rastogi, et al., 2004). In Table 15 is depicted in more detailed the methods used and the main conclusions.

Osmotic dehydration with a 50% sucrose solution and a 10% sodium chloride solution were performed with onion slices during 3 and 1h, respectively (Debnath, et al., 2004). Afterwards, the samples were air dried at 60°C during 12h, with a tray load of 0.33 kg/m^2. Assessments, as rehydration kinetics was evaluated for onion slices immersed in water at 25°C during 2h with a ratio product to water of 0.04 g_{onion}/g_{water}. During rehydration, metallic nets were used to hold the onion samples (Debnath, et al., 2004). The results showed that onion samples used as controls (no osmotically pre-treated) had more ability to absorb water during rehydration compared with the ones pre-treated with osmotic solutions of sodium chloride and sucrose (Debnath, et al., 2004). The authors explained that the lower

ability to absorb water of osmotically dehydrated onion may be due to shrinkage and collapse of onion cells (Debnath, et al., 2004).

Apple cubes (Italian *Golden Delicious*) were osmotically dehydrated in a sucrose solution of 50% (w/w) at 22°C during 16 h (Prothon, et al., 2001). Afterwards, the cubes were dried in a microwave oven assisted by air drying (MW-AD) at three different temperatures of 50, 60 and 70°C with a fixed air velocity of 2 m/s for 5 h (Prothon, et al., 2001). After the osmotic dehydration pre-treatment followed by the drying process, rehydration as an assessment was evaluated for apple cubes immersed in distilled water at 20°C during 14 h. The results from this research showed that samples not osmotically pre-treated (the controls, which were only dried) had higher rehydration capacities in comparison with osmosed ones (Prothon, et al., 2001). The apple cubes rehydration capacity was calculated as a rehydration ratio between the mass of rehydrated sample and the mass of samples prior rehydration. Thus, the control apple cubes showed a rehydration ratio approximately of 5.5 while a value around 4 was obtained for the ones osmotic dehydrated (Prothon, et al., 2001). The authors tried to clarify that apple samples that underwent a pre-treatment with the osmotic sucrose solution were less porous due to sugar impregnation, and, as a consequence, impaired the entrance of water through the cell walls (Prothon, et al., 2001). The main results of the research made by (Prothon, et al., 2001) are depicted in Table 15.

Drying kinetics

In the study conducted by Garcia, et al. (2007) mature pumpkins were subjected to a osmotic dehydration pre-treatment in commercial sugar solutions of 60% (w/w) with further air drying stages at 50 and 70°C (see Table 15). The authors observed that in the osmotically treated samples the water diffusion outwards the solid during the drying process was facilitatedcompared with pumpkin samples that were just air dried (Garcia, et al., 2007).

Prothon, et al. (2001) also showed that apple cubes osmotically dehydrated reduced the time of drying in a microwave oven assisted by air drying (MW-AD) compared with only dried apples (controls).

Texture/structure (Cell structure)

Onion slices were osmotically dehydrated using two different treatments (Debnath, et al., 2004). In one of the methods, the authors used a 50% sucrose solution to immerse the samples during 3 h and in the other, the samples were immersed for 1 h in a 10% NaCl solution. After osmotic dehydration the samples were air dried at 60°C, during 12 h (see Table 15) and submitted to hardness tests. The same tests were conducted with controls (samples directly dried). Thus, the control samples showed a resistance of 16.20 N while the hardness of samples osmotically treated with sucrose and NaCl solutions showed a hardness

increasing of 57% (25.44 N) and 11% (18.00 N), respectively. These values are in accordance with the solutions concentration and the osmotic dehydration time of the treatment which can be seen in more detailed in Table 15. Overall, it can be concluded that the incorporation of solutes in onion samples during both osmotic dehydration treatments gave toughness and firmness to the cell tissues (Debnath, et al., 2004).

Apple cubes underwent an osmotic pre-treatment in a sucrose solution of 50% (w/w) at 22°C during a period of 16 h, followed by a dehydration stage (Prothon, et al., 2001). The dehydration stage of the apple samples was conducted during 5 h in a microwave oven assisted by air drying (MW-AD) at temperatures of 50, 60 and 70°C, and with an air velocity of 2 m/s (Prothon, et al., 2001). Thereafter, rehydration assessment was evaluated soaking the apple cubes in distilled water (20°C for 14 h). Puncture texture measurements were done after samples being rehydrated and compared with the results obtained for fresh apple cubes. The cubes were cut in halves and the perforation was done in each halve. The results showed that apple samples osmotically dehydrated and dried at temperatures of 60 and 70°C were more pliable compared to samples dried at 50°C (Prothon, et al., 2001). The authors explained that the strengthen loss of the apples cells may be related with calcium ions and pectin methyl esterease enzyme (PME) content. They explained that apple cubes during osmotic dehydration may have lost Ca^{+} ions by a leaching process. Moreover, the PME enzyme promotes the hydrolysis of pectin into pectic acid. The pectic acid can form bridges between Ca^{+} ions which in turn lead to stronger cell tissues. However, when drying is applied at 60 and 70°C the enzyme PME lose its activity (denaturation), and as a consequence, the carboxyl groups were not formed (Prothon, et al., 2001). Once that osmotically dehydrated samples had less Ca^{+} ions added because no bridges between Ca^{+} and carboxyl groups of pectic acids were formed (see Table 15), the cellular structure of apples lost strengthen (Prothon, et al., 2001).

Volume/ Shrinkage

The behavior of pumpkin (*Curcubita moschata*) subjected to osmotic dehydration in sucrose solutions and further conventional air drying was studied by Garcia, et al. (2007). Osmotically dehydrated and subsquently air dried pumpkin samples when compared with controls (solely air dried) did not showed significant changes in terms of final density. Both samples showed a similar density increasing. However, osmotically dehydrated pumpkin samples showed a sligthly prevention of volume shrinkage (Garcia, et al., 2007). In Table 15 can be seen in more detailed the study of Garcia, et al. (2007).

Conclusions

In which concerns the nutrition attribute, Kowalska, et al. (2001) referred that the extent of sugar incorporation depends on the crop used**.**

Concerning rehydration attribute, osmotically pre-treated carrot discs with sugar solutions at low concentration (until 10°Brix) had more ability to incorporate water during rehydration (Rastogi, et al., 2004). In addition, according to Debnath, et al. (2004), onion samples not osmotically treated had more ability to incorporate water during rehydration when compared to samples treated with NaCl and sucrose osmotic solutions. This fact means that osmose had a negative impact during further rehydration assessments of onion (Debnath, et al., 2004). The authors related cellular collapse of onion when subjected to osmotic pre-treatments which will have a direct and negative impact in water incorporation during rehydration kinetics (Debnath, et al., 2004).

The results from the research of Debnath, et al. (2004) reinforce the conclusions referred previously by Prothon, et al. (2001). Thus, Prothon, et al. (2001) showed that apple samples only dried had higher rehydration capacities in comparison with osmotically dehydrated samples in sucrose solutions (Prothon, et al., 2001). The authors explained that apple samples dehydrated with sucrose solutions showed cellular pores impregnated with sugar that did not let the entrance of water during rehydration (Prothon, et al., 2001).

In accordance with drying attribute, the usage of osmotic solutions of sugar had a positive effect during drying stages in the study of (Garcia, et al., 2007) and (Prothon, et al., 2001). In the case of Garcia, et al. (2007) osmotic solutions lead to higher water diffusion during drying. For Prothon, et al. (2001) the drying times during microwave assisted air drying obtained with apple samples osmotically dehydrated were reduced.

With regard to texture attribute, the impregnation of solutes in onion samples during osmoses promoted strengthener onion cells (Debnath, et al., 2004). For Prothon, et al. (2001) the cellular strengthens of apples was reduced if drying was performed at 60 and 70°C due to the lack of Ca^{+} ions content after osmotic dehydration. The depletion of Ca^{+} ions observed results from the enzymatic denaturation of PME enzyme, but also, due to leaching. No significant volume changes were observed in pumpkins samples that were osmotically dehydrated and simply air dried (Garcia, et al., 2007).

At last, with regard to color attribute, no significant color differences were detected during the study of Prothon, et al. (2001) between samples dehydrated with sucrose solutions and simply dried.

Moreover, the subject of osmotic dehydration must be studied on more detailed since there is vast information with regard the several osmotic parameters which may comprise the pre-treatment.

2.1.6. High electric pulsed field (HELP)

General considerations

High Electrical Pulse Field (HELP) is known to be a non-thermal technology since the temperature used during the treatment is below temperatures used in conventional treatments (Maged, et al., 2012).

Food products (liquids or semi-solids) are placed between electrodes. An electrical field is generated using pulses with high voltages (up to 100 kV) and frequencies (up to 1000 Hz) between the two electrodes. The pulse time, at in such treatment is very short, between 1-10 µs, and most of the cases, the total treatment time is below 1 s (Lyng, 2012; Maged, et al., 2012). This processing time is calculated by multiplication of the pulse duration and the number of pulses.

The Figure 22 describes the basics of HELP technology. The elementary process makes use of a power supply (generator) which produces short pulses of high voltage to be applied to the food product placed in a chamber. In addition, a monitoring system makes the waveform decoding by an oscilloscope to control the process (Maged, et al., 2012). The industries make use of this technology mainly for dairy products (e.g. yogurt drinks), soy milk and juices (Lyng, 2012; Maged, et al., 2012).

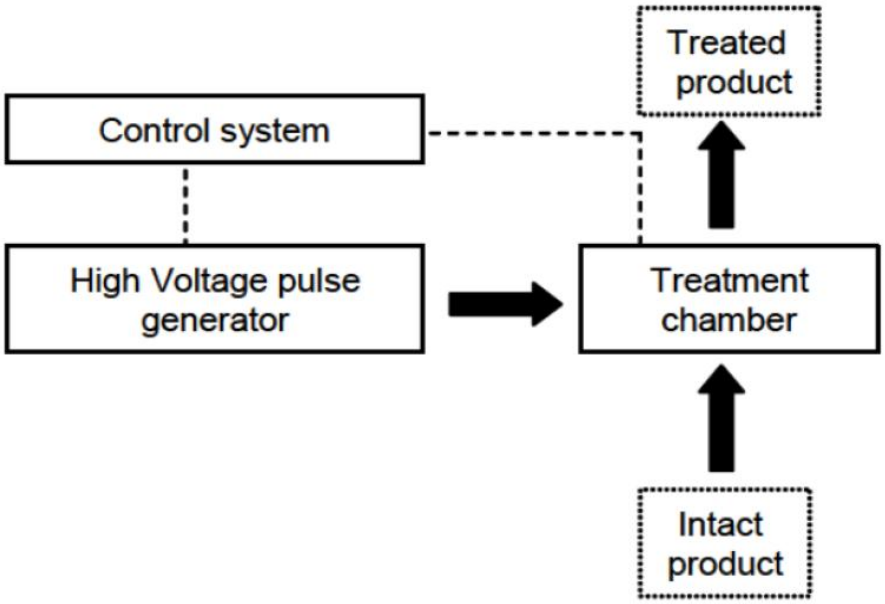

Figure 22 - General scheme of HELP treatment for food **(Maged, et al., 2012)**.

The main advantage of the application of HELP is the permeabilization of membranes. In Figure 23 there is a scheme representing the effect of electric pulse fields in cell membranes placed in a certain medium. Thus, in **a)** is represented a section of a cell membrane in the absence of the electrical field (E=0). As the cell is placed between two electrodes and the generation of electrical pulses is initiated, the positive and negative ions start to move

through the membrane (positive ions towards the negative electrode (anode) and the negative ions towards the positive electrode (cathode)). However, for lower electrical fields (E>0) the cell wall acts as a barrier and does not allow the ions movement through the cell membrane (cell membrane represented in Figure 23 by **b)**). If the electrical fields are applied to the cell up to a critical value (E_c), the ions are able to perforate the cell membrane, creating pores **c)** as suggested by Lyng (2012). On the other hand, if the electrical field is stopped (E return to 0), the membrane recover its initial state, which is called the reseal of the cell membrane, represented by **c)** in Figure 23 (Lyng, 2012).

Although the membrane presents this behavior and return to its initial state, if the electrical field applied is higher than E_c the formation of pores can be irreversible (Lyng, 2012). The formation of these permanent holes in the membrane is called *Electroporation* of membrane phenomena and is represented by **d)** in Figure 23.

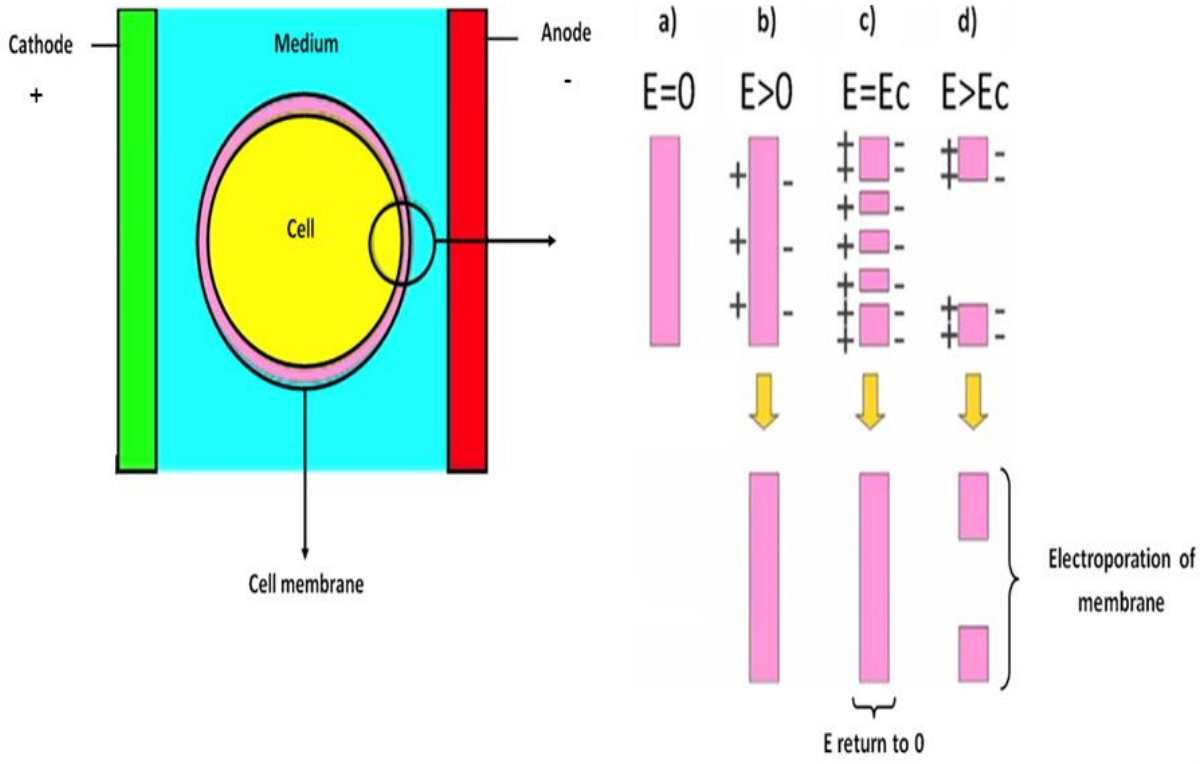

Figure 23 - Membrane permeabilization using HELP technology. **Adapted from (Lyng, 2012)**.

As it was mentioned, electrical pulse fields can cause permeabilization of membranes by an *Electroporation* phenomena, which in turn bring other advantages to food processing. These advantages can be divided in two different classes: preservation and cell disintegration (Lyng, 2012). Preservation is directly linked to microbial inactivation, since the method induced the disruption of microorganism cell membranes present in the medium to be

treated (Figure 23). Cell disintegration is intrinsically related with higher drying rates for vegetables and fruits when drying needs to be applied after HELP (Lyng, 2012). Furthermore, the preservation of color, flavor, texture and nutrients are another advantages of the method (Maged, et al., 2012). However, the incapacity to destroy vegetative bacteria and yeasts remains a drawback for HELP technology, when compared with thermal treatments (Maged, et al., 2012).

2.1.7. Additional pre-treatments – paprika and tomato

General considerations

Pre-treatments such as osmotic dehydration and high electric pulsed filed (HELP) that were already explained, are reported in this section specifically for paprika and tomato variety. In some cases, is just explained the impact of sole drying methods in food matrix with the absence of pre-treatment methods. In addition, acidic solutions among other treatments are also reported. All the food attributes found in the open literature for paprika and tomato cultivars are depicted in Table 16 and Table 17 and explained in next sections.

Attributes

Along the present section will be discussed the impact of different pre-treatments in the attributes of paprika and tomato cultivars. The present attributes will be described as follow: (i) nutrition, (ii) color, (iii) rehydration kinetics, (iv) drying and (v) texture.

Nutrition (ascorbic acid)

Previously of an air drying step at temperatures of 50, 60 and 70˚C conducted by Marfil, et al. (2008) different osmotic solutions (NaCl and sucrose solutions) were applied to tomatoes. It was found that an increase in air drying temperature lead to a higher degradation level of ascorbic acid in all samples submitted to the considered osmotic solutions. Chang, et al. (2006) also studied the ascorbic acid reduction in tomatoes. Although, the experiments were done without any pre-treatment before the drying step. It was applied two different technologies to dry the samples of tomato: freeze-drying and hot air drying (Table 17). The authors concluded that freeze drying helped the reduction of ascorbic acid around 10% while air drying caused reduction of 56 to 61%, depending on the tomato variety (Chang, et al., 2006).

In addition, the ascorbic acid retention was improved by the pre-application of solutions to red bell pepper (*var. Lamuyo*) in the study of Vega-Galvez, et al. (2008).

Color (lycopene, enzymatic browning, carotenes)

Goula, et al. (2005) presented the effects of a spray drying processes applied to tomato pulp regarding to lycopene. They found that parameters such as water activity, temperature, oxygen and light exposure have direct effect on degradation of lycopene.

Davoodi, et al. (2007) applied a pre-treatment where a combined solution of $CaCl_2$ and KMS (potassium metabisulfite) was used to improve samples of tomatoes *var. Avinash*. Afterwards, a hot air and sun drying technologies were applied separately to the product (Table 17). They concluded that the combined solution improved the retention of lycopene. Also, the drying rate of tomatoes increased and the combined solution was effective preventing enzymatic browning (Davoodi, et al., 2007).

Zanoni, et al. (1998) studied the effect of enzymatic browning and lycopene stability in tomatoes using a dehydration process in the absence of pre-treatment. The drying step was performed in a drier with a hot air stream at temperatures of 80˚C and 110˚C and velocity of 1.5 m/s. It was reported that the enzymatic browning was higher when the temperature of 110°C was used. Lycopene remained in tomato even at 110˚C, which indicates that lycopene is stable at high air temperatures. However, when tomatoes were stored for long periods the loss of lycopene was evident (Zanoni, et al., 1998). In Table 17 is detailed the operation conditions and results obtained in the study conducted by Zanoni, et al. (1998).

Giovanelli, et al. (2002) studied the effect of a hot air drying process in tomato pulp and canned peeled tomato regarding the lycopene stability. The hot air drier was conducted with temperatures of 60, 70, 80, 110 ˚C and the air stream flows with a velocity of 1.5 m/s. Results have shown that lycopene is reasonable stable during hot air drying for these two kinds of products.

The main work of Hackett, et al. (2004) was to study the effects of storage temperature and light on color attributes for tomatoes. Thus, tomatoes were stored in the dark at different temperatures (25, 50, 75 and 100 ˚C). They conclude that the isomerisation of lycopene is intrinsically related with storage temperature conditions and for a temperature below 50˚C, the oxidation process is mainly responsible for product degradation (see Table 17).

Chang, et al. (2007) performed experiments with tomato pulp of different varieties and cultivars and the authors did not use a pre-treatment prior to hot air drying. The dehydration process was performed in an usual air drier at 40, 80, 120 ˚C and an air stream with velocity of 1.5 m/s. For all processed tomatoes, lycopene content depends on variety, cultivar, drying temperatures and drying time. They also reported that high temperatures decrease the total phenolics and flavonoids contents (Chang, et al., 2007).

Baloch, et al. (1997) presented results related with modifications of carotenoid loss and enzymatic browning during long periods of tomato storage. The experiments were performed by soaking the tomato pieces in $CaCl_2$, NaCl and KMS solutions before a hot air drying step. It was found that the immersion in $CaCl_2$ solutions improved the loss of

carotenoids and helped the product against enzymatic browning reactions. On the other hand, NaCl solutions had no effect on carotenoids loss and KMS solutions decreased the rate of loss of carotenoids (Baloch, et al., 1997).

The study conducted by Pani, et al. (2008) also showed that tomato color of dehydrated tomatoes was kept by the prior use of osmotic solutions prepared with corn syrup alone or with the addition of $CaCl_2$ (see Table 17). In the chapter devoted to Freezing, explains briefly how some external factors (as light, catalysts, high temperatures) lead to a decrease of carotenoids activity, such as lycopene.

Doymaz, et al. (2002) applied different solutions to whole or sliced red peppers samples. Regarding the study of these authors, red peppers that were treated with ethyl oleate solutions improved color characteristics when compared to untreated control samples.

Color of red bell pepper (*var. Lamuyo*) was retained by the immersion into NaCl and metabisulfite solutions prior an air drying stage (Vega-Galvez, et al., 2008). In Table 16 is reported the main conditions and conclusions of this study.

Rehydration kinetics

Davoodi, et al. (2007) concluded that rehydration kinetics of tomatoes is improved when a combined solution of $CaCl_2$ and KMS is applied (see Table 17). Also Durance, et al. (2005) reported the behavior of tomatoes attributes regarding to density, color and rehydration capacity using just a drying method. When drying process uses a vacuum microwave technology the tomato samples presented lower density, best color retention and better rehydration capacities compared with air drying (Durance, et al., 2005).

A rehydration experiment was performed in distilled water at 30°C during 1 day with a ratio of pepper to water of 0.02 g_{pepper}/g_{water} by Vega-Galvez, et al. (2008). The study conducted by these authors showed that rehydration kinetics of red peppers is improved when solutions of sodium and metabisulfite are applied as pre-treatments before air drying stage. The main results are indicated in Table 17.

Drying kinetics

Pani, et al. (2008) performed experiments using osmotic and isotonic ($CaCl_2$) solutions and combining hot air drying at 180˚C to *cv. Cencara* tomatoes variety. The results reported by these authors showed that the kinetic of dehydration is enhanced by the osmotic solution or with the presence of Ca^{2+} ions. On the other hand, Doymaz, (2007) reported that a pre-treatment with an alkaline ethyl oleate solution, previous to an air drying step, could decrease the drying time of tomato for a specified drying temperature. The results of Souza, et al. (2007) are related with the influence of osmotic solutions on tomatoes before a air drying step at 60˚C. They concluded that an osmotic solution of 35% sucrose and 5% NaCl it

was the most appropriated regarding to water loss (see Table 17). Also, they reported that peeled tomatoes dry faster than whole tomatoes (Souza, et al., 2007).

The research of Doymaz, et al. (2002) showed that solutions of ethyl oleate and K_2CO_3 prepared with different proportions improve the drying rate of red peppers compared to untreated samples.

After three different solution (NaCl, $CaCl_2$ and $Na_2S_2O_5$) treatments applied to red bell pepper in the study of Vega-Galvez, et al. (2008), an air drying step was performed. The authors stated that when NaCl and $Na_2S_2O_5$ solutions are used, the drying step is slower compared to non-treated samples.

The research performed by Ade-Omowaye, et al. (2001) studied different treatments to red paprika before a drying step being applied in a fluidized bed with hot air at 60°C and 1 m/s during 6 h. The main finding was concerning to a reduction of drying times in all treatments when compared to non-treated samples.

Texture/structure (Cell structure)

After a microwave assisted by hot air drying, Heredia, et al. (2007) reported the influence of the addition of Ca^{2+} salts to the solution where the tomatoes were placed. The presence of Ca^{2+} salts increase the soluble solids uptake from the tomato matrix, prevented a textural deterioration on tomato pulp and helped maintaining the color of tomato.

The microstructure of red bell pepper is preserved by using different solution prior a drying step in the study of Vega-Galvez, et al. (2008). The detailed conditions used in this study can be seen in Table 16. High pressure and high electrical pulsed field (HELP) treatments were applied to red paprika by Ade-Omowaye, et al. (2001) enhancing the permeabilization of cellular structure which, as a consequence, improved the mass and also the heat transfer coefficients during drying stage. A detailed explanation with regard to membrane permeabilization can be seen in section 2.1.6 devoted to the chapter High electric pulsed field (HELP).

Lewicki, et al. (2004) introduced a pre-treatment with a $CaCl_2$ solution before an air drying step at 60˚C. They concluded that the treatment gave rise to a shrinkage process of tomato pieces because Ca^{2+} salts caused a penetration of whole tomato and the cell tissue was disrupted (see Table 17).

Pre-treatments – Mapping of attributes

After all the studied pre-treatments being presented and discussed, it was very useful mapping them in terms of attributes in food products. In a general way, the present map will allow the selection of the most adequate pre-treatment to be applied during food processing aiming a particular attribute.

Table 8 - Mapping of attributes in accordance with the pre-treatments studied. Positive effect in food attribute: **+**; Negative effect in food attribute: **-** ; Pre-treatment not available in the literature: **n.a.**

		Pre-treatments						
Attributes		**Water blanching**	**Steam blanching**	**Ultrasound**	**Freezing**	**High pressure**	**Osmotic dehydration**	**HELP**
Enzymatic Inactivation		**+**	**+**	**n.a.**	**n.a.**	**+**	**n.a.**	
Drying kinetics		**+**	**n.a.**	**+**	**n.a.**	**+ -**	**+**	
Rehydration kinetics		**+**	**-**	**+**	**+**	**+**	**-**	
Nutrition		**-**	**+ -**	**-**	**+**	**+ -**	**+**	
Visual aspect	**Color**	**+ -**	**-**	**+**	**+**	**+ -**	**+**	
	Volume	**n.a.**	**n.a.**	**+ -**	**n.a.**	**-**	**-**	
Texture/ Structure		**-**	**-**	**-**	**+ -**	**+ -**	**+**	
Stability during storage		**+**	**+**	**+**	**-**	**+**	**n.a.**	

Mapping Legend:

Pre-treatment had a positive effect for the attribute: **+** Pre-treatment had a negative effect for the attribute: **-** Pre-treatment not available in the literature: **n.a.**

2.2. Post-treatments

As it was mentioned along the present thesis, pre-treatments were investigated and studied from scientific literature to be applied to food in general before air drying in order to attain better quality, as near as possible of the quality of freeze dried products. However, post-treatments (carried out after air drying) are also used and most of the times can be coupled with a pre-treatment in order to improve, or even overcome, the quality of freeze dried food.

The scientific works pointed out two post-treatments used after air dehydration that are able to enhance some of food attributes, these technologies are denominated as:

- Puffing
- Instant Controlled Pressure Drop (DIC).

Puffing is known to be a technology which uses the liberation of a gas into a product creating internal expansion of the product (Payne, et al., 1989). In this section will be described the puffing technology used as post-treatment. In addition, will be also described an emerging technology denominated Instant Controlled Pressure Drop (DIC), which also expands cellular tissues of food products.

2.2.1. Puffing

General considerations

Puffing of food is a method that consists in the liberation of a gas within the product promoting structural changes (Payne, et al., 1989). Normally, the gas promotes internal expansion of food but also can lead to cell disruption (Payne, et al., 1989). In the open literature, puffing can be applied to several food products using different gases. In general, puffing make use of air, steam, CO_2 and N_2 in products such as cereals, vegetables, fruits, meat and fish (Barrett, et al., 1988). Currently, puffed products are extensively used by consumers in instantaneous soups, ready-to-eat cereals, snacks, among others, (Payne, et al., 1989; Gleich, 1987).

It is known that freeze dried products have higher quality compared to conventional drying. Thus, producing dried food combining puffing and air drying processes could be the path to achieve products with improved quality (Payne, et al., 1989). Among several advantages of puffed products, can be highlighted the prevention of shrinkage phenomena that frequently occur during conventional air drying, since puffing expands the cellular structure (Shilton, et al., 1998). This fact may contribute to approach the quality of air drying combined with puffing to the quality of a freeze dried product (Shilton, et al., 1998).

Other advantages of puffing are very often referred in the literature indicating that it can lead to drying rate improvement enhancing rehydration attributes, volume expansion and visual aspect for consumers, (Shilton, et al., 1998; Payne, et al., 1989). Furthermore, puffing

operation conditions such as: temperature, pressure, holding time, depressurization time, gas concentration, dimension of food pieces and moisture content of samples before puffing are decisive. As an example, Shilton, et al. (1998) applied air puffing at two different temperatures (120 and 130°C) to potato cubes. The authors found that both conditions used allowed a volume expansion of the samples. However, the puffed samples at 120°C did not maintain their structure during cooling and are accomplished by collapse (Shilton, et al., 1998).

The time duration of puffing according to Shilton et al. (1998) it is also an important aspect that should be taking into account. In that research the optimum puffing time was recorded as 4.5 min since higher times did not increase the volume of potatoes. However, color changes in potato samples can occur for longer times than 4.5 min, thus, this time should not be exceed (Shilton, et al., 1998) (see Table 18). The referred authors also gave importance to the size of samples, since potato cubes with 7.5 – 12.5 mm experienced the higher volume ratio expansion lying between 1.37 and 1.38.

In addition, pre-treatments can be also applied to minimize browning reactions (Barrett, et al., 1988) or to increase volume expansion of puffed products such as blanching (Varnalis, et al., 2001; Shilton, et al., 1998).

Basically, from Figure 24 can be seen the main steps of puffing process. After the product being introduced in a vessel, a pressurization step is performed until the desired pressure is reached. The pressure is maintained during a very short period of time and a very fast depressurization is performed until the atmospheric pressure is attained. After this step the product is removed from the vessel.

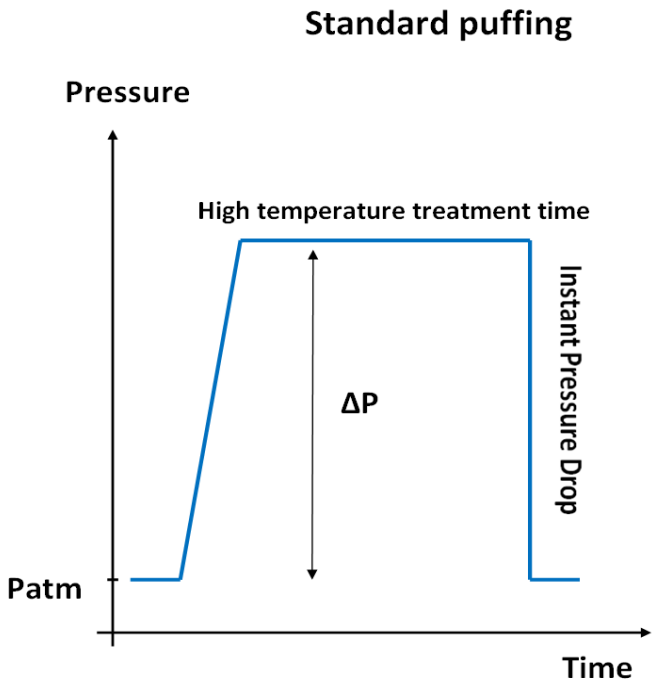

Figure 24 – Representation of puffing process in terms of pressure and time.

Moreover the optimization of all the puffing conditions mentioned above, a drying step is also required before puffing stage (Wu, 2009; Varnalis, et al., 2001; Tabeidie, et al., 1992; Barrett, et al., 1988; Gleich, 1987). The research conducted by Varnalis et al. (2001) explained exactly the need of a drying step before and after puffing being applied as it is depicted in Figure 25. Thus, the authors introduced puffing in different stages to potato cubes **1)** and stated that the samples required a short drying step in order to create a dry surface which enhanced further puffing **2)**. Hence, the first drying step, a dry layer is formed at the product surface which prevents mass transfer of moisture outwards. During puffing, the water vapor formed due to the high temperatures involved escapes with difficulty through the dried layer and high pressures are build inside the solid, which forces the dilatation of pores creating a porous structure of the potato cube **3)**. As a consequence, a higher volume is attained **4)**. In a final stage, drying is applied again in order to create a product with the desired final moisture content (Varnalis, et al., 2001).

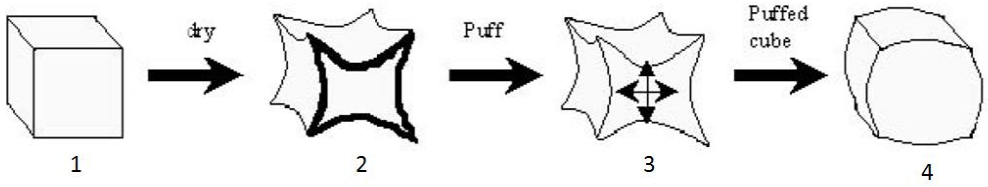

Figure 25 – Proposed puffing method of potato cubes **(Varnalis, et al., 2001)**.

In most cases, supercritical conditions of the medium fluid are required as referred in the open literature. In Figure 26 is depicted typical phase diagram with the supercritical conditions indicated. At higher temperatures than the critical temperature and pressures above the critical pressure, the fluid exists not as liquid or gas but as a supercritical fluid. The substance in that supercritical condition can diffuse through solid matrixes like a gas and can replace organic solvents due to the dissolution ability.

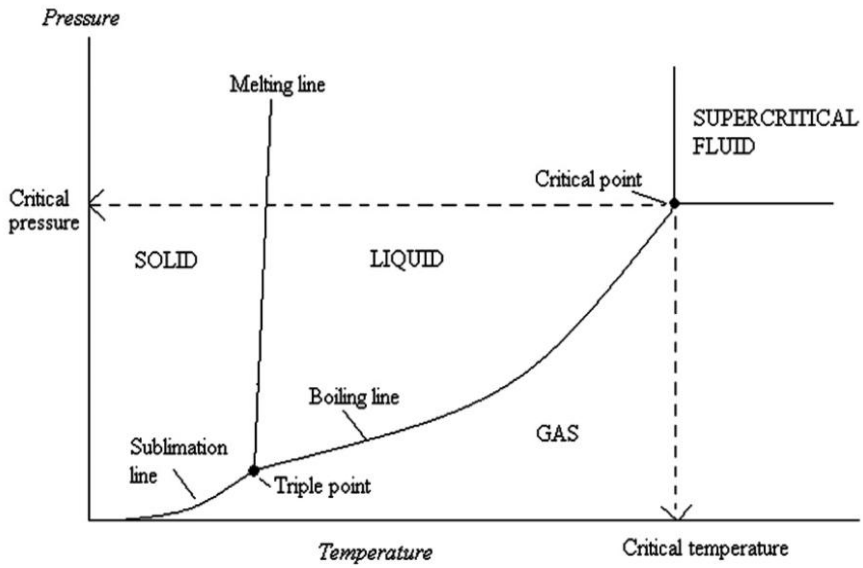

Figure 26- Supercritical fluids (Brown, et al., 2008).

There are other studies regarding to puffing where the medium fluid used varies between CO_2 and air. In Table 18 is depicted all the conditions and main findings of these researches. The Table 19 is devoted to present briefly the description and main conditions used in three registered patents using CO_2 and N_2 as medium to be used during puffing.

In the next sections are described the puffing process using different gas medium, such as CO_2, steam, air and N_2.

2.2.1.1. Puffing with CO_2

Barrett, et al. (1988) presented a patent where a gas (preferably CO_2) at a pressure above atmospheric conditions is applied to a wide range of foodstuff - vegetables, fruits, cereals. The study also underlies a drying and a vacuum steps to evacuate the puffing vessel before the release of the pressurizing gas, promoting puffing. The authors pointed four important aspects as: puffing temperature, holding time of puffing, product moisture content before puffing and CO_2 concentration in the gas used (Barrett, et al., 1988).

The research made by Wu, (2009) was based in CO_2 puffing of several vegetables and fruits. In this research the products were exposed to a conventional drying stage to attain the desired moisture. A vacuum pressure of 0.08-0.1 MPa was applied before CO_2 puffing at 1.5-10.5 MPa during 0.5 to 60 min (Wu, 2009). After this stage the pressure was reduced to the atmospheric pressure. As a final step, drying was applied again until the product reached final moisture content between 3-5% (Wu, 2009).

2.2.1.2. Puffing with steam

Instant Controlled Pressure Drop (DIC) technology can be understood as a puffing process since high pressure is applied during pressurization stage but DIC usually makes use of steam as heating medium. However, the main difference between DIC and puffing is related with the final pressure attained during depressurization stage which makes the difference between these two technologies. In the next section 2.2.2 devoted to the chapter Instant controlled pressure drop (DIC) it can be seen a detailed explanation of this emerging technology.

2.2.1.3. Puffing with air

In the different researches conducted by Varnalis, et al. (2001) and Shilton, et al. (1998) a puffing stage was applied to potatoes samples using air as heating medium.

In the study of Varnalis, et al. (2001) the puffing step was performed in a fluidized bed where the air stream passed through the potatoes samples at 200°C during 50 s. The samples were

air dried in a cabinet dried before and after the puffing step as it was mentioned previously in this section.

For the study of Shilton, et al. (1998) a fluidized bed of salt particles (300 μm) was used for the puffing stage applied to potatoes samples. The samples were introduced in a wire mesh where the air stream with a velocity of 1.5 m/s and a temperature range between 120 to 130°C attained the samples. The final moisture content after puffing was around 55 to 52% (w.b) which was dependent on puffing time of 1.5, 3 and 4.5 min. After puffing stage the samples were dried in an oven drier (90°C; 0.1 m/s) which reduced the moisture content of potatoes to 14% w.b. The conditions applied to both studies can be seen on detailed in Table 18.

2.2.1.4. Puffing with N_2

It was patented a puffing method applied to vegetables, fruits, meat and fish for application in soups and ready-to-eat meals (Gleich, 1987). Also, in that research, initial drying step and pliability of the product is required to ensure an adequate puffing stage. In this case, puffing consists in gas N_2 impregnation to the product at high pressure. As a result, a volume expansion and a porous structure of the product was obtained when the depressurization occurs. In addition, some flavors can be added in order to give a desired final product for consumers (Gleich, 1987). In Table 19 is described on detail methods, requirements and main claims of the study. Barret et al. (1988) patented also their study of puffing food products such as cereals, fruits and vegetables using replacing CO_2 by N_2.

Attributes

Along the present section will be presented and discussed information found in the literature regarding to the impact of puffing in some food attributes. The attributes will be described in different subjects: (i) texture, (ii) rehydration kinetics and (iii) volume and shape.

Texture/structure

The resistance offered by carrot samples to a puncture forces was measured by Brown, et al. (2008). After several treatments (Table 18) and consequent rehydration process, a texture test was applied. After rehydration at 50˚C, samples that were air dried showed the higher resistance (around 16 N) compared to samples treated with supercritical CO_2 and ethanol which presented values of 15 N and 11.27 N, respectively. However, these treatments enhanced the resistance offered by carrot samples to a puncture force when compared to the raw samples (around 11 N). In addition, the same resistance test was performed after rehydration at 80˚C. As it was expected, increasing the rehydration temperature results in lower resistance forces for all samples tested (Brown, et al., 2008). The maximum force to penetrate potato pieces was determined after rehydration with boiling water during 2 min

(Tabeidie, et al., 1992). Air dried samples presented a maximum force of 13.2 N while puffed samples supported forces around 10 N. The resistance measured for freeze dried potatoes was only 1.2 N (Tabeidie, et al., 1992).

Rehydration kinetics

Brown, et al. (2008) introduced different treatments to carrot discs with the aim of study it's rehydration kinetics. Thus, rehydration of carrot discs, with a moisture content ranging 6 to 10% (w/w), was performed in 100 mL of distilled water at 50°C and 80˚C during 40 min. The experiments of rehydration kinetics were conducted at 50°C with carrot samples submitted to a set of five different treatments: **(i)** air drying; **(ii)** blanching followed air drying, **(iii)** supercritical CO_2, **(iv)** blanching followed supercritical CO_2 and **(v)** ethanol combined with supercritical CO_2. The experimental conditions are presented in more detail in Table 19. Carrots showed higher moisture contents during rehydration after 5 min when ethanol was introduced in conjunction with supercritical CO_2. Furthermore, carrot samples treated with ethanol presented a porous structure and maintained the same shape and volume. And this fact is pointed by the authors to be responsible for the increase of water absorption during rehydration. In addition, the samples treated with ethanol remained on the water surface while the others merge down. However, after 40 min of rehydration, blanching applied before supercritical CO_2 showed to be the greatest treatment among all the others depicted above (Brown, et al., 2008).

Rehydration was evaluated for potato pieces in boiling water during 2 min (Tabeidie, et al., 1992). In this study, air dried samples showed a rehydration ratio of 1.31 while puffed potatoes with 43% of moisture content presented a ratio of 1.76 (Tabeidie, et al., 1992). It is important to underline that rehydration ratio is dependent on the initial moisture content of CO_2 puffed samples. Even that, puffing resulted in higher rehydration ratios compared to air drying but freeze dried potatoes presented the highest value of 5.53 (Tabeidie, et al., 1992). In Table 18 can be seen the detailed conditions and conclusions concerning this research.

Volume and shape

Brown, et al. (2008) used supercritical CO_2 combined with ethanol in the puffing treatment applied to carrot discs. The authors observed that the volume of samples was maintained after this treatment, but with a porous configuration (lower densities).

As it was mentioned previously, a prior drying step before air puffing of potato cubes is an obligatory requisite for an efficient puffing in the research of Varnalis et al. (2001) (see Table 18). Even the initial drying stage is considered crucial for the efficiency of puffing, an extensive drying time is responsible for a volume reduction of puffed samples (Varnalis, et al., 2001). The volume remained the same (around 0.3 cm^3) for dried samples at 90°C during

60 and 80 min. However, for 90 min of drying the volume was reduced in 0.1 cm^3. Blanching before the preliminary air drying stage of potato cubes enhanced the volume expansion of puffed cubes. The maximum volume of puffed cubes was attained for a blanching treatment during 2 min prior drying (90°C, 40 min). When blanching is not used the volume of puffed potato cubes was smaller (Varnalis, et al., 2001).

Shilton, et al. (1998) also proved that blanching enhanced the volume of puffed potatoes compared to unblanched ones. They suggested that gelatinization of starch may preserve the samples volume (Shilton, et al., 1998). The starch gelatinization effect was explained on detail in the section 2.1.1 devoted to Blanching chapter.

2.2.2. Instant controlled pressure drop (DIC)

General considerations

Instant Controlled Pressure Drop (DIC) technology applied in food processing can be used with several aims and it is an emerging technology which comprises various steps.

It is used to expand cell tissues of food products as milk powders (Mounir, et al., 2010), volatilize certain compounds for the extraction of essential oils of citrus and caffeine emulsions (Allaf, et al., 2013; Kamal, et al., 2012). DIC is also known to improve rehydration kinetics of several food products compared with freeze dried ones (Allaf, et al., 2014). In the Figure 27 it is schematically represented a DIC equipment (Kamal, et al., 2012). Basically a DIC equipment is composed by a reactor where the product is placed **(1)**, a vacuum tank **(2)**, a valve to control the pressure **(3)**, a vacuum pump **(4)** and a steam generator **(5)** (Kamal, et al., 2012).

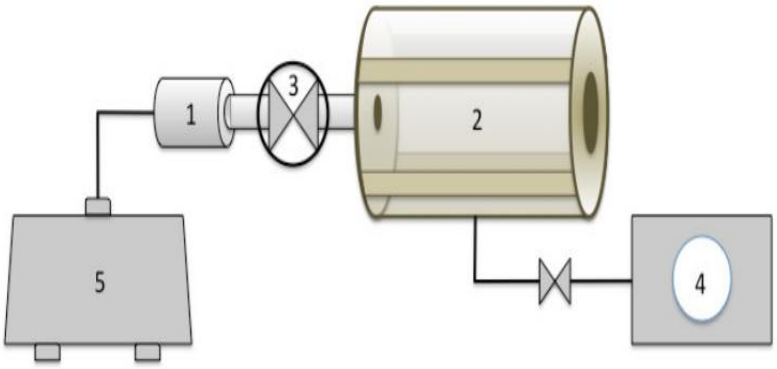

Figure 27 - Schematic representation of Instant Controlled Pressure Drop (DIC) equipment. **1)** Treatment reactor, **2)** Vacuum tank, **3)** Valve to control the pressure, **4)** Water ring vacuum pump, **5)** Steam generator **(Kamal, et al., 2012).**

In the present case, steam is used as heating medium in the pressurization step, represented by step **b** in Figure 28. However, other heating systems (hot air, CO_2, microwaves) can be used to heat up the product as it will be mention later (Allaf, et al., 2014). After the product being placed in a vessel at atmospheric pressure, the method consists of the following steps (Figure 28):

i) The product is subjected to a vacuum pressure of around 5 kPa **(a)**.

ii) The injection of saturated steam in a range of 0.1 to 0.6 MPa is performed suddenly **(b)** which implies a temperature increase of the system itself to 100-160 °C (see also the temperature profile of the product on Figure 29).

iii) The high pressure is maintained during a short period of time, from 5 to 60 s, represented by **(c)** in the Figure 28.

iv) A very fast depressurization is applied ($\Delta P/\Delta t$ > 0.5 MPa.s^{-1}), denominated here by instant controlled pressure drop **(d)** towards a vacuum pressure about 5 kPa which is normally kept for 5-20 s **(e)**.

v) The pressure is released towards atmospheric pressure and the product is removed from the vessel (Allaf, et al., 2014; Téllez-Pérez, et al., 2012).

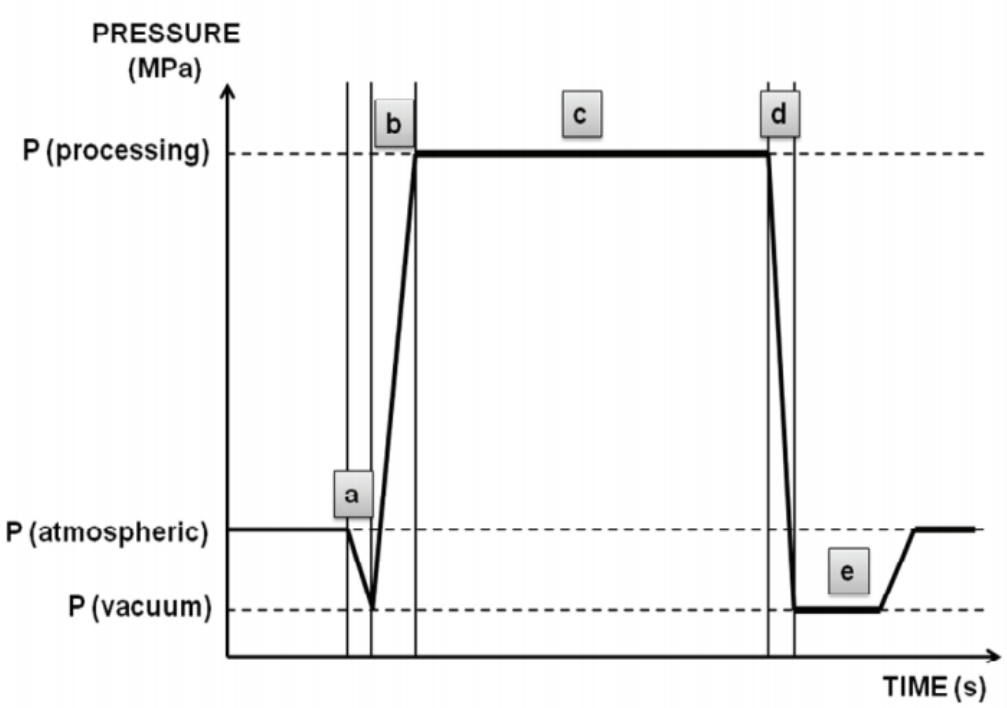

Figure 28 - Pressure profile during DIC process **(Téllez-Pérez, et al., 2012)**.

During DIC, the product also experience structural changes due to the temperature variations resulting from the pressure cycle in the vessel (Figure 29). As it can be seen from Figure 29 the final vacuum stage can give lower temperatures than the equilibrium product temperature (T_e), minimizing thermal degradation of heat sensitive products (Allaf, et al., 2014). In addition, as the pressurization stage is conducted during a short period of time the thermal impact towards the product is also not severe (Allaf, et al., 2014).

To understand better the effect of temperature in the product during DIC is depicted the Figure 29. In addition, this Figure 29 is in accordance with Figure 30 that relates the temperature and moisture content (db %) of certain product with the glass transition curve represented. In Figure 30, above the red curve of glass transition it corresponds to a *rubber zone* (rubbery state with soft and flexible structure) and below the curve to a *glass zone* (amorphous state, generally with hard, rigid and brittle structure) (Allaf, et al., 2014).

The explanation of both figures can be described in some steps, as the following (Allaf, et al., 2014):

A_0 - B_0 - A_0 represents the product conditions when it is placed in the DIC vessel. After a short vacuum stage the pressurized steam is injected and a high pressure is imposed during a short period of time (see both Figure 29 and Figure 30). The pressure increase is followed by an increase of the product temperature. The product also gained moisture content (**B_0**) as a consequence of the amount of condensed saturated steam (see also the arrow in Figure 30).

The amount of heat absorbed by the product during this pressurization step can be determined using Equation 1:

$$Q = m_d(c_d + W c_w)(T_i - T_a) \qquad \text{(Eq. 1)}$$

Where Q is the amount of heat absorbed by the product; m_d is the weight of dry sample; C_d and C_w designate the specific heat of the dry product and water, respectively; W is the water content in solid matrix (db); T_a is the initial temperature of the product (before being introduced in the vessel) and T_i is the treatment temperature of the product during pressurization.

B_0 - C_0 – The depressurization towards a strong vacuum makes the vaporization of water contained within the product. At this stage the product provides the heat needed for the water within the product to evaporate (autoevaporation). As a consequence, the moisture content and product temperature is reduced to T_f (depict by **C_0**). As the depressurization rate is very high, the product is cooled down (instantaneously), passing the glass transition curve limit towards the *glass zone* (glassy state).

The sensible heat corresponding to the cooling process ($Q^{'}$) is:

$$Q^{'} = m_d(c_d + Wc_w)(T_f - T_i) \quad \text{(Eq. 2)}$$

and is used to (auto) evaporate water that constitutes the solid moisture content. T_f is the final temperature attained when the pressure is abruptly reduced, which could be different to the equilibrium product temperature T_e (Allaf, et al., 2014).

A large amount of autoevaporated water is essential to have a well-expanded product. For and adiabatic system, the amount of water removed from the product by autovaporization (m_v) is obtained by Equation 3 (Allaf, et al., 2014):

$$m_v = \frac{Q^{'}}{L} \quad \text{(Eq. 3)}$$

Where L is the evaporation latent heat of water.
Thus, m_v:

$$m_v = m_d \frac{(c_d + Wc_w)(T_f - T_i)}{L} \quad \text{(Eq. 4)}$$

As the pressure is abruptly dropped the final temperature of the product T_f could be much lower than the equilibrium temperature T_e (Figure 29). This happens because the temperature modification occurs during a very short period and the conventional (quasi-static) thermodynamic laws for long transformations are no more respected (Allaf, et al., 2014).

However, for longer pressure drop times (low depressurization rates):

$$T_f \cong T_e$$

The vacuum stage of DIC technology has a direct effect in terms of temperature of the product as it was mentioned.

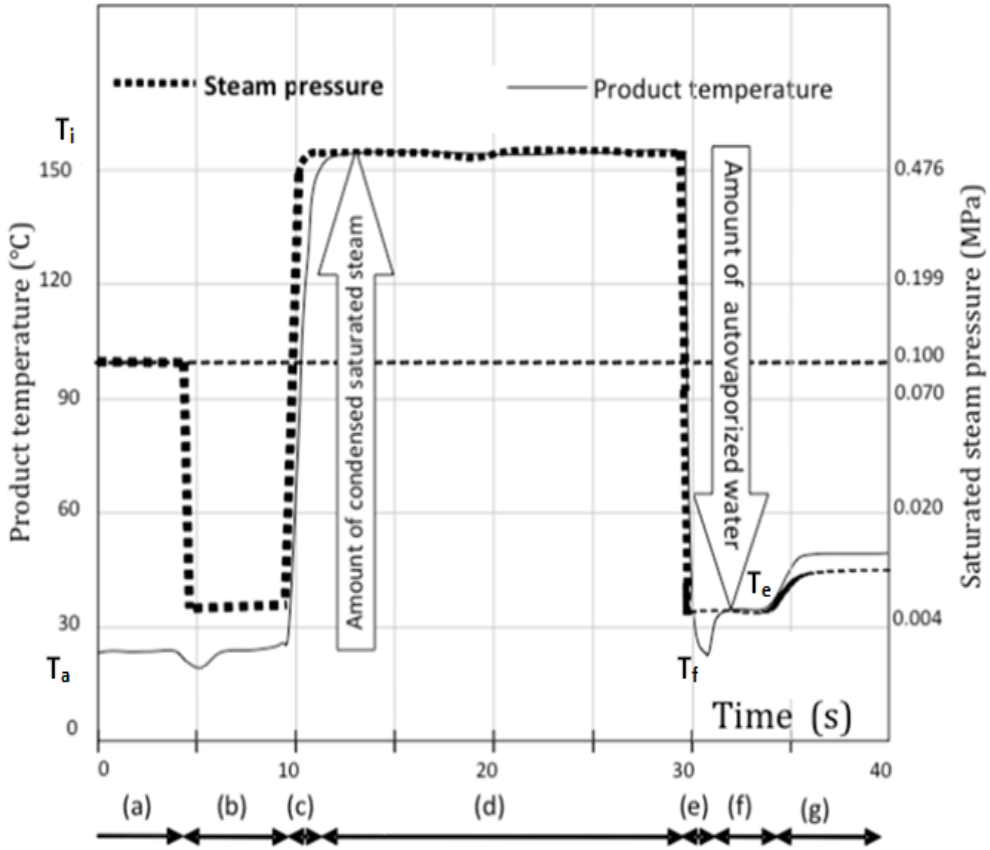

Figure 29 - DIC in terms of pressure and temperature processing. **Ta-** Initial product temperature before being introduce in the vessel; **Ti-** Maximum temperature attained by the product during pressurization; **Tf**- Final temperature of the product after decompression; **Te** – Equilibrium product temperature. **a)** Product at ambient temperature; **b)** Vacuum stage; **c)** Fast pressurization of steam to reach the desired pressure; **d)** Constant temperature corresponding to saturated steam pressure; **e)** Fast decompression towards a vacuum pressure; **f)** Vacuum stage; **g)** Vacuum release towards atmospheric pressure. **(Allaf, et al., 2013)**

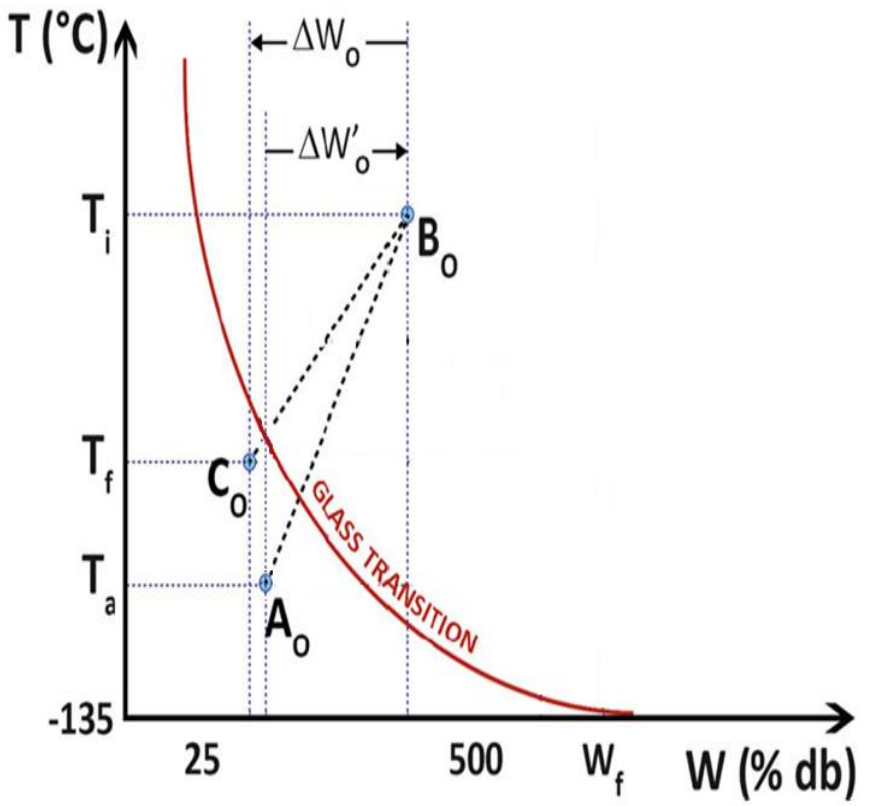

Figure 30- Temperature/moisture content (db%) during DIC treatment (A_0; B_0; C_0) **(Allaf, et al., 2014)**.

Swell Drying

In addition, as it was mention before, the DIC technology in combination with traditional stages of air drying is dominated as *Swell Drying* (Allaf, et al., 2014; Téllez-Pérez, et al., 2012). This method can be applied to a wide range of vegetables and fruits.

The main difference is that air drying is applied before and after DIC. Thus, *Swell Drying* is performed as followed:

i) Pre-drying step is performed until samples get certain value of moisture content.

ii) Instant Pressure Drop is applied as it was explained previously.

iii) Final drying step is applied to conclude *Swell Drying* (Téllez-Pérez, et al., 2012).

In the Figure 31 is represented a first air drying stage (***A***, $\boldsymbol{A_D}$, $\boldsymbol{A_D'}$, $\boldsymbol{A_0}$) prior to DIC process which can be denominated as *Swell Drying* as mentioned before.

From the Figure 31 can be observed that the first drying stage reduced the moisture content of the product to a certain value $\mathbf{A_D'}$. Afterwards, the product experienced a temperature reduction passing from a *rubber state* to a *glassy state*, until $\mathbf{A_0}$ (see Figure 31). It is important to refer that no variations of moisture in the product matrix occurred from $\mathbf{A_D'}$ to $\mathbf{A_0}$, and the moisture content of the product at $\mathbf{A_0}$ stage should be the required to attain further expansion during DIC (Allaf, et al., 2014).

If drying continued further from the point $\mathbf{A_D'}$ the product will pass the glass transition border for the glass zone while the moisture content will be more and more reduced. In this case, the product will experience volumetric shrinkage, however by introducing DIC this problem is overcome (Allaf, et al., 2014).

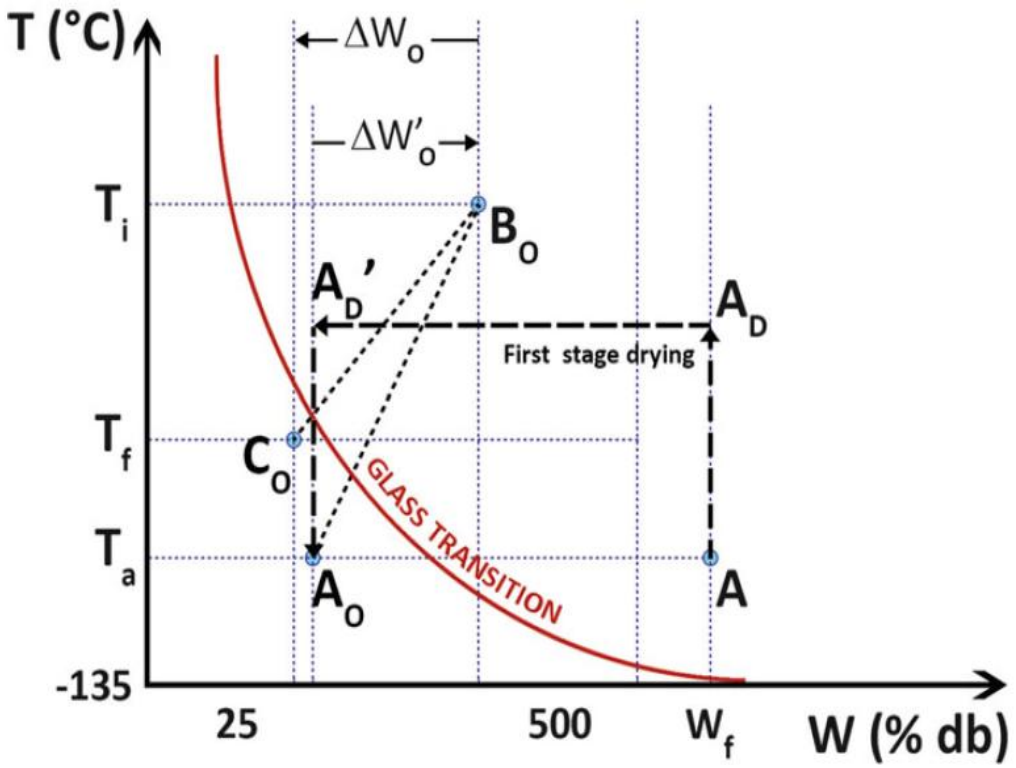

Figure 31 - Temperature/moisture content (db %) during the first drying (*A, A_D, A_D´, A_0*) stage and DIC treatment (A_0, B_0, C_0) **(Allaf, et al., 2014)**.

The advantages of DIC coupled with a dehydration method can overcome the shrinkage phenomena which occur when air drying is used as sole method. In addition, once the structure of the product is expanded, the second drying stage is shorter, since the surface product to drying air is improved (Allaf, et al., 2014).

Some advantages of *Swell Drying* are depicted below (Allaf, et al., 2014):

- Preservation of vitamin content compared to conventional air dehydration;
- Preservation of flavor and color;
- Availability of flavonoids and antioxidant activity compared with raw product.
- Microbiological inactivation – extended shelf-life, storage.

It is essential to notice that for a large range of food products an initial drying step is required before DIC. However, in some cases, DIC can be directly tried on fresh food such as beef meat, chicken, fish and seafood without a first dehydration stage (Allaf, et al., 2014).

Post-treatments – Mapping of attributes

After all the post-treatments have been presented and discussed it was very useful mapping them in terms of attributes in food products (Table 9). In a general way, the present map will allow the selection of the most adequate medium (air, steam, carbon dioxide or nitrogen) of the post-treatment to be applied during food processing aiming a particular attribute.

Table 9 - Mapping of attributes in accordance with the post-treatments studied. Positive effect in food attribute: **+**; Negative effect in food attribute: **-** .

		Post-treatments			
Attributes		**Air**	**Steam**	**CO_2**	**N_2**
Rehydration kinetics			**+**	**+**	
Microbial Inactivation			**+**	**+**	
Visual aspect	**Color**	**-**		**-**	
	Volume	**+**	**+**	**+**	**+**
Texture/Structure		**+**		**+**	

Chapter 3 Experimental Work

3. EXPERIMENTAL WORK

The chapter devoted to Experimental Work was removed from the present Master Thesis due to confidential reasons of the company Unilever R&D Vlaardingen.

Chapter 4 Results and Discussion

4. RESULTS AND DISCUSSION

From all the attributes depicted along this work, rehydration kinetics was chosen and performed for two randomly food samples A and B in order to show differences between a freeze dried and an air dried product. The sample A was freeze dried and the sample B was submitted to conventional air dehydration.

Therefore, from Figure 32 it can be seen the evolution of water absorption during the rehydration process. It is evident that at the beginning of rehydration for the freeze dried sample A (green curve) is much faster compared with air dried sample B (blue curve). This fact is due the arrangement of the primary cellular structure of freeze dried products as explained by Ratti (2001), which enhance the water intake quickly, improving rehydration assessment in the first periods of rehydration.

As expected, the air dried sample showed lower rehydration capacity and the water intake is slowly compared with freeze dried sample (Figure 32). As example, the rehydration rate was calculated for the first minute from rehydration kinetics, the air dried sample B presented a rate of 0.75 $g_{water}/(g_{dry\ sample}.min)$ while for the freeze dried sample A a higher value of 1.20 $g_{water}/(g_{dry\ sample}.min)$ was obtained.

Similar results were shown in the research work conducted by Jambrak, et al. (2007) once the rehydration capacity of freeze dried button mushrooms, Brussels sprouts and cauliflower was enhanced compared with the ones submitted to an air drying process (see section 2.1.1 of the Blanching chapter).

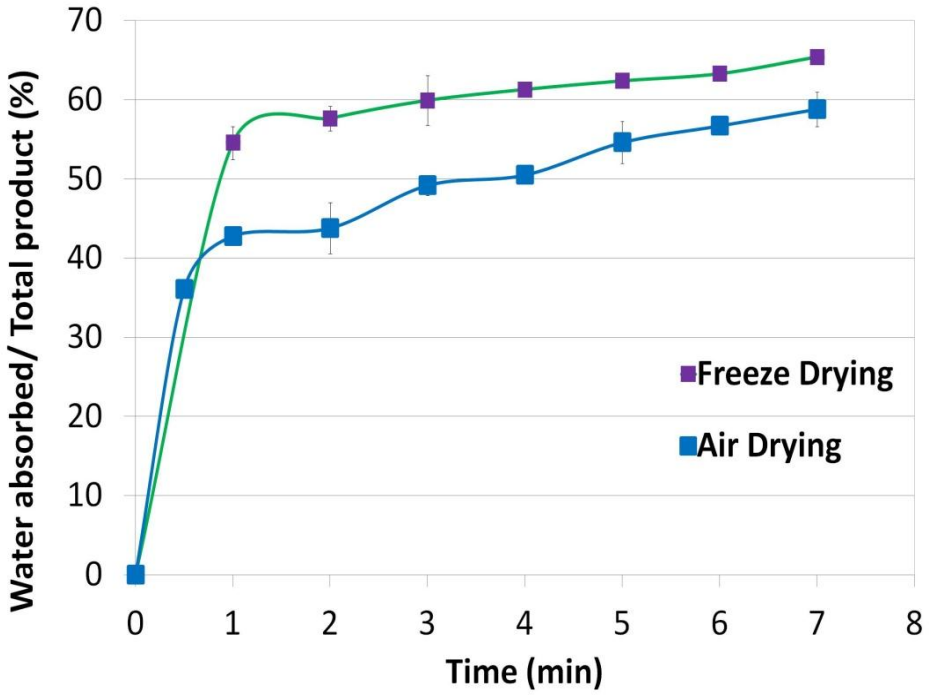

Figure 32 - Rehydration kinetics of freeze dried (sample A) and air dried (sample B). The vertical bars indicate the standard deviations associated to replicates.

The chapter devoted to Results and Discussion was removed from the present Master Thesis due to confidential reasons of the company Unilever R&D Vlaardingen.

Chapter 5 Conclusions-Learning

5. CONCLUSIONS – LEARNING

With the presentation of all the studied subjects and main scientific results obtained along this literature review completed, it is relevant to make an overall conclusion taking into account its main goal.

It was verified, by the collected scientific data, that several pre-treatments applied alone or in conjugation with post-treatments enhanced diverse attributes of air dried vegetables and fruits with the purpose to improve its quality. With respect to the hypothesis of the present thesis it can be conclude that in some researches the main goal it was attained in order to improve food attributes close, or even better, than a freeze dried product. However, in other published works it could be seen that is still difficult to attain the quality of freeze dried products in terms of other food attributes. In addition, it has to be highlighted that according with the treatments used, the results showed the improvement of some attributes while others were prejudice.

This literature review allowed to understand which pre and/or post-treatment is more suitable for a certain attribute improvement. Therefore, the choice of unique treatment or coupled treatments must be done carefully when certain attribute is desired.

After all, from the attributes studied, an overall conclusion as to be draw for pre and post-treatments. It can be concluded that for inactivate enzymes the recommended pre-treatments are water blanching, steam blanching or high pressure which in turn leaded also to food preservation during long storage periods. If a good performance of further drying kinetics is required, where most of the times the drying periods are shortened, ultrasound and osmotic dehydration are the most recommended pre-treatments. However, water blanching and high pressure can be also used to promote better drying performances. With regard to rehydration kinetics attribute, treatments such as water blanching, ultrasound, freezing and high pressure are highly recommended. For the nutritional value of food, based on the collected data, osmotic dehydration and freezing are the most suitable treatments to be applied but steam blanching or high pressure can be also used even that in a less extent. With regard to the visual appearance which comprises color and volume attributes of food products, ultrasound, freezing and osmotic dehydration must be applied to improve color since these treatments showed to be the ones that promoted less color changes compared with controls, while, for volume enhancement ultrasound could be barely required. Finally, osmotic dehydration showed to be the best pre-treatment if texture and structure of food material needs to be improved, however, freezing and high pressure can be also used for the same purpose but in less extent.

With respect to post-treatments, puffing and DIC promote cellular expansion of food products which lead to shrinkage prevention of air dried products. Therefore, puffing as a post-treatment improves the volume attribute of food pieces which improves it visual

aspect, enhances also the drying rates and rehydration capacities. With respect to DIC couple to air drying (*Swell Drying*) it was verified that rehydration attributes are improved such as visual aspect in terms of volume/format and color of food pieces, the nutritional value is ensured in terms of vitamins content, the products are preserved for longer periods due to elimination of microorganisms, flavor is maintained, among other attributes. The DIC post-treatment coupled to conventional dehydration method showed to be the treatment which presented more attributes compared to all the other treatments studied.

However, there are still a large number of variables that compromises the success of such pre and/or post treatments with respect to food products to be treated such as its origin, variety, correct periods and conditions of harvesting, cellular arrangement, state of food (fresh, ripe, raw).

In conclusion, this literature review permitted a detailed study from each pre and/or post-treatment applied which allows the reader to choose the treatment in order to enhance a particular or a desired attribute for a certain purpose.

Due to confidential reasons of the company Unilever R&D Vlaardingen, the experimental conclusions were removed from the present chapter.

Chapter 6 Recommendations-Next Steps

6. RECOMMENDATIONS - NEXT STEPS

As recommendations for further research in order to clarify some aspects it could be mentioned the following suggestions:

- The improvement of a particular attribute must be always taking into consideration before the application of a certain pre and/or post-treatment.
- Since this study was based in the presented literature, an even more deeply study of each pre and post-treatment could be considered, once there are more scientific data that relate attributes with food quality.
- The attribute tables could be further updated since more scientific studies are frequently published.
- High pressure, blanching and ultrasound must be studied in more detail once showed to be the pre-treatments that enhanced more attributes.
- The quality attributes that the pre-treatment High electric pulsed field (HELP) can promote it must be considered for further study.
- The Instant controlled pressure drop (DIC) showed to be a new technology that can improve even more food attributes.

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Appendix 1 Literature Review-Attribute Tables

APPENDIX 1 LITERATURE REVIEW - ATTRIBUTE TABLES

The followed tables presented in this section permitted the elaboration of the chapters of the literature review which are also divided in food attributes. The tables provide an enlarged and simplified prospected view of all the methodology used for each pre or post-treatment. In addition, the tables indicate if drying was applied after such treatments and the main effects in food products in terms of: **i)** enzymatic inactivation, **ii)** drying kinetics, **iii)** rehydration kinetics, **iv)** color, **v)** nutrition, **vi)** volume/bulk density, **vii)** texture and **viii)** stability during storage.

The effect of such treatments was studied for a large group of vegetables and fruits where the variety, origin and the state (fresh, ripe, raw) at which crop was used in the experiments is depicted most of the times.

In the present tables Table 10 and Table 11 are depicted all the blanching technologies used for different food (vegetables and fruits). In some cases dehydration methods are applied after water and steam blanching treatments.

Table 10 – Attribute table of water blanching pre-treatment.

Pre-treatment: Water blanching											
Attributes / **Crops** / **References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
Gooseberry (*Phillanthus emblica L.*) (Ripe, Bangkok) (Chinprahast, et al., 2013)	• Gooseberries stored at 4±1°C, selected for 2-2.5 cm diameter, washed with water. • Blanching at: 70°C/20s; 80°C/40s; 90°C/60s. • Ratio: NI • Stop blanching: Ice water. • Peel removed.	NI	POD inactivated at 90°C/60s.			No effect on ΔE.					
Green pepper berries (*Piper nigrum Linnaeus*) (Fresh, China) (Gu, et al., 2013)	• Blanching at: 80°C/1 min; 90°C/2 min; 100°C/3 min. • Ratio: NI • Stop blanching: NI • Blanched berries were compared with berries dipped in 100°C/ 10 min. • Control: Unblanched.	• Sun Drying • 16h of drying • Samples weighed every 2h	PPO inactivated at 100°C/10 min.	Blanching has a positive effect on drying.		Blanching affects oxidation of phenolic pigments. Resinoids also increase the darkness. After drying, blanching temperature has an effect on darkness.					
Brussels sprouts (*Brassica oleracea L. gemmifera DC*) (Fresh, Buenos Aires Argentina) (Vina, et al., 2007)	• Dimensions of Brussels sprouts: Weight of 25.1 ± 3.4 g; Width of 35.8 ± 0.22 mm; Height of 49.2 ± 0.16 mm. • <u>Blanching treatments:</u> • Water immersion (50°C/5 min) prior blanching at 100°C/3 min. • Microwave heating (700 W/5	NI				*Lightness* decreases by blanching. Chlorophyll degradation depends on temperature/time of blanching. Higher blanching time results in higher chlorophyll losses.	Blanching causes ascorbic acid losses. No changes in flavonoid content.		Blanching results in less firm product. Increase in blanching time reduces material firmness (N).		

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
	min) previously blanching at 100°C for 2 min. • 100°C/1min. • 100°C/3min. • 100°C/4min. • Ratio:0.052 $g_{product}/g_{water}$ • Stop blanching: Ice-water/3 min. • Control: Unblanched.										
Carrots (*Daucus Carota L. var. Nanco*) (Turkey) (Koca, et al., 2007)	• Carrots stored at 1°C and 97% of humidity until drying. Samples were washed, peeled and sliced (5 mm thickness). • Blanching at: 90°C/7min. • Ratio: NI • Stop blanching: Cooling with tap water (22°C). • Control: Unblanched.	• Air Drier • 60 ± 5°C • 1.5 m/s • HR= 6–10% • Load 3.0–3.4 kg/m^2. • Final moisture: 6-7% • Storage: polyethylene bags at 27, 37, 47, 57 ^{o}C for 6 months.				Blanching decreases the loss of β-carotene about 17% in comparison to control.				Blanching enhances color and carotenoid retention.	
Chili puree (*C.annum var Kulai*) (Fresh, Penang Malasya) (Ismail, et al., 2006)	• Chilies were washed and slit longitudinally. • Blanching at: 90±1°C; 95±1°C, 100±1°C during 1-10 min for each temperature. • Ratio: NI • Stop blanching: Cooling with tap water every minute to 10 min. • Control: Unblanched.	NI	POD inactivated at 100°C/6min. LOX inactivated at 100°C/1min.								

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
Pumpkin (*Cucurbita pepo*) (Warsaw) (Kowalska, et al., 2008)	• Pumpkins were stored in a refrigerator at 5°C with a relative humidity of 80–90% during 1-2 months before use. MC 83-84% (w/w), wet basis. • Pumpkin was washed and peeled. The flesh of pumpkin was use and cut into cubes (10 mm). • Blanching at: 80°C/1 min • Ratio: NI • Stop blanching: Cooling water at 10°C/5s. • Freezing: -18±1°C for 16h. • Control: Unblanched	• **Osmotic dehydration (OD)** • Glucose 49.5%; Sucrose 61.5%; Starch syrup 67.5%; (distilled water) • Ratio product to solution 1:4 (w/w). • 30°C/0-180 min • The solution was placed in a water bath with continuous stirring of suspension. • Freezing samples were not defrosted before OD. • Samples were dipped in distilled water for 2s at T_{Room} to eliminate osmotic solution. • Drained by absorbent paper.		No effect of blanching before osmotic drying							
Yam (*Dioscorea alata* and *Dioscorea rotundata*) (Fresh, Ibadan Nigeria) (Falade, et al., 2007)	• Moisture contents: White Yam 71.32 ± 1.4% Water Yam 69.44 ± 0.2% (wet basis) • Samples were washed, peeled, cut into rectangular shape. • 80°C/5min for slices of 50x20x10 mm. • 100°C/2min for slices of 50x20x20	• Air Drier • 50,60,70,80°C • 1.5 m/s • HR=NI		No blanching effect on drying rates.							

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
	and 50x20x30 mm. • Ratio: NI • Stop blanching: Water at 25°/5 min. • Control: Unblanched										
Leek (*Allium porrum L.*) (Fresh, Istanbul) (Doymaz, 2008)	• MC=91.1±0.5%(w.b) • Leeks were peeled, cut at 1, 2 and 3 ± 0.1 cm thickness. • **Lot 1 –** Slices thickness of 1 and 2 cm were blanched 70°C/3min. • Ratio: NI • Stop blanching: Cooling in tap water at T_{Room} /3 min. • Placed on tissue paper. **Lot 2-** Slices thickness 1, 2 and 3 cm, unblanched.	• Air Drier • Load of 150 g of leek in the drying basket. • 50±1°C • Parallel air flow of 2.5 m/s • HR= 25%. • Final moisture: 10±0.5% (w.b.) • Cooling step of product and packing in low density polyethylene (LDPE) bags.		Drying times are reduced by blanching.	Blanching has a positive effect in Rehydration kinetics.						
Potatoes (*Solanum tuberosum*) (Fresh, Bangkok) (Leeratanarak, et al., 2006)	• Potatoes were stored at 4°C, washed, peeled, sliced in chips (3.5±0.3 mm thickness) • Blanching at: 90±2°C for 1, 3, and 5 min. • Ratio: 0.015 $g_{product}/g_{water}$. • Stop blanching: Cooling in water, 4°C;	• Air Drier (Tray load) • 70,80,90°C • 0.8m/s (inlet velocity) • HR=NI • Samples collected every 15 min. • Tray: 30x40 cm^2 • Samples: 28 slices for experiment	POD inactivated at 90°C/1min.	Positive effect on drying speed.		POD inactivation prevents enzymatic browning.					

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
Garlic (*Allium sativum L.*) (Fresh, Rio Grande do Sul Brazil) (Fante, et al., 2012)	• Garlic heads were cleaned, stored at T_{Room} 22±2°C. • Samples were peeled and sliced to diameters of 15±2.4 and thicknesses 1±0.35 mm. • Blanching at: 80, 90°C for 1, 2, 4, 6, 8, 10 min. • Ratio: NI • Stop blanching: Ice bath for 3 min. • Control: Unblanched	NI	POD, PPO and inulinase were inactivated for 90°C/4min and 80°C/6min.			Blanching enhances ΔE and L^*. $a^*$and b^* decrease with blanching time. BI is affected by blanching time.	Blanching at 90°C/4min reduced inulin in 44%, fructose and glucose were reduced of 42% compared with controls.				See steam blanching.
Button mushrooms (*lat. Agaricus biosporus*) (Fresh, Coventry UK) (Jambrak, et al., 2007)	• MC=9.7 g/g dm, samples were wiped and cut in 2x1.5cm; • Blanching at: 80°C/3min • Ratio:0.068 $g_{product}/g_{water}$ • Stop blanching: NI • Control: Unblanched.	• Air Drier • 60°C • 0,3 m/s • HR=35.3±3% • 200 g of product were placed in perforated basket (300 x 400 mm; perforation 5 mm x 5 mm) • Conditions of air room T=20 ± 1°C HR=65±5% • Final moisture: 0.4 g water/g dm. Freeze drying (-45°C for 3h) was applied after blanching and US as a comparative method to air drier.		Blanching has no effect on drying time.	Blanching does not result in higher Rehydration kinetics.						See Ultrasound chapter.

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
Butternut squash (*C. moschata* Duch) (Fresh, Mar del Plata city) (Aguero, et al., 2008)	• Butternut squashes were washed with soap and brushed, dipping in water for 30s and peeled. • Samples were sliced (1.5-2 mm thickness) • Blanching at: 60, 65,70,80,85,90 °C for 0-60min. • Ratio:0.015 $g_{product}/g_{water}$ • Stop blanching: 0-4°C for 3 min. • Control: Unblanched	NI	Inactivation of POD for temperatures above 70°C.				Blanching at lower temperature and long time gives high losses of ascorbic acid.				
Brussels sprouts (*lat. Brassica oleracea var. gemmifera*) (Fresh, Coventry UK) (Jambrak, et al., 2007)	• Brussels sprouts MC:5.6 g/gdm; samples were washed and cut in half; • Blanching at: 80°C/3min • Ratio:0.068$g_{product}/g_{water}$ • Stop blanching: NI • Control: Unblanched	• Air Drier • 60°C • 0.3 m/s • HR=35.3±3% • 200 g of Brussels sprouts were placed in perforated basket (300 x 400 mm; perforation 5 mm x 5 mm) • Conditions of air room T=20 ± 1C HR=65±5% • Final moisture: 0.4 g water/g dm. Freeze drying (-45°C for 3h) was applied after blanching and US as a comparative method to air drier.		Drying time was not affected by blanching	Blanching does not enhance rehydration kinetics. FD improves rehydration.						See Ultrasound chapter.

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
Potato (Variety Maris peer) (Fresh) (Abu-Ghannam, et al., 2006)	• Blanching at: 60, 65,70,80,90,100 °C during 5-60min. • Ratio: NI • Stop blanching: Cooling ice/5 min. • Control: Unblanched	NI	PME inactivated at 75°C/10min and at 80°C /5 min.						High blanching temperature results in firmness loss (N).		
Cauliflower *(lat. Brassica oleracea var. botrytis)* (Fresh, Coventry UK) (Jambrak, et al., 2007)	• Cauliflower MC: 10.9 g/gdm; samples were washed and cut in small pieces (1.5x1.5cm) • **Blanching at:** 80°C/3min • Ratio:0.068$g_{product}$/g_{water} • Stop blanching: NI • Control: Unblanched	• Air Drier • 60°C • 0.3 m/s • HR=35.3±3% • 200 g of Brussels sprouts were placed in perforated basket (300 x 400 mm; perforation 5 mm x 5 mm) • Conditions of air room T=20 ± 1C HR=65±5% • Final moisture: 0.4 g water/g dm. Freeze drying (-45°C for 3h) was applied after blanching and US as a comparative method to air drier.		Drying time was not reduced by blanching	Blanching has no effect in rehydration kinetics.						See Ultrasound chapter.
Potato (*viz. Kufri Chandramukhi*) (India) (Mukherjee, et al., 2007)	• Potatoes were peeled, washed and cut into cubes. • <u>Blanching Treatments</u> • <u>Blanching at:</u> 93°C/165s and 100°C/129s. • Ratio:0.13 $g_{product}$/g_{water} • Stop blanching at 2°C. • <u>Whirling bed:</u> saturated mixture of steam and hot	NI	POD was inactivated for all blanching treatments.				Whirling bed at 85°C helps reducing sugars and ascorbic acid retention.				(The conditions of optimum T/t for the 3 different blanching techniques were considered for 90% of POD inactivation)

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
	air at 80°C/136s and 85°C/93s at velocity of 3.5-4 m/s. • Controls: NI										
Amasya red apples (*Malus domestica*) (Istanbul) (Doymaz, 2010)	• Apples stored at 4°C, washed, peeled and sliced (thickness of 5mm). • MC fresh apples 83.3%±0.3 (w.b.) • Blanching at: 70°C/2min. • Ratio: NI • Stop blanching: Cooling with tap water. • Citric treatment: 0.5% citric acid solution at T_{Room}/2 min. • Controls: Unblanched	• Air Drier • 55-75°C (increment of 10°C) • 2m/s • HR:NI • Samples of 100±2g spread in perforated baskets • Final moisture:14% ±0.5 (w.b) Samples cooled down and packed in bags of low-density polyethylene.		Drying time is reduced by citric acid pre-treatment compared with blanched and control samples.	Blanching enhances rehydration kinetics.						
Pumpkin (*Cucurbita maxima L.*) (Fresh and ripe, Lisbon) (Gonçalves, et al., 2007)	• Pumpkin was peeled and cut in discs (50mm diameter and 15mm height) • Blanching at: 75,80,85,90 and 95°C, samples were collected until 50 min (maximum). • Ratio:0.0083 $g_{product}/g_{water}$ • Stop blanching: Ice water/2min. • Controls: Unblanched	NI	Inactivation of POD at 90°C/5.8min and 95°C/3.9min.			Blanching has a negative effect in color retention.			Blanching enhances losses of Firmness (kN) and Energy ($J.10^3$).		

Pre-treatment: Water blanching											
Attributes / **Crops** / **References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
Carrot (*Daucus carota L. cv "*Nantes*")* (Fresh, Lisbon) (Gonçalves, et al., 2010)	• Samples peeled, washed and sliced (5±1mm) • Blanching at: 70,75,80,85 and 90°C, (not fixed time) • Ratio:0.0083$g_{product}/g_{water}$ • Stop blanching: Ice bath/2min. • Controls: Unblanched	NI	POD was inactivated at 90°C/2min.			Retention of phenolic components are function of blanching temperature and time. Blanching decreases color retention.			Firmness (N) is affected by blanching. Firmness was decreased around 36% compared to control.		
Potato (*cv. Accent*) (Wageningen) (Mate, et al., 1999)	• Samples stored at 7°C and HR=95% in darkness during 3 months. • Potatoes were peeled, cut in slices (diameter 4cm, thickness of 0.8cm) sliced strips of 9.5 to 10.5g were used. • Blanching at: 90°C/2min (short blanching) and 90°C/30min (long blanching) in deionized water. • Ratio: NI • Stop blanching: Cold water • Control: Unblanched	• Air Drier • 48°C • 3.5m/s • HR=10% • 17h of drying			Blanching has no effect in RR.			*	Blanching provide higher strain and stress values (N/cm^2).		*Starch gelatinization can promote less porosity of potato. (Maté, et al., 1998) .
Carrot (*Daucus carota L. var Nantesa)* (Fresh, Madrid) (Gamboa-Santos, et al., 2013a)	• Carrots stored at 4°C, washed. Samples were cut into slices (diameter of 24mm and thickness of 4mm). Samples were minced (1-2mm). • <u>Blanching at:</u> 98°C/1min, 95°C/5min, 60°C/40min. • Ratio: 0.2 $g_{product}/g_{water}$	• Air Drier (tray load) • 46°C • Parallel air flow, 4.9m/s • HR=NI • Sliced samples:9h • Minced samples:7h drying • Sliced samples: 9h drying • Dry matter after drying: 85-89%			After rehydration, sensory quality is affected by water blanching compared with steam blanching.		Vitamin C retention is function of blanching time. Short time high retention of vitamin C.	Samples geometry influenced vitamin C retention.			See Steam Blanching table and Ultrasound chapter.

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
	• Stop blanching: Ice bath.										
Green beans (Fresh, Ankara) (Bahceci, et al., 2005)	• Green beans were washed and drained. • Blanching at: 60-96°C • Ratio: NI • Stop blanching: Ice bath • *Storage in polyethylene bags (-18°C, 12 months) • Controls: Unblanched	NI	90% of POD and LOX inactivated for 90˚C/3min and 70˚C/2min, respectively.			Blanching at 90°C/3min enhances *Chl a* and *Chl b* half-lifes.	Blanching enhances half life of ascorbic acid.			Blanching improves quality during frozen storage.	* During frozen storage enzymes (POD and LOX), ascorbic acid and chlorophyll contents were measured monthly.
Carrots (*Daucus carota*, cv. Nerac) (Raw, Dublin, Ireland) (Rawson, et al., 2012)	• Stored at 4°C, 24 h. • Peeled, vertically sliced (5 mm thickness) • Blanching at: 80°C/3 min. • Ratio: 0.77$g_{product}/g_{water}$ • Stop blanching: NI • Controls: Air Dried	• Air Drier • 60°C • 0.3 m/s; • Samples of 150 g. • Polythene packing bags; stored at -20°C.				Blanching + Air Drying reduced *ΔE* compared with Ultrasound + Air Drying.* Slightly reduction of carotenoids compared with controls. Blanching + Air Drying reduced 23.7; 2.9 and 11.5% of FaDOH, FaDOAc and FaOH, respectively Compared with controls.					*See Ultrasound chapter.
Carrot (*Daucus carota L. var Nantesa)* (Fresh, Madrid) (Gamboa-Santos, et al., 2013b)	• Carrots stored in dark room at 4°C, 5 days, washed. • Sliced: diameter of 24mm, 4mm of thickness. • Minced: 1-2 mm. • Blanching at: 98°C/1min, 95°C/5min 60°C/40min in distilled water • Ratio: 0.21 $g_{product}/g_{water}$	• Air Drier (tray load) • 46°C • Parallel air flow, 4.9m/s • HR=NI • Sliced samples: 9h drying • Minced samples:7h drying Freeze Drier			Blanching improve rehydration ratios compared with Freeze dried samples.		Blanching and ultrasound enhance carbohydrate losses.		High water blanching temperatures induce plant cell deformation.		See Steam Blanching table and Ultrasound chapter.

Pre-treatment: Water blanching											
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Stability during storage**	**Comments**
	• Stop blanching: NI • Controls: Freeze Dried										
Carrots (*Daucus Carota L., cv. Nantesa*) (Spain) (Neri, et al., 2014)	• Carrots were washed, peeled and cut in slices (1cm thick), 4 different batches. • Blanching at: 75°C/3min, 90°C/3min, 75°C/10min, 90°C/10min. • Ratio:0.13 $g_{carrots}/g_{water}$ • Packaging in polyethylene bags, cooling in ice bath/5min. • Controls: Unblanched	NI	Positive effect of blanching in enzymatic inactivation of POD and PE.					Cellular damage is improved by extended blanching conditions.			See Freezing chapter.

Table 11- Attribute table of steam blanching pre-treatment.

Pre-treatment: Steam blanching								
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Comments**
Garlic (*Allium sativum L.*) (Fresh, Rio Grande do Sul Brazil) (Fante, et al., 2012)	• Garlic heads were cleaned, stored at T_{Room} 22±2°C. • Samples were peeled and sliced to diameters of 15±2.40 and thicknesses 1±0.35 mm. • Steam blanching at: 100°C, 1 atm. The samples were placed in metal baskets to an autoclave for 1, 2, 4, 6, 8 and 10 min. • Ratio: NI • Stop blanching: Ice bath for 3 min. • Control: Unblanched	NI	POD, PPO and inulinase were inactivated for 90°C/4min.		*ΔE* increased for higher steam temperatures. *L** increased by blanching. *a**and *b** decrease with blanching time.	Steam blanching at 100°C/4min reduced inulin in 7% and increased glucose and fructose in 28% and 24% compared with controls.		For steam blanching at 100°C during 10 min *ΔE*=14.76, higher color variation compared to water blanching at 80°C/10min (*ΔE*=9.32). See water blanching.
Potato (*viz. Kufri Chandramukhi*) (India) (Mukherjee, et al., 2007)	• Potatoes were peeled, washed and cut into cubes. • Steam blanching at: 97°C for 112s, 20 g of sample were placed in an autoclave. • Controls: NI • Ratio: NI (The conditions of optimum T/t for the 3 different blanching techniques were considered for 90% of POD inactivation)	NI	POD was inactivated for all blanching treatments.			Steam blanching has a positive effect in solids, ascorbic acid and sugar retention.		See water blanching.
Carrot (*Daucus carota L. var Nantesa)* (Fresh, Madrid) (Gamboa-Santos, et al., 2013a)	• Carrots stored at 4°C, washed. Samples were cut into slices (diameter o 24mm and thickness of 4mm). Samples were minced (1-2mm). • Steam blanching: 98°C/2min at atmospheric pressure • Ratio: $0.2g_{product}/g_{water}$ • Stop blanching: Ice bath.	• Air Drier (tray load) • 46°C • Parallel air flow • 4.9 m/s • HR=NI • Sliced samples: 9h drying • Minced samples:7h drying • Dry matter after drying: 85-89%		After rehydration, sensory score was 3±1.2. (Scale: 1"like very much" and 8 "dislike very much")		Steam blanching improved vitamin C retention.		See water blanching. Samples geometry influenced vitamin C retention.

Pre-treatment: Steam blanching								
Attributes / **Crops** / **References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Comments**
Kiwifruit (*Actinidia deliciosa*, A. Chev.) (Unripe, New Zealand) (Llano, et al., 2003)	• Kiwifruit with 11.2 °Brix; aw 0.985; MC 83.8% • Samples were cleaned with detergent, dipped in a 0.1% (w/v) NaClO solution/5min, dipped in distilled water. • Peeled and cut into halves. • Steam blanching at: 99.8°C for 1 atm during 1, 3, 5 and 8 min. • Stop blanching: Ice bath at 7°C until the T<40°C in the kiwifruit core.	NI	POD and PME were inactivated for 99.8°C/8min.		Steam blanching enhances browning colors and chlorophyll degradation.		Firmness (N/cm^2) is affected by blanching time.	
Yacon Roots (*Smallanthus Sonchifolius*) (Brazil) (Fante, et al., 2013)	• Roots were immersed in water, dried with paper and stored at 8±2°C until used. Roots were peeled, cut into slices of 1.75± 0.35 mm thickness. • Samples placed in a basket autoclave. • Steam blanching at: 100°C, 1 atm for 1, 2, 4, 6, 8 and 10 min. • Stop blanching: Ice bath cooling (0-4°C) for 3 min. • Control: Unblanched	• Air Drier • 50,60,70°C • Samples removed after 5 h of drying. • HR= NI	POD and PPO inactivated for 100°C/4min.		a* decreases with blanching time. Slightly increase of b* value with time. Blanching enhances *Lightness*. ΔE increases with blanching time.	Steam blanching improves sugar losses.		
Potatoes (*Solanum tuberosum L., c.v. danshaku*) (Japan) (Sotome, et al., 2009)	• Potatoes were stored at 10°C until used. • Potatoes were used as whole and sliced (diameter of 8mm and 40mm of length). • SHS (Super heating system) at 115°C and a steam flow rate 3kg/h. • SHS+WMD (Super heating system + water microdroplets) at 115°C, almost atmospheric pressure; steam flow rate 2.46kg/h and water	NI	POD and PPO inactivated at 16min and 11min respectively, for both pre-treatments used.		SHS and SHS+WMD allow color losses.		Firmness (N/cm^2) is dependent on heating time.	SHS and SHS+WMD enhance starch gelatinization.

Pre-treatment: Steam blanching								
Attributes / **Crops References**	**Blanching Method**	**Drying technology**	**Enzymatic Inactivation**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Comments**
	droplet flow rate 0.54kg/h; • Ratio steam/water • SHS and SHS+WMD performed during 11 and 16 min. • Samples fixed at 150mm from the nozzle. • Control: Raw sample.							
Carrot (*Daucus carota L. var Nantesa)* (Fresh, Madrid) (Gamboa-Santos, et al., 2013b)	• Carrots stored in dark room at 4°C, 5 days, washed. • Sliced: diameter of 24mm, 4mm of thickness. • Minced: 1-2 mm. • Blanching at: 98°C/2min • Control: Freeze dried	• Air Drier (tray load) • 46°C • Parallel air flow, 4.9m/s • HR=NI • Sliced samples: 9h drying • Minced samples:7h drying Freeze Drier		Lower rehydration ratios compared with control.		Glucose, sucrose and fructose are preserved compared with control.		See water blanching and ultrasound chapters.

In the present Table 12 will be describe all the ultrasound technology used for different food (vegetables and fruits). In some cases dehydration methods are applied after ultrasound treatments.

Table 12 - Attribute table of ultrasound pre-treatment.

Pre-treatment: Ultrasound								
Attributes / **Crops** / **References**	**Ultrasound Method**	**Drying technology**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Comments**
Carrots (*Daucus carota*, cv. Nerac) (Raw, Dublin, Ireland) (Rawson, et al., 2012)	• Stored at 4°C, 24 h. • Peeled, vertically sliced (5 mm thickness) • Ultrasonic bath: Distilled water at 25°C, 20kHz for 3 and 10 min. Amplitudes of 24.4, 42.7 and 61 µm. • Acoustic energy density 0.39–0.95 W/ml. • Ratio: 0.75 $g_{product}/g_{water}$ • Controls: Freeze Dried	• Air Drier • 60°C • 0.3 m/s; • Samples of 150 g. • Polythene packing bags; stored at -20°C. • Blast freezing at -30°C/60min prior Freeze Drying at 0°C/0.04 mbar for 72 h. • Polythene packing bags; stored at -20°C.	NI		Air drying reduced *ΔE* compared with freeze dried. Ultrasound + Freeze drying enhance carotenoid retention. Ultrasound + Freeze drying gave better polyacetylene retention compared with ultrasound + Air drying.			See blanching chapter.
Button mushrooms (*lat. Agaricus biosporus*) (Fresh, Coventry UK) (Jambrak, et al., 2007)	• MC=9.7 g/gdm, samples were wiped and cut in 2x1.5cm; • Ultrasound probe at: Frequency of 20 kHz and intensity of 39–43 W/cm^2 for 3 and 10 min. • Ratio: 0.067$g_{product}/g_{water}$ • Ultrasonic bath at: Frequency of 40 kHz and intensity of 0.5 W/cm^2 during 3 and 10 min. • Ratio: 0.33$g_{product}/g_{water}$ • Controls: Freeze dried	• Air Drier • 60°C • 0.3 m/s • HR=35.3±3% • Final moisture: 0.4 g water/g dm. Freeze drying • -45°C for 3h	No significant differences in drying times between sonicated and control samples.	Ultrasound has a positive effect on rehydration kinetics. (Rehydration ratios close to Freeze Drying)				See blanching chapter.
Melon (*Curcumis melo L.)* (Fortaleza, Brazil) (Fernandes, et al., 2008a)	• Melons harvested at 65 days. • Fruit cut in cubes (0.02mm); • Ultrasonic bath at: 30°C for 20, 30 min and $P_{atm.}$ • Frequency of 25 kHz; Intensity of 4870 W/m^2 • Ratio:0.25 $g_{product}/g_{water}$ • Samples drained and cleaned with absorbent paper. • Controls: Air dried	• Air Drier Oven • 60°C; • HR=18% (dry and wet bulb T) • 12h of drying.	D_{eff} (m^2/s) increases 39.3% compared with controls.			Sugar loss and water gain is improved by ultrasound.	Ultrasound enhances the formation of bloated and needle cells.	

Pre-treatment: Ultrasound								
Attributes / **Crops** / **References**	**Ultrasound Method**	**Drying technology**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Comments**
Banana **cv Pacovan** (Fresh, Juazeiro Brazil) (Azoubel, et al., 2010)	• Bananas were cleaned with water, peeled and sliced (0.5 cm thickness and 3.21 cm diameter). • Ultrasonic bath: Distilled water at 30°C for 10, 20 and 30 min. • Frequency of 25 kHz. • Ratio: 0.25 $g_{product}/g_{water}$ • Samples drained and cleaned with absorbent paper.	• Bed Drier (continuous flow) • 50, 70°C • 3.0 m/s • Vertical air flow through 1 tray in closed circuit.	Ultrasound increases D_{eff} (m^2/s).			Ultrasound enhances water gain and solid losses.		
Carrot (*Daucus carota L. var Nantesa)* (Fresh, Madrid) (Gamboa-Santos, et al., 2013a)	• Carrots stored at 4°C, washed. Samples were cut into slices (diameter of 24mm and thickness of 4mm). Samples were minced (1-2mm). • Ultrasound probe at: 20 kHz and intensity of 0.26W/cm^3 for 60°C/10min and 70°C/15min. • Ratio: 0.2 $g_{product}/g_{water}$ • Stop blanching: Ice bath	• Air Drier (tray load) • 46°C • Parallel air flow • 4.9 m/s • HR=NI • Sliced samples: 9h • Minced samples: 7h drying • Sliced samples: 9h drying • Dry matter after drying: 85-89%	NI			Vitamin C is drastically reduced by ultrasound.		See blanching chapter.
Brussels sprouts (*lat. Brassica oleracea var. gemmifera*) (Fresh, Coventry UK) (Jambrak, et al., 2007)	• Brussels sprouts MC: 5.6 g/gdm; samples were washed and cut in half; **Ultrasound probe** • Frequency of 20 kHz and intensity of 39–43 W/cm^2 for 3 and 10 min. • Ratio: 0.067$g_{product}/g_{water}$ **Ultrasound bath** • Frequency of 40 kHz and intensity of 0.5 W/cm^2 for 3 and 10 min. • Ratio: 0.33$g_{product}/g_{water}$ • Controls: Freeze dried	• Air Drier • 60°C • 0.3 m/s • HR= 35.3±3% • Final moisture: 0.4 g water/g dm. • Freeze drying at -45°C for 3h.	Drying time is reduced by ultrasound compared with blanched and control samples.	*Ultrasound has a negative effect on rehydration kinetics.			*Compact form of vegetable lead to lower rehydration capacities.	See blanching chapter.

Pre-treatment: Ultrasound								
Attributes / **Crops** / **References**	**Ultrasound Method**	**Drying technology**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Comments**
Banana (*Musa ssp. Variety nanica*) (Fortaleza, Brazil) (Fernandes, et al., 2007b)	• Bananas were cut into discs (0.01 m height; 0.026 m diameter). • Ultrasonic bath: Distilled water at 30°C for 10, 20, 30 min • Frequency of 25 kHz; Intensity of 4870 W/m^2 • Ratio: 0.25$g_{product}/g_{water}$ • Samples drained and cleaned with absorbent paper. • Controls: Air dried	• Air Drier Oven • 60°C; • HR=16% (dry and wet bulb T)	Drying time is reduced by ultrasound.			Sugar loss and water gain is improved by ultrasound.		
Apple var. Idared (Warsaw) (Nowacka, et al., 2012)	• Stored at 5–8°C, peeled, cut into cubes 0.01 m; dipped in 0.1% citric acid solution. • Ultrasonic bath: Distilled water at 25°C for 10, 20, 30 min. • Frequency of 35 kHz. • Ratio: 0.25 $g_{product}/g_{water}$ • Samples cleaned with paper. • Controls: Air dried	• Air Drier • 70°C • 1.5 m/s • Parallel air flow • Net load: 1.13 kg/m^2)	Ultrasound reduces drying time in 31-40% and enhances drying rate compared with controls.			Ultrasound induces water elimination.	Shrinkage is enhanced by ultrasound around 9-11%, compared with controls. Long period of ultrasound allow cell damage.	
Cauliflower *(lat. Brassica oleracea var. botrytis)* (Fresh, Coventry UK) (Jambrak, et al., 2007)	• Cauliflower MC: 10.9 g/gdm; samples were washed and cut in small pieces (1.5x1.5cm) **Ultrasound probe** • Frequency of 20 kHz and intensity of 39–43 W/cm^2 for 3 and 10 min. • Ratio: 0.067 $g_{product}/g_{water}$ **Ultrasound bath** • Frequency of 40 kHz and intensity of 0.5 W/cm^2 for 3 and 10 min. • Ratio: 0.33 $g_{product}/g_{water}$ • Controls: Freeze dried	• Air Drier • 60°C • 0.3 m/s • HR=35.3±3% • Final moisture: 0.4 g water/g dm. • Freeze drying -45°C for 3h	Drying time is reduced by ultrasound compared with blanched and control samples.	Ultrasound probe increases rehydration ratios.				See blanching chapter.

Pre-treatment: Ultrasound								
Attributes / **Crops** / **References**	**Ultrasound Method**	**Drying technology**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Comments**
Pineapple Perola variety (Fortaleza, Brazil) (Fernandes, et al., 2009c)	• Pineapples were cut in triangles (height of 2±0.2cm and length of 3±0.2cm). • **Ultrasonic bath:** Distilled water • **Ultrasonic assisted osmotic bath:** Osmotic solution of sucrose and distilled water (35 and 70°Brix). • 30°C for 10,20,30 min. • Frequency of 25 kHz; • Intensity of 4870 W/m^2 • Ratio: 0.25$g_{product}/g_{water}$ • Control: Air dried	• Air Drier Oven • 60°C; • HR=18%	Drying time is reduced by Ultrasound*.			Ultrasound enhances sugar losses and water gain.		*Ultrasound assisted osmotic bath at 70°Brix reduced D_{eff} (m^2/s).
Carrots (*Daucus carota L. var. Nantesa*) (Fresh, Madrid) (Gamboa-Santos, et al., 2013b)	• Carrots were washed. • Sliced: diameter of 24 mm, 4mm of thickness. • Minced: 1-2 mm. • Ultrasonic probe: Distilled water at 60 and 70°C for 10, 15 min. • Frequency of 20 kHz; • Power of 400W • Ratio: 0.21 $g_{product}/g_{water}$ • Controls: Freeze Drying samples	• Air Drier (tray load) • 46°C • Parallel air flow • 4.9 m/s • HR=NI • Sliced samples: 9h drying • Minced samples: 7h drying • Freeze Drier	NI	Rehydration is improved by ultrasound in 8.6 to 20% compared with controls.	Ultrasound preserve Phenolic content compared with controls.	Similar losses of carbohydrates for Ultrasound and water blanching compared with controls.	Ultrasound provokes a porosity structure of cells.	See blanching chapter.

In the present Table 13 will be describe all the freezing technologies used for different food (vegetables and fruits). In some cases dehydration methods are applied after freezing treatments.

Table 13 - Attribute table of freezing pre-treatment.

Pre-treatment: Freezing								
Attributes / **Crops** / **References**	**Freezing Method**	**Drying technology**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Stability during storage**	**Comments**
Carrots (*Daucus Carota L., cv. Nantesa*) (Spain) (Neri, et al., 2014)	• Carrots were washed, peeled and cut in slices (1cm thick), 4 different batches. • Blanching at: 75°C/3min, 90°C/3min, 75°C/10min, 90°C/10min. • Ratio: 0.13 $g_{carrots}/g_{water}$ • Packaging in polyethylene bags, cooling in ice bath/5min. • **Freezing conditions:** • Blast Freezing at: -80°C/1 day. Storage in blast freezer at -18°C for 1, 3 and 8 months. • Thawing at 20°C for 3h. • Controls: Unblanched	NI				Freezing during 1 month impair cellular structure (polyhedral form) of carrots.		See blanching chapter.
Apples (*var.Jonagold*) (Fresh, Hungary) (Antal, et al., 2013)	• Apples stored at 5°C, washed, peeled, sliced (thickness 5 mm); MC= 86.5%(w.b) • **Freezing conditions:** • Household freezer at: 0.5°C/min, cooling to -25°C. • Contact plate freezer: 2°C/min, cooling to -25°C. • Chamber of vacuum freezer: 3°C/min, cooling to -25°C. • Temperature probes inserted in the top, middle and below the samples. • Experiments in triplicate	Freeze Drier • 200g of samples used in FD. • 0.45-0.82 mbar • - 50 to -55°C • Heating plate: 18°C • Drying time: 22-24h. • Experiments in triplicate	Slow freezing rate gave similar RR compared to FD.	Slow freezing rate of 0.5°C/min retained color (ΔE=9.7) compared to freezing rates of 2°C/min (ΔE=12) and 3°C/min (ΔE=14.3).		Freezing pre-treatments reduced apple firmness. Vacuum freezer was the best pre-treatment with a loss of 25.47% (N).		Apple firmness and rehydration kinetics is dependent on the apple variety and freezing speed. (see apples *var. Idared* in this table)
Green beans (German baby beans) (Estiaghi, et al., 1994)	• Beans cut in 2 cm • *Freezing at -18°C/1 day • *Blanching at: 100°C/7min; Ratio: NI; Stop blanching: Tap water/10 min. Samples drained • *High Pressure: Samples packed in polyethylene bags and placed in water at 50°C/5 min; 600 MPa, 70°C, 15 min; cooled in tap water/20min. • Pressurization in: 150 s • Depressurization in: 10 s • Controls: Sole drying	• Fluidized Bed Drier • 70°C • 4 m/s (for 1h) • After 1h: 3.2m/s	Freezing, Blanching/Freezing and High pressure/Freezing enhanced 32%, 73% and 38%, of water uptake, respectively compared to controls. Blanching before freezing were the best pre-treatments among all.					*The treatments were applied in sequence as follow: **i)** Drying (ref) **ii)** Freezing/ Drying **iii)** Blanching/Freezing/Drying **iv)** High Pressure/Drying **v)** High Pressure/Freezing/Drying ** See carrot and potatoes of the same author for comparison. (same study in Table 14)

Pre-treatment: Freezing								
Attributes / **Crops** / **References**	**Freezing Method**	**Drying technology**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Stability during storage**	**Comments**
Carrots (*Daucus carota*, cv. *Nazri*) (Fresh, Dublin) Fonte especificada inválida.	• Carrots stored at 4˚C, 24h. • Peeled, cut in discs (5mm) • *Blanching at 90˚C for 75 s. • Ratio: 0.057 $g_{carrots}/g_{water}$ • **Freezing conditions:** • Slow freezing -20˚C, 12h • Blast freezing -30˚C, 8 m/s, 2h. Storage at -20˚C. • Blanched and unblanched samples were submitted to both freezing conditions. • 60 days storage. • Control: Fresh	NI		Blast freezing (ΔE=6.3) retained higher color compared to slow freezing (ΔE=9.1) rates. Blast freezing retained higher content of polyacetylenes compared to slow freezing.		Texture (N) is reduced by freezing conditions	The content of polyacetylenes is reduced during storage by freezing conditions.	*Blanching helped color retention.
Pumpkin (*vs. Justynka*) (Warsaw) (Kowalska, et al., 2008)	• Pumpkins stored in a refrigerator at 5°C, %HR= 80–90%, during 1-2 months before use. • MC 83-84% (w/w), wet basis. • Pumpkin was washed and peeled. The flesh of pumpkin was use and cut into cubes (10 mm). • Freezing: -18±1°C for 16h. • Control: unblanched	**Osmotic dehydration** • Glucose 49.5% Sucrose 61.5%; Starch syrup 67.5% (distilled water) • Ratio product to solution 1:4 (w/w). • 30°C/3h. • The solution was placed in a water bath with stirring of suspension. • Samples were dipped in distilled water: 2s/T_{Room} to eliminate osmotic solution. • Drained by absorbent paper.			Freezing reduces water loss and enhance solids gain during OD.			Freezing samples were not defrosted before OD. See blanching chapter.
Apples (*M. domestica Borkh*) (Chassagne-Berces, et al., 2010)	• Apples used: Golden Delicious, Granny Smith ripe and unripe. • Apples stored at 4°C, one month. Keep at 21±1°C. • Apples cut in discs (2cm height, 1.2cm diameter) • **Freezing conditions** • Slow freezing in cold chamber at -20°C (1°C/min) • Intermediate freezing in N_2 gas chamber at -80°C, high convection (8°C/min) • Very fast freezing N_2 liquid at -196°C (310°C/min) • Polyethylene packaging • Thawing at 4°C. • Placed at T_{Room}= 21±1°C. • Control: Fresh.	NI		ΔE≈30 for all treatments compared with controls.	Soluble solids are improved by freezing.			Comparison with mango fruit, same authors.

Pre-treatment: Freezing								
Attributes / **Crops** / **References**	**Freezing Method**	**Drying technology**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Stability during storage**	**Comments**
Carrots (Dutch washing carrots) (Estiaghi, et al., 1994)	• Carrots cut in cubes (1 cm) • *Freezing at: -18°C/ 1 d. • *Blanching at: 100°C/7min; Ratio: NI; Stop blanching: Tap water/10 min. Samples drained • *High Pressure: Samples packed in polyethylene bags and placed in water at 50°C/5 min; 600MPa, 70°C, 15 min; cooled in tap water/20min. • Pressurization in: 150s • Depressurization in:10s • Controls: Sole drying	• Fluidized Bed Drier • 70°C • 4.8 m/s (for 1h) • After 1h: 4.6m/s	Freezing, Blanching/Freezing and High pressure/Freezing enhanced 100%, 38% and 50%, of water uptake, respectively compared to controls. Freezing was the best pre-treatments among all.					*The treatments were applied in sequence as follow: **i)** Drying (ref) **ii)** Freezing/ Drying **iii)** Blanching/Freezing/Drying **iv)** High Pressure/Drying **v)** High Pressure/Freezing/Drying ** See green beans and potatoes of the same author for comparison. (same study in Table 14)
Brussels sprouts (*Brassica oleracea L. gemmifera* DC) (cultivar Oliver, Buenos Aires) (Olivera, et al., 2008)	• Sprouts size (Weight 25.1±3.4g; Height 49.2±0.16mm; Diameter 35.8±0.22mm) • **Water immersion** (50°C/5 min) prior **blanching** at 100°C/3 min. • **Microwave heating (MW)** (700 W/5min) prior **blanching** at 100°C/2 min. • **Sole blanching** at 100°C/4min. • Ratio: 0.052$g_{product}$/g_{water} • Stop blanching: Ice-water/3 min. • Control: Unblanched. • **Freezing conditions** • Cabinet freezer: Liquid N_2 at -35°C, (2.3°C/min). • ***Storage at**: -18°C for 2,4,6,8 months. • **Thawing:** Boiling water immersion/7 min. • Controls**:** Untreated samples.	NI		Chlorophyll was reduced compared with controls.	Microwave followed freezing increases Asc acid retention. No differences in flavonoid content.	Firmness of water immersion prior blanching, MW prior blanching and sole blanching were reduced in 83.5%, 81.3% and 86%, respectively, compared with controls.	Texture is drastically reduced for treated and untreated samples during frozen storage of 8 months.	*No significant results between storage of 2,4,6 months compared to 8 months.
Mangos (*M. indica L. cv.* 'KENT') (Chassagne-Berces, et al., 2010)	• Mangoes stored at (21±1°C), one day. • Samples cut in cylinders (2cm height, 1.2cm diameter) • **Freezing conditions** • Slow freezing in cold chamber at -20°C (1°C/min) • Intermediate freezing in N_2 gas chamber at -80°C, high convection (8°C/min) • Very fast freezing N_2 liquid at -196°C (310°C/min) • Polyetilene packaging • Thawing 4°C. • Placed at T_{Room}= 21±1°C. • Control: Fresh	NI		*ΔE*=11 compared with controls.	Insignificant relation between freezing and soluble solids.			Comparison with apple fruit for the same author.

Pre-treatment: Freezing								
Attributes / **Crops** / **References**	**Freezing Method**	**Drying technology**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Texture/ Structure**	**Stability during storage**	**Comments**
Tomato (Micra RS) (Ripe, Krakow) (Lisiewska, et al., 2000)	• Tomatoes were kept in light room at 18°C, HR=80%. Sorted, washed, cleaned and cut in cubes (12mm side). • **Freezing conditions** • 500 g of tomato was used in a blast freezer at -40°C, frozen storage at -20°C and -30° for 1 year. • Control: Raw	NI		Freezing did not reduce β-carotene and lycopene significantly compared with controls.	No significant difference in vitamin C content.	Pectin reduction is caused by freezing method and frozen storage.	pH increased during storage. Higher storage temperatures preserved vitamin C, β-carotene and lycopene.	
Apples (*var.Idared*) (Fresh, Hungary) (Antal, et al., 2013)	• Apples stored at 5°C, washed, peeled, sliced (thickness 5 mm); MC= 86.5%(w.b) • **Freezing conditions:** • Household freezer at: 0.5°C/min, cooling to -25°C. • Contact plate freezer: 2°C/min, cooling to -25°C. • Chamber of vacuum freezer: 3°C/min, cooling to -25°C. • Temperature probes inserted in the top, middle and below the samples. • Experiments in triplicate	Freeze Drier • 200g of samples used in FD. • 0.45-0.82 mbar • - 50 to -55°C • Heating plate: 18°C • Drying time: 22-24h. • Experiments in triplicate	Slow freezing rate was the best pre-treatment applied to enhance rehydration kinetics.	Slow freezing rate of 0.5°C/min retained color (ΔE=7.3) compared to freezing rates of 2°C/min (ΔE=11.3) and 3°C/min (ΔE=16.8).		Freezing pre-treatments reduced apple firmness. Vacuum freezer was the best pre-treatment with a loss of 22.61% (N).		Apple firmness and rehydration kinetics is dependent on the apple variety and freezing speed. (see apples *var. Jonagold* in this table)
Potatoes (Bintje) (Estiaghi, et al., 1994)	• Potatoes peeled and cut in dices (1 cm) • *Freezing at -18°C/ 1 d • *Blanching at: 100°C/4min; Ratio: NI; Stop blanching: Tap water/10 min. Samples drained • *High Pressure: Samples packed in polyethylene bags and placed in water at 50°C/5 min; 600MPa, 70°C, 15 min; cooled in tap water/20min. • Pressurization in: 150s • Depressurization in:10s • Controls: Sole drying	• Fluidized Bed Drier • 70°C • 4.6 m/s (for 1h) • After 1h: 3.7m/s	Sole freezing did not enhance water uptake. Blanching/Freezing and High pressure/Freezing enhanced 117%, 29% of water uptake, respectively compared to controls. Blanching before freezing were the best pre-treatments among all.					*The treatments were applied in sequence as follow: **i)** Drying (ref) **ii)** Freezing/ Drying **iii)** Blanching/Freezing/Drying **iv)** High Pressure/Drying **v)** High Pressure/Freezing/Drying ** See carrot and green beans of the same author for comparison. (same study in Table 14)

In the present Table 14 will be describe all the high pressure technologies used for different food (vegetables and fruits). In some cases dehydration methods are applied after high pressure treatments.

Table 14 - Attribute table of high pressure pre-treatment**.**

Pre-treatment: High Pressure												
Attributes / **Crops** / **References**	**High Pressure Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Sensory quality**	**Stability during storage**	**Comments**
Olives (*Olea europaea etnovar. Cornezuelo*) (Jaén Spain) (Pradas, et al., 2012)	• Olives harvested in September-October, 2008. • Cracked olives were washed/5 days (water changed each day). • Olives were placed in a liquid (100L water for 6kg NaCl, 0.3kg thyme, 1kg garlic, 0.5kg fennol, 1L vinegar), Ratio:2.5g_{olives}/g_{water} • <u>High Pressure at:</u> • 400 MPa/5 min • 400 MPa/10 min • 600 MPa/ 5 min • 600 MPa/ 10 min • Pressure fluid: Water • Control: Untreated • Storage at ambient temperature • $T_{storage}$=15˚C First two months • $T_{storage}$=22˚C after 2nd month to 186th day • $T_{storage}$=30˚C from 187th onward.	NI				No relevant differences.			Controls and HP at 600 MPa/5 min lost firmness (N) after 1 year compared to other treatments.	HP at 400 MPa/5 min gave the best Overall sensory quality, odor and flavor compared to controls and other treatments.	HP at 400 MPa/5 min improved olives shelf life.	*Ratio considered (ρ_{water}=997 kg/m^3)
Apple (Amasya) (Yucel, et al., 2010)	• MC=87.1±0.3% • Storage at 4°C, cut in rectangular shape (1x1x4 cm) • Samples wrapped in LDPE paper. • <u>High Pressure at:</u> 100, 200, 300 MPa; 5,15,45 min; 20, 35˚C.	• Tunnel Drier • 45°C, HR=12±2% • 65°C, HR=5±0.5% • 85°C HR=2.5±0.3% • 0.4 m/s • 0.8 m/s		Drying time is reduced by P>100 MPa.				Cell permeabilization is improved by P>100 MPa.				

Pre-treatment: High Pressure												
Attributes / **Crops** / **References**	**High Pressure Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Sensory quality**	**Stability during storage**	**Comments**
Green beans (German baby beans) (Estiaghi, et al., 1994)	• Beans cut in 2 cm • *Freezing at -18°C/1 day • Ratio: NI; Stop blanching: Tap water/10 min. Samples drained • *High Pressure: Samples packed in polyethylene bags and placed in water at 50°C/5 min; 600 MPa, 70°C, 15 min; cooled in tap water/20min. • Pressurization in: 150 s • Depressurization in: 10 s • Controls: Sole drying	• Fluidized Bed Drier • 70°C • 4 m/s (for 1h) • After 1h: 3.2m/s		Freezing applied after HP enhances drying rate compared to HP.	High Pressure/ Freezing increases water uptake in 38% compared with controls. Sole high pressure pre-treatment did not enhance water uptake.							*The treatments were applied in sequence as follow: **i)** Drying (ref) **ii)** Freezing/ Drying **iii)** Blanching/ Freezing/Drying **iv)** High Pressure/Drying **v)** High Pressure/Freezing /Drying ** See carrot and potatoes of the same author for comparison. (same study in Table 13)
Apple (Red delicious) (Yucel, et al., 2010)	• MC=85.6±0.3% • Storage at 4°C, cut in slabs (1x1x4 cm) • Samples involved in LDPE paper. • High Pressure at: 200 MPa; 15,45 min; 20, 35°C.	• Tunnel Drier • 45°C, HR=12±2% • 0.4 m/s		Drying time is reduced by P>100 MPa.				Cell permeabilization is improved by P>100 MPa.				
Carrot (Yucel, et al., 2010)	• MC=90.5±0.3% • Storage at 4°C, cut in rectangular shape (1x1x4 cm) • Samples involved in LDPE film. • High Pressure at: 100, 200, 250, 300 MPa; 5,15,30,45 min; 20, 35°C.	• Tunnel Drier • 27°C, HR=35±5% • 45°C, HR=12±2% • 65°C, HR=5±0.5% • 85°C, HR=2.5±0.3% • 0.4 m/s		Drying time is reduced by P>100 MPa.				Cell permeabilization is improved by P>100 MPa.				

Pre-treatment: High Pressure												
Attributes / **Crops References**	**High Pressure Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Sensory quality**	**Stability during storage**	**Comments**
Strawberry (*Fragaria ananassa, cv Camarosa*) (Sulaiman, et al., 2013)	• Puree or whole fruit were packed in bags of polyester lined with silicon oxide, laminated to nylon and cast polypropylene. • Puree (pH=3.31±0.15; 9.3±0.1 °Brix) • 40 g of puree was packed in small containers (150mmx 105mm, 1mm thick) • High Pressure at: • T_{Room} • 200 MPa/5 min • 600 MPa/15 min • Liquid medium: Distilled water	NI	HP at 600 MPa/15 min inactivate PPO in 82%.									
Carrots (Dutch washing carrots) (Estiaghi, et al., 1994)	• Carrots cut in cubes (1 cm) • *Freezing at: -18°C/ 1 d. • Ratio: NI; Stop blanching: Tap water/10 min. Samples drained • *High Pressure: Samples packed in polyethylene bags and placed in water at 50°C/5 min; 600MPa, 70°C, 15 min; cooled in tap water/20min. • Pressurization in: 150s • Depressurization in:10s • Controls: Sole drying	• Fluidized Bed Drier • 70°C • 4.8 m/s (for 1h) • After 1h: 4.6m/s		No significant differences in drying rate for all treatments.	High pressure/Freezing increases water uptake in 50% compared with controls. Sole high pressure pre-treatment did not enhance water uptake.							*The treatments were applied in sequence as follow: **i)** Drying (ref) **ii)** Freezing/ Drying **iii)** Blanching/ Freezing/Drying **iv)** High Pressure/Drying **v)** High Pressure/Freezing /Drying ** See green beans and potatoes of the same author for comparison. (same study in Table 13)
Green beans (Yucel, et al., 2010)	• MC=90.8±0.2% • Storage at 4°C, cut in 3 cm length. • Samples covered by LDPE paper. • High Pressure at: 100, 200, 300 MPa; 15,45 min; 20, 35°C.	• Tunnel Drier • 45°C, HR=12±2% • 65°C, HR=5±0.5% • 0.4 m/s		Drying time was not reduced by high pressure.				HP at 20°C/200 MPa resulted in tissue contraction.				
Potatoes (Bintje) (Estiaghi, et al.,	• Potatoes peeled and cut in dices (1 cm) • *Freezing at -18°C/ 1 d • Ratio: NI; Stop blanching: Tap water/10 min. Samples	• Fluidized Bed Drier • 70°C • 4.6 m/s (for 1h)		HP has a negative effect in drying rates compared to dried samples	High pressure and High pressure/Freezing increases							*The treatments were applied in sequence as follow: **i)** Drying (ref)

Pre-treatment: High Pressure												
Attributes / **Crops** / **References**	**High Pressure Method**	**Drying technology**	**Enzymatic Inactivation**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Sensory quality**	**Stability during storage**	**Comments**
1994)	drained • *<u>High Pressure:</u> Samples packed in polyethylene bags and placed in water at 50°C/5 min; 600MPa, 70°C, 15 min; cooled in tap water/20min. • Pressurization in: 150s • Depressurization in:10s • Controls: Sole drying	• After 1h: 3.7m/s		and freezing treatment.	water uptake in 23% and 30% , respectively compared with controls.							**ii)** Freezing/ Drying **iii)** Blanching/ Freezing/Drying **iv)** High Pressure/Drying **v)** High Pressure/Freezing /Drying ** See green beans and carrots of the same author for comparison. (same study in Table 13)
White Cabbage *(Brassica oleracea L. var. capitata alba)* (Fresh) (Alvarez-Jubete, et al., 2013)	• Cabbages stored 4°C/1d. • Elimination of leaves and stalk; Cut in parts, grated; Packs of 220 g were double vacuum packed to avoid deterioration in HP. • High Pressure at: 200, 400, 600 MPa; 20,40°C; 5 min • Pressure medium: Ethanol-castor oil (90:10). • Compression and decompression: 300 MPa/min. • <u>Blanching:</u> Samples kept in pierced bags, 90-95°C/ 3min; Ratio: NI; Stop blanching: water/ice mixture • Controls: Non treated • <u>Texture/Color analysis:</u> 1 d after treatments.	NI	POD may be inactivated by higher pressure treatments (600 MPa).			Significant color changes at 400 MPa and 20-40°C.	HP at 600 MPa and 20-40°C retained AscA compared to other HP treatments. Lower pressure levels resulted in higher AscA losses.		All HP treatments enhanced firmness. Blanching kept same texture as the controls.			* For color measurement leaves of cabbage were included

In the present Table 15 will be describe all the osmotic dehydration methods used for different food (vegetables and fruits). In some cases air dehydration is applied after osmotic dehydration treatments.

Table 15 - Attribute table of osmotic dehydration treatment.

Pre-treatment: Osmotic dehydration									
Attributes / **Crops References**	**Osmotic Dehydration Method**	**Drying technology**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Comments**
Apple, Carrot, Pumpkin (Kowalska, et al., 2001)	• Stored 5°C, air humidity 80-90%; washed, peeled, cut in cubes of 10 mm; • Sugar solution: 61.5% at 30°C during 180 min. • Ratio solution to product: 0.25$g_{product}/g_{solution}$ • Continuous stirring at: 100 min^{-1} of suspension. • Samples blotted with a filter paper.	NI				Apple incorporated better sugar compared with pumpkin and carrot.*			*Sugar incorporation was dependent on the crop.
Pumpkin (*Cucurbita moschata*) (Mature) (Garcia, et al., 2007)	• Pumpkins were cut, peeled, seeded and sliced (3.97±0.15 mm thickness). • Commercial sucrose solution: 60% (w/w) at constant 27°C. • Single times: 1h. • Ratio solution to product was approximately 15:1 (w/w). • Stirring device. • Samples cleaned with wet tissue; blotted with paper. • 48h of OD were enough to reach the equilibrium state. • Controls: Untreated, dried.	• Air Drier • 50 and 70°C • 2 m/s, parallel flow. • 0.3 kg of fresh and OD samples dried until equilibrium moisture.	OD enhanced water diffusion during drying.				Volume reduction and density improvement was detected for OD and sole dried samples. Slightly shrinkage prevention for OD samples.		
Carrots (*Daucus carota*) (Fresh) (Rastogi, et al., 2004)	• Carrots were peeled and sliced (2.5±0.1 mm thickness) • MC=85.57±0.5%, fresh weight basis. • Commercial sucrose solution of 0, 5, 10, 20, 40, 60°Brix concentration at 25 ± 1°C during 5h. • Ratio: 0,04 $g_{product}/g_{solution}$ • Constant stirring. • Carrots rinsed in water, blotted gently with paper. • Controls: Fresh dried carrots.	• Air Drier • 60±1°C • Other drying parameters: NI		Lower concentration of sugar during OD (0-10°Brix) gives higher rehydration capacity of dried samples.					
Onion (*Allium cepa L.)* (Bellary red variety)	• Onions peeled, cut (perpendicular to the axis) into 5mm slices. • MC=86.77±0.5% (w.b)	• Air Drier • 60°C • 12h • Tray load: 0.33		*Rehydration was not improved when samples were OD				Osmotic solutions improved the firmness of cell tissues	*During rehydration, the slice of onion was used as an infinite beam.

Pre-treatment: Osmotic dehydration									
Attributes / **Crops** / **References**	**Osmotic Dehydration Method**	**Drying technology**	**Drying kinetics**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Nutrition (Vitamin, Ascorbic Acid, Nutrients)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Comments**
(Fresh) (Debnath, et al., 2004)	• NaCl solution (10%) at T=25±2°C for 1h • Sucrose solution (50%) T=25±2°C for 3h • Ratio: 0.04 $g_{product}/g_{solution}$ • Stirring device and slices dipped with wire mesh. • Samples removed, rapidly washed with water, blotted with tissue paper. • Control: Untreated, dried.	kg/m^2		compared with controls.				compared to controls.	
Apple (Italian *Golden Delicious*) (Prothon, et al., 2001)	• Apples stored at 4°C, washed, cut in cubes (13 mm); immediately soaked in 20°C tap water (prevent browning). • Sucrose solution of 50% (w/w) at 22°C during 16 h. • 50 apple cubes to 600 mL • Stirring device. • Control: Untreated, dried.	• Semi-continuous, hot air and microwave oven (MW-AD) • 50, 60, 70°C • 2 m/s; • 5 h; • HR_{final}= 8-10%. • Power level 0,1-1,0 W/g_{apple}	OD reduced the drying time.	Rehydration capacities were not improved by OD (RR around 4) compared with control samples (RR around 5.5).	No relevant differences of ΔE between osmotically dehydrated samples and controls.			* Apple samples firmness is dependent on OD (leaching of Ca^+ ions) and MW-AD temperatures of 60 and 70°C (denaturation of PME).	*Texture measurements were made after water rehydration in distilled water at 20°C/14h and related to fresh apple samples.

In the present Table 16 will be describe different treatments applied to different paprika cultivars. In some cases dehydration methods are applied after treatments.

Table 16 - Attribute table for different cultivars of paprika.

Attributes / Peppers References	Method	Drying technology	Drying kinetics	Rehydration kinetics	Color (Chlorophyll, β-carotene, polyphenols)	Nutrition (Vitamin, Ascorbic Acid, Nutrients)	Texture/ Structure	Comments
Red Pepper (*Capsicum annum L.)* (Turkey, Fresh) (Doymaz, et al., 2002)	• Pepper MC=81.9% wet basis; 0.3kg of fresh pepper was used in each experiment. • Whole peppers dipped/1min at T_{Room}: • 2% ethyl oleate and 4% K_2CO_3 solution. • 2% ethyl oleate and 5% K_2CO_3 solution. • 2% ethyl oleate and 6% K_2CO_3 solution. • Sliced peppers 1cm; 1min; T_{Room}: • Dried untreated with dipping solution. • 2% ethyl oleate and 5% K_2CO_3 solution. • Controls: No solution.	• Air Drier (Batch) • 50/60°C; • 10-60min • Perpendicular air flow • Final MC= 11%, wet basis. • Cooling at T_{Room}/15 min	Sliced peppers dipped in ethyl oleate solution provide faster drying rates compared to other treatments.		Ethyl oleate solutions preserved red color of peppers.			
Red bell Pepper (*var. Lamuyo*) (Vega-Galvez, et al., 2008)	• Red peppers stored at 5°C, 4h before use; cut in slabs (7 mm thickness) • Samples dipped in aqueous solution: • 20% (w/w) NaCl; • 1.0% (w/w) $CaCl_2$; • 0.3% (w/w) $Na_2S_2O_5$ • 10 min at 25°C. • Controls: No treated, dried.	• Oven • 50, 60, 70, 80°C. • 2.5±0.1 m/s. • Load density: 10 kg/m^2 of samples used. • Samples dried to constant weight at 70°C.	*Samples treated with solutions of NaCl and $Na_2S_2O_5$ dried slower.	Rehydration was improved by solutions of NaCl and $Na_2S_2O_5$.	Calcium salts and sodium metabisulfite improved color quality.	AscA is retained by the solutions applied.	Microstructure of cells is preserved by solutions compared to controls.	*Solutions created hygroscopic structure which decrease water movement from peppers to the surface.
Red Paprika (*Capsicum annumL.*) (Fresh) (Ade-Omowaye, et al., 2001)	• Paprika cut into slices (1 cm) perpendicular to length axis; MC=91.2%, wet basis. • Blanching at: 100°C/3min; Ratio: NI; Stop blanching: Cooled in tap water; Whole paprikas were blanched • Skin treatments: Lye peeling, samples dipped in 5% (w/v) NaOH solution at 25, 35°C/20 min; samples washed with tap water.	• Fluidized Bed Drier (closed loop with hot air re-circulation) • 60°C, 6 h, 1 m/s. • $T_{wet\ bulb}$=30°C; $T_{dry\ bulb}$=63°C.	Drying rate is increase by all treatments during constant rate drying.				HHP and HELP might induced cell permeabilization, improving heat and mass transfers.	*PE- Polyethylene

Attributes / Peppers / References	Method	Drying technology	Drying kinetics	Rehydration kinetics	Color (Chlorophyll, β-carotene, polyphenols)	Nutrition (Vitamin, Ascorbic Acid, Nutrients)	Texture/ Structure	Comments
	• Acid treatment: 5% (v/v) HCl solution at 25, 35°C/20 min; samples washed with tap water. • High hydrostatic pressure: samples vacuum packed in PE bags; 400 MPa, 10 min, 25°C.* • Water and anti-corrosion fluid was used as a pressure- transmitting medium. • High intensity electric field pulse (HELP): • Peak field strength in the sample: E=2.4 kV/cm; • Pulse duration: t=300µs; • Pulsing rate:1 Hz; • Number of pulses: n=10. • The capacitor was discharged at 1 Hz through the food material in water (conductivity 0.8 mS/cm; 25°C) • Specific energy input: 3 kJ/kg product.							

In the present Table 17 will be describe different treatments applied to different tomato cultivars. In some cases dehydration methods are applied after treatments.

Table 17 - Attribute table for different cultivars of tomato.

Attributes / Tomato References	Method	Drying technology	Drying kinetics	Rehydration kinetics	Color (Chlorophyll, β-carotene, polyphenols)	Nutrition (Vitamin, Ascorbic Acid, Nutrients)	Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density	Texture/ Structure	Stability during storage	Comments
(Lycopersicon esculentum Mill.) (Turkey) (Doymaz, 2007)	• Tomato pieces immersed in alkaline ethyl oleate solution (2% ethyl oleate + 4% potassium carbonate) for 1min.	• Air Drier • 55, 60, 65 ,70˚C • 1.5m/s	Drying time was reduced by 8.5 - 15.1% according to the drying temperature. The alkaline ethyl oleate solution enhanced D_{eff}	Dried tomato at 65˚C absorbed more water than samples dried at 55, 60 and 70˚C.						Same results were reported for red pepper.
(Lycopersicon esculentum Mill.) (Pear-shaped type, Brazil) (Marfil, et al., 2008)	• Tomatoes samples were peeled and other non-peeled. • Samples dipped in a sodium hydroxide solution (6 g NaOH/100 g solution) at 30˚C /30 min. • <u>Osmotic treatment:</u> Peeled tomatoes dipped in a NaCl/sucrose solution (10 g NaCl/100 g solution and 35 g sucrose/100 g solution) 1 h/30˚C; Ratio: $0.1 g_{tomato}/g_{solution}$ • Controls: Fresh	• Air Drier • 50, 60, 70˚C • 1m/s	Drying of peeled tomatoes improved ascorbic acid retention compared with cut and non-peeled.			Peeling and osmotic treatment reduced ascorbic acid content compared to controls. Higher drying temperature lead to AscA and VitC degradation.				
(I-Tien-Hung and Sheng-Neu) (Twain) (Chang, et al., 2006)	• Tomatoes were cut in dices (1cm)	• Air Drier • 80 ˚C/2h and after 60˚C/6h. • Freeze Drier • -50˚C, 5Pa, 24h.				AscA was reduced in 56- 61% by air drying, according to tomato variety. Freeze drying reduced 10% of AscA. Drying conditions improved the nutritional value of tomatoes.				(Gahler, et al., 2003) reported that the ascorbic acid content of tomatoes depended on the tomato varieties.
Cherry tomatoes (*Lycopersicon esculentum var. Cerasiforme cv. Cocktail*)	• Tomatoes were cut into halves and placed in a stirred container with an osmotic solution. • Solution heated up by a water bath. • Brine solution of 20%	• Microwave assisted hot-air. • Microwave at:0, 1, 3, 7 and 10 W/g. • Hot air • 50˚C • 1.6m/s.	Addition of Ca^{2+} allowed an increase in up taking of soluble solids and slight increase of water removal.		Ca^{2+} avoids changes in ΔE.			Ca^{2+} prevents textural deterioration on tomato pulp.		

Attributes / Tomato References	Method	Drying technology	Drying kinetics	Rehydration kinetics	Color (Chlorophyll, β-carotene, polyphenols)	Nutrition (Vitamin, Ascorbic Acid, Nutrients)	Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density	Texture/ Structure	Stability during storage	Comments
(Spain) (Heredia, et al., 2007)	(w/w) at 30 ˚C was stirred at 70 rpm/3 h. • Ternary solution of 27.5% sucrose (w/w) and 10% of NaCl (w/w) at 30˚C was stirred at 70 rpm/3 h.									
Tomatoes v. Hazera, cv. 516TmVF1F2 (Poland) (Lewicki, et al., 2004)	• Tomatoes immersed in water: 100˚C/3 min. • Peeled and seeds removed. • Soaking in 1% $CaCl_2$ solution/30 min.	• Air Drier • 60°C • 2m/s	During convective drying of pre-treated tomato larger tissues cavities are formed.				Dipping in $CaCl_2$ gave rise to an isometric shrinkage around 15%.	Pre-treatment with Ca^{2+} affected the cell tissue of tomato.		
(var. Avinash) (India) (Davoodi, et al., 2007)	• Tomatoes cut (thickness about 5mm). • Soaking in 1 g/100 g $CaCl_2$ in water solution 1:1 (w/w) at T_{Room}/10 min. • Immersed in KMS 0.2 g/100 g solution (1:1) at T_{Room} /10 min. • Immersed in 1 g/100 g $CaCl_2$ with 0.2 g/100 g KMS and the same mass of water/10 min. • Immersed in 7 g/100 g NaCl at 80˚C/5 min in an equal mass of solution.	• Sun Drier • Air Drier • 65°C • 1.2m/s	Advantage of $CaCl_2$ and KMS solution: Increase drying rate.	Advantage of $CaCl_2$ and KMS solution: Improve rehydration and storage conditions.	Advantage of $CaCl_2$ and KMS solution: Prevent enzymatic browning, fermentation and improve retention of lycopene.					$CaCl_2$ is used to prevent enzymatic browning. KMS is used to preserve lycopene.
Oval-type tomato (Pakistan) (Baloch, et al., 1997)	• Tomatoes were cut (thickness of 2mm) • Soaking in 1% $CaCl_2$ • Soaking in 2% NaCl • Soaking in 2% KMS • Controls: Dipped in water. • All the samples were soaking at 30°C/2 min. • Samples grinded and stored at 40˚C (Dark environment and polyethylene bags).	• Air Drier • 51˚C/8h and after 46˚C/16h							NaCl had no effect on carotenoid loss but CaC_{l2} improved the loss of carotenoid components. $CaCl_2$ avoids enzymatic browning. Potassium metabisulfite and NaCl avoid enzymatic brown reaction compared with control samples but the effect is less strong than $CaCl_2$.	Potassium metabisulfite decreased the rate of loss of carotenoid during storage
(Lycopersicum esculentum, variety industrial long life)	• Tomato samples had triangular shape. • Samples dipped in NaOH solution (3% w/w) at 100˚C/1 min; skin removed. • Osmotic treatments at	• Air Drier • 60°C • 0,087m/s	Drying time decreases if the dried tomatoes are skinned. Osmotic dewatering increased the							

Attributes / Tomato References	Method	Drying technology	Drying kinetics	Rehydration kinetics	Color (Chlorophyll, β-carotene, polyphenols)	Nutrition (Vitamin, Ascorbic Acid, Nutrients)	Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density	Texture/ Structure	Stability during storage	Comments
(Brasil) (Souza, et al., 2007)	30°C; 0.5-3h: • Sucrose 25%, salt 5% • Sucrose 25% , salt 10% • Sucrose 35%, salt 5% • Sucrose 35%, salt 10% • Ratio: 0.25$g_{Tomato}/g_{Solution}$		drying kinetic of dehydration.							
(cv. Cencara) (Italy) (Pani, et al., 2008)	• Tomatoes were cut in slices (1 cm) • Isotonic solution + $CaCl_2$ 2% (wt/wt) • Osmotic solution of Corn Syrup 60% (wt/wt) at 25°C /120 min. • Osmotic solution of Corn Syrup 60% (w/w) + $CaCl_2$ 2% (wt/wt) at 25°C/120 min.	• Air Drier • 180°C • 1.5 m/s	*The kinetic of dehydration is increased by osmotic solution or presence of Ca^{2+}.		Osmotic solutions increased the color retention of dehydrated tomatoes.		No clear results concerned to shrink pieces of tomato.			*This kinetic is decreased at the end of drying process.
(Rita cultivar Peviani srl) (Italy) (Zanoni, et al., 1998)	• Tomatoes were cut into halves, seeds removed.	• Air Drier • 80, 110°C • 1.5 m/s			Lycopene remain in tomato even at 110˚C (lycopene stability during hot air drying). Enzymatic browning is higher at high temperature 120˚C than at 80˚C.				Loss of lycopene take place during long periods of storage.	
(Roma tomatoes) (California, USA) (Durance, et al., 2005)	• Tomatoes were cut in longitudinal radial sections.	• Air Drier • 70°C; 1.5 m/s • Vacuum Microwave • 6,65kPa • 16 kW • 6 rpm • 10 L/min		Rehydration capacity is enhanced by vacuum microwave compared with air drying.	Vacuum microwave gave best color compared with air drying.		Vacuum microwave gave lower density compared with air drying.			
Commercial concentrated tomato pulp (Greece) (Goula, et al., 2005)		• Spray Drier • Air inlet T:110,120, 230, 240˚C • Drying air flow rates: 17.5; 19.25; 21 and 22.75 m^3/h			Water activity, temperature, oxygen, and light exposure have direct effect on degradation of lycopene.					
Commercial tomato pulp Insoluble solid-rich tomato (concentrated from canned peeled tomato)		• Air Drier • 60,70,80,110˚C • 1.5m/s	Lycopene is reasonable stable during air drying for all variety of products.			AscA was very susceptible to oxidative heat deterioration.				

Attributes / Tomato References	Method	Drying technology	Drying kinetics	Rehydration kinetics	Color (Chlorophyll, β-carotene, polyphenols)	Nutrition (Vitamin, Ascorbic Acid, Nutrients)	Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density	Texture/ Structure	Stability during storage	Comments
(Italy) (Giovanelli, et al., 2002)										
Roma, High Lycopene (FG98-218) Tangerine tomatoes (USA) (Hackett, et al., 2004)		• Storage in dark • 25,50,75,100˚C							Isomerisation of lycopene is intrinsically related with storage temperature.	*For a temperature below 50˚C, the oxidation process is mainly responsible of degradation.
Japan-Golden (orange) Chin-Yan (yellow) Holland-Golden (yellow) Holland-Red (red) Sheng-Neu (red) Taur-Tay-Lang (red) (Taiwan) (Chang, et al., 2007)	• Blended to slurry	• Air Drier • 40, 80, 120°C • 1.5 m/s			*For all processed tomatoes lycopene content was affected by dying temperatures. High temperatures decreasing the total phenolics and total flavonoids contents.					*Lycopene content was also affected by tomato cultivars.

In the present Table 18 will be describe puffing technology applied to different food (vegetables and fruits). In some cases dehydration methods are applied before and after puffing treatments.

Table 18 - Attribute table of puffing technology.

Post-treatment: Puffing							
Attributes / **Crops** / **References**	**Method**	**Drying technology**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Comments**
Carrot (Fresh, Birmingham) (Brown, et al., 2008)	• Carrots stored at 4˚C, cut in discs (length 2.5cm, diameter 0.4cm from the cortex) • Blanching at: 100˚C/10 min; Ratio: NI; Stop cooling: NI • For the Sc CO_2 treatments: 4 carrot discs placed in a 50 mL vessel. • Sc CO_2 at: 40, 50, 60˚C and 20MPa Depressurization: 0.4MPa/min. • Sc CO_2 ethanol-modified: (6% mol ethanol) 40, 50, 60˚C and 20MPa. Depressurization: 0.4MPa/min • Oven Drier: 40, 50, 60˚C until 6-10% (w/w) moisture content) • Controls: Raw	*NI	Sc CO_2 ethanol-modified enhanced water gain in the early stages of rehydration at 50˚C. Blanching followed Sc CO_2 increased rehydration after 40 min at 50˚C.	Sc CO_2 allows pale colors compared to controls.	Sc CO_2 ethanol-modified promotes lower density and maintains initial volume.	Texture is enhanced by air drying treatments.	*Oven drier was applied separately.
Potato (Fresh, cv. *Estima* variety) (Shilton, et al., 1998)	• Potatoes cut in dices. • Blanching at: 100°C/80s; Ratio: NI; Stop cooling: cold water; Excess water removed with paper. • Fluidized Air Bed Puffing: Column (0.16m) of salt particles 300μm, air at 120-130°C during 1.5 ,3 and 4.5 min and velocity of 1.5m/s. Samples placed in wire mesh. Final MC=55-52% (w.b)	• Oven Drier • 90°C • 45, 60, 75, 90, 105 min • 0.1 m/s • Samples placed in perforated metallic plates. • Final MC=14% (w.b)		Browning color appeared for puffing times higher than 4,5min.	Blanched samples show higher volume. Smaller dimensions of samples improved volume ratio during puffing.		
Potato (Fresh, cv. Estima variety)	• Storage at 10°C/ 1week • Potatoes were washed, peeled, cut in dices (1 cm) and sieved.	• Cabinet Drier • 60, 80, 90 °C • 1.5 m/s • Side drying was			Blanching helps puffing in volume expansion.	Blanching avoids tissue rigidity which improves puffing.	*The success of puffing is dependent on blanching. Sulfiting has no

Post-treatment: Puffing							
Attributes / **Crops** / **References**	**Method**	**Drying technology**	**Rehydration kinetics**	**Color (Chlorophyll, β-carotene, polyphenols)**	**Volume shrinkage/ Deformation/ Shape/ Porosity/ Bulk density**	**Texture/ Structure**	**Comments**
(Varnalis, et al., 2001)	• *Blanching at: 100˚C; Ratio: NI; Stop cooling: NI • Sulfiting at: 400 ppm of $Na_2S_2O_5$, immersed in tap water to remove extra SO_2. • Fluidized Air Bed Puffing at: 200°C/ 50s	changed • *Drying was performed before and after puffing.					influence in puffing. Longer initial drying times do not favor volume expansion of puffed samples.
Potato (Russet Burbank, Fresh) (Tabeidie, et al., 1992)	• Potatoes stored 4h/week, 10°C, HR=90%. • Washed, peeled and cut (3x7x20.3 mm) • *Blanching at: 100°C/ 5 min; Ratio: 0.19g_{potato}/g_{water} • CO_2 puffing: 6.55 kPa/15 min; Fast depressurization; Samples placed in plexiglas box, dried at 70±10 °C.	• Air Drier • 55°C • HR=20% • Moisture contents: 23, 33, 43, 53 % (w.b) • 2d storage in desiccator, T_{Room}. Air drier used before and after puffing. • Freeze Drier • -20°C • 0.03mbar;	CO_2 puffing improved RR compared to air drying. Freeze drying showed the highest RR.		Volume of puffed potatoes is dependent on moisture content.	Maximum force decrease 23% for puffed samples compared to air dried.	* Blanching was applied before other treatments.

In the Table 19 are present three patents using carbon dioxide as a medium for the puffing step. In general terms, the Table 19 is organized with the main description of the process which comprises the purpose of the method (goal), the principle and the application which is mainly to foods (vegetables, fruits, cereals, etc). In addition, the operation steps are also described in more detailed and some conditions required are depicted.

Table 19- Main characteristics of three patents using carbon dioxide for puffing.

Patent • Number • *Applicant* • Filing date • Publication date	**Title**	**Description** • Goal • Principle • Application	**Steps/operation**	**Conditions/requirement**	**Comments**
• DE 3540544 A1 • *R. Vecsei* • 15/11/1985 • 21/05/1987 (Gleich, 1987)	Process for producing dry food products to be prepared rapidly	• To produce dry food pieces (fruit, vegetable, meat and fish) that can be re-constituted by pouring hot water on them without boiling. • Infusing pre-dried pieces with pressurized gas and subsequent puffing. • Application: instant dry soups and meals.	• A dried product is exposed to a gas like nitrogen under high pressure up to 800 bar • The gas pressure is then reduced and the gas remaining in the foodstuff at low temperature is expelled by dry heating. • A porous dry food product is obtained • Flavors that have been solubilised in a gas (e.g. CO_2) under supercritical conditions can be infused into the dry food pieces.	• Drying before puffing	• Starting point of the invention are pre-dried food pieces without specifying the moisture content. • Claims up to 100% increase in volume of the pre-dried material • Efficiency of the puffing process should depend on the plasticity of the dry material. • Heating the pieces to 90°C to drive out the residual gas for puffing might also help to plasticize the food matrix. • Our puffing works at lower temperatures since it relies on plastization by moisture.
• EP 0280402 A2 • *Massey Univ. / New Zealand Min.Agriculture & Fisheries* • 26/01/1988 • 31/08/1988 (Barrett, et al., 1988)	Puffed food products and methods of making such products	• Production of puffed products • Subjecting a food to a diffusive gas environment (preferably CO_2 under pressure) • Food products such as cereals, fruits, vegetables (etc.)	• Washing +coring +peeling +cutting • Pre-treatment (anti-browning) • Frozen and pricked material can be used as raw product before drying • Drying 15-70% • Equilibrating • Vacuum (500-700mmhg) • Vacuum release with CO_2 • Heating 70°C • Holding 1 (3h-24h) • Holding 2 • Drying less than 5% • Packaging	• Vacuum before puffing • Drying before puffing • Drying after puffing	• Intermediate moisture content which a food attains when dried below its normal raw moisture but not to a low moisture content at which is appropriate for marketing • N_2 was also tried rather than CO_2 • Coated products are also considered • The higher the T during the exposure to CO_2, the shorter the exposure time • Temperature 0-90°C can be used during exposure • Crucial parameters: Holding time, temperature, gas

Patent • Number • *Applicant* • Filing date • Publication date	**Title**	**Description** • Goal • Principle • Application	**Steps/operation**	**Conditions/requirement**	**Comments**
					concentration and moisture.
• US 2009/0214735 A1 • *Boamin Zhao* • 13/12/2006 • 27/08/2009 (Wu, 2009)	Process for puffing-drying fruits and vegetables	• Production of puffed food products at normal temperature • Pressurizing with CO_2 • Fruits and vegetables	• Pre-treatment (washing, cutting, removing of product nuclear) • Conventional drying (remove of free water: 20-60% of moisture content) • Vacuum (0.08-0.1MPa) • Pressurizing with CO_2 (1.5-10.5MPa) • Holding (0.5-60min) • Release to atmospheric pressure (0.5-4min) • Drying (3-5% moisture content) • Vacuum Packaging (0.05-0.1MPa)	• Vacuum before puffing • Drying before puffing • Drying after puffing	• The puffing process is performed at normal temperature • Cost of the process is 1/5-1/10 of FD • Examples are for personal use (kitchen oven used for drying before puffing and after puffing)

Appendix 2 Experimental Design

APPENDIX 2 – EXPERIMENTAL DESIGN

The section devoted to Appendix 2– Experimental Design was removed from the present Master Thesis due to confidential reasons of the company Unilever R&D Vlaardingen.