"Dunarea de Jos" University of Galati

Doctoral School of Fundamental and Engineering Sciences

DOCTORAL THESIS SUMMARY

THERMAL PROCESSING TECHNIQUES: SCIENTIFIC AND TECHNOLOGICAL ASPECTS

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Series 7: Food Products Engineering No. 7

GALAȚI

2019

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CONTENT

Keywords: *ohmic heating, thermal processing, hydrocolloids, puree, courgette, bell pepper, pectin, sodium alginate, starch, dysphagia, antioxidants, carotenoids, viscosity, rheology, ready-to-eat, polyphenols, bioactive compounds, vegetables.*

INTRODUCTION

Ready-to-eat products and special-purpose products tend to occupy a special place on the current Romanian market. *Ready-to-eat* products are fairly present in the domestic market as an expected consequence of contemporary life lacking effective time to cook in the domestic environment. Specially designed products also managed to find their place on the domestic market and serve different needs such as those of people suffering from various diseases and who, for various reasons, fail to provide a proper diet alone.

Moreover, the current society tends to re-educate the consumer's needs and to guide him towards healthy products, which not only satisfy his primary need for satiety but also for nutrition and health. The consumer is guided towards products with high bioavailability, but which do not require long-term processing. Thus, the courgette and bell pepper proposed in the study overlap with the needs of the current consumer, mainly those suffering from dysphagia, as well as other groups of consumers.

Addition of food hydrocolloids supports various diseases, especially those related to the digestive system, such as Gastroesophageal Reflux Disease (GERD), gastritis and dysphagia. In these symptoms, nutrition is essential, medical treatment not accompanied by a diet adapted to the needs of the patient can not help to improve or heal.

Technological aspects:

1. Identification and selection of plant based raw materials for the design of *ready-to-eat* products;
2. Testing and selection of hydrocolloids to determine the desired texture for *ready-to-eat* products;
3. Establishment of technological schemes, with indication of process parameters, for bell pepper and courgette puree with apple and citric pectin, sodium alginate and starch, treated by ohmic heating;
4. Choosing the right type of *ready-to-eat* product after correlating technological and scientific aspects.

Scientific aspects:

1. Measuring and calculating process parameters characteristic of ohmic heating;
2. Measurement and calculation of physical and electrical parameters for vegetable purees processed by heating;
3. Determination of antioxidant activity by DPPH and ABTS methods, and antioxidant capacity by TEAC method;
4. FT-IR spectroscopic analysis;
5. Viscosimetric and textural deviations;
6. Confocal microscopy analysis;
7. Simulation of physical parameters, characteristic of vegetable purees, using Artificial Neural Networks (RNAs).

Vegetable puree products adapted to the needs of people suffering from dysphagia are definitely new to the domestic market and will certainly find a niche for their integration, especially since there are specific regulations in Europe that require such products to exist on the market. Designing, obtaining and characterizing *ready-to-eat* vegetal products alongside other special-purpose products, such as those for babies, children, people with diabetes or those with a low-fat or hypolipidic diet, is a challenge for the Food Products Engineering field.

The doctoral thesis contains the following novel elements representing original contributions:

- Design, obtaining and optimization of *ready-to-eat* vegetal products with special purpose;
- Using the thermal processing technique - ohmic heating - within the technological schemes of *ready-to-eat* vegetal products;
- Choosing hydrocolloids adapted to special purpose products;
- Identification of some correlations between the electrical and physical properties of some components of bell pepper and courgette with added hydrocolloids;
- Complex (compositional, textural, rheological, microstructural and bioactive compounds content) characterization of *ready-to-eat* vegetal products.

The infrastructure used belongs to the *Dunarea de Jos University of Galati*, *Food Science and Engineering Faculty* and *Sciences and Environment Faculty.* The laboratories that provided the necessary infrastructure for carrying out the experiments underlying the researches in the present PhD thesis are: *Unit operations laboratory from Food Science and Engineering Faculty, The Research Units (UC) (Institutes, Research Centers, Laboratory) within Dunarea de Jos University of Galati (UDJG) (http://www.unicer.ugal.ro/index.php/en/), Ficobiotehnology laboratory from the Institute of Microbiology and Biotechnology Sciences Academy of Moldavia, Laboratory of Plant Biotechnology, Institute of Genetics and Plant Physiology of the Sciences Academy of Moldavia Republic*.

Doctoral thesis *Thermal Processing Techniques: Scientific and technological aspects* is structured in two parts: documentary and experimental study. Chapters that constitute the experimental part are presented as research reports that comprise the standard structure of general aspects, materials and methods, results and discussions, and partial conclusions.

The doctoral thesis consists of 145 pages, 14 tables and 87 figures. The documentary study and reporting to the literature is based on a number of 272 bibliographic references.

The **documentary study**, structured in 4 chapters, contains general information on the current state of knowledge in the field of products of plant origin chosen for study and their destination. There are also presented general notions about the benefits of the vegetal products consumption. The selected vegetables as courgettes and bell peppers are characterized from the biological, nutritional and phisico-chemical point of view.

Considering that the doctoral thesis wishes to propose new products based on vegetal material intended for people with a special diet suffering from dysphagia, theoretical considerations regarding the production of vegetable purees are highlighted. These special purpose purees require a specific consistency, which is due to the addition of hydrocolloids. Thus, hydrocolloids are presented and those selected for experiments (apple and citric pectin, sodium alginate and starch) are described. Due to the chosen preservation method, which is ohmic heating (OH), important aspects related to this processing technique are presented. The addition of hydrocolloids as *ready-to-eat* products can also be used by people suffering from dysphagia, which is a deficiency or disfunction of the musculature that supports the transport of food or beverages in the stomach, especially in the swallowing area, so there are also theoretical elements related to dysphagia.

The **experimental study** is structured into three chapters having the main purpose to investigate and optimize ways to obtain *ready-to-eat* products like puree for people suffering from dysphagia, the importance of using ohmic heating as a processing technique and the effects of hydrocolloid additions on the properties of the products obtained. Also, simulation and modeling of the experimental data is aimed at the possibility of using this data in similar experiments.

Chapter 5 is entitled *The conception, characterization and evaluation of courgette and bell pepper puree with pectins addition especially designed for people with dysphagia*. Choosing of courgettes and bell peppers as raw materials to obtain the novel *ready-to-eat* products was based on the compositional and economical considerations (cheap price and high content of bioactive compounds).

14 types of products were designed, obtained and characterized, 7 based on courgettes puree with variable apple or citrus pectin additions and 7 bell pepper with variable apple or citrus pectin additions. Pectin was chosen for this experiment because it comes from a vegetable source and is extremely used to increase the consistency of juices, purees and jams.

Thermal ohmic heating (OH) is the basis for preserving the specific qualities of these types of products, especially since their destination is a special one. For this, a temperature gradient of 20 V / cm was chosen which favored the correct processing and ensured the consistency of the refrigerated product for 30 days.

Within this chapter were determined the electrical, physicochemical, rheological, textural and microstructural properties of purees. For both pectin, apple and citrus variants, an optimal hydrocolloid concentration of 0.3% was identified.

Chapter 6 entitled *The* d*esign and characterization of pepper or courgette purees with starch or sodium alginate addition for people suffering from dysphagia* investigates the use of sodium alginate and maize starch as hydrocolloids. The rheological behavior of the purees after the hidrocolloids addition and ohmic heating were followed. The transformations of the purees are observed by physico-chemical, textural and microstructural changes. The rheological behavior is not affected by the hidrocolloids addition. Structural changes indicate that ohmic heating is a mild treatment that ensures the final consistency of the products. It is clearly pointed out that ohmic heating treatment is well suited to this type of *ready-to-eat* products and that it keeps a series of biologically active compounds naturally occurring in the plant material and also does not completely distort the structure of the obtained products having in view of the fact that the plant material is already subjected to mechanical processes before it is thermally treated.

Chapter 7 *Modeling and Simulation of Thermal Processing Techniques* wishes to use the experimental data to simulate the process under consideration. Artificial Neural Networks (RNAs) have fallen perfectly on the types of experiments conducted within the thesis as they are designed to model data of complex matrices, such as food matrices. The main advantage of this type of modeling is the choice of the mathematical model corresponding to the experimental data and the detection of any errors that could distort the simulation process. Identifying and removing them is the basic feature of RNA.

The general conclusions highlight the importance of the study and its relevance in the national and international contexts with regard to the use of poorly exploited vegetal materials as compared to their biologically active properties and their functional potential.

The original contributions of the doctoral thesis are disseminated in 3 published scientific papers or in reviews in prestigious journals (*The Annals of the University Dunarea de Jos of Galati, The Volume of the 22nd International Exhibition of Inventics, INVENTICA 2018, Journal of Food Science and Technology)*, 2 articles in ISI Proceedings and 8 participations in international and national conferences.

The final results were also used in an invention patent entitled ***Vegetable ready-to-eat food for elderly people*** filed with *OSIM*, which is being published on the on-line platform.

The thesis was conducted under the following scientific committee:

Prof. Eng. Elisabeta BOTEZ - PhD coordinator
Prof. Eng. Nicoleta STĂNCIUC - coordinator of technological studies and spectrometry
Assoc. Prof. Eng. Aida VASILE - coordinator of microscopy studies
Assoc. Prof. Eng. Sorin CIORTAN - mathematical modeling and simulation coordinator

Notations and abbreviations

MD - courgette puree control sample
DPC0,1 - courgette puree sample with 0,1% added citrus pectin
DPC0,2 - courgette puree sample with 0,2% added citrus pectin
DPC0,3 - courgette puree sample with 0,3% added citrus pectin
DPM0,1 - courgette puree sample with 0,1% added apple pectin
DPM0,2 - courgette puree sample with 0,2% added apple pectin
DPM0,3 - courgette puree sample with 0,3% added apple pectin

MA - bell pepper puree control sample
APC0,1 - bell pepper puree sample with 0,1% added citric pectin
APC0,2 - bell pepper puree sample with 0,2% added citric pectin
APC0,3 - bell pepper puree sample with 0,3% added citric pectin
APM0,1 - bell pepper puree sample with 0,1% added apple pectin
APM0,2 - bell pepper puree sample with 0,2% added apple pectin
APM0,3 - bell pepper puree sample with 0,3% added apple pectin

DM - courgette puree control sample
DAM1 - courgette puree sample with 1% added starch
DAM2 - courgette puree sample with 2% added starch
DAM3 - courgette puree sample with 3% added starch
DAL1 - courgette puree sample with 1% added alginate
DAL2 - courgette puree sample with 2% added alginate
DAL3 - courgette puree sample with 3% added alginate

AM - bell pepper puree control sample
AAM1 - bell pepper puree sample with 1% added starch
AAM2 - bell pepper puree sample with 2% added starch
AAM3 - bell pepper puree sample with 3% added starch
AAL1 - bell pepper puree sample with 1% added alginate
AAL2 - bell pepper puree sample with 2% added alginate
AAL3 - bell pepper puree sample with 3% added alginate

OH - ohmic heating
ANN - Artificial Neural Networks
FT-IR - Fourier Transform Infrared Spectroscopy
MSE - Mean Square Error
TPA - Texture Profile Analysis
ABTS - 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)
DPPH - 2,2-diphenyl-1-picrylhydrazyl
TEAC - Trolox Equivalent Antioxidant Capacity

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DOCUMENTARY STUDY

1. General aspects

Vegetables are the basis of human food on the globe, consuming about 10000 plant species, of which only 50 are the most commercialized species [*Decoteau, 2000*]. They participate both in supporting a balanced diet and in stimulating appetite.

Vegetables contribute to human nutrition with starch, minerals, vitamins, fiber and protein as an important source of energy. Vegetables are rich in vitamin C. Bioactive compounds such as carotenoids are abundant in courgettes, bell peppers and tomatoes. Vegetable fibers include cellulose, hemicelluloses, pectic substances and lignin, which play an essential role in the prevention of various diseases [*Vaugban and Geissler, 1999*]. Organic and volatile acids are aromatic compounds, while colorants are chlorophylls, carotenoids and anthocyanins.

Vegetables are the main source of antioxidants in human nutrition with a defensive role against free radicals. The increased level of antioxidants in courgettes, onions and green beans can often be influenced by the use of appropriate heat treatment.

Following the action of thermal processes on plant cells, new compounds with strong antioxidant activity or new substances with antioxidant potential and inhibition of oxidative enzymes can be formed [*Morales and Babel, 2002*].

2. Used vegetables

2.1. Common courgette *(Cucurbita pepo var. obloga)*

Cucurbitaceae are an extremely important family of the vegetable class that dates back more than 10000 years ago. The family consists of 118 genres, of which only 9 are used as vegetables, and only 3 of these (Cucumis, Citrullus and Cucurbita) are commercially important worldwide, with the exception of some Asian areas where the Benincasa, Lagenaria, Luffa, Momordica, Sechium and Trichosanthes [*Robinson and Decker-Walters, 1997*].

Cucurbits are annual herbaceous, except for the chayote courgette that is perennial. The cucumber (Cucurbita pepo var. Obloga) is a kind of courgette cultivated for its green and long fruit. The fruit has an elongated shape, cylindrical or slightly thickened to a white, yellow, green, from open to dark peak, and its growth rate is fast.

2.2. The bell pepper (*Capsicum annum*)

Bell pepper was discovered about 9000 years ago, originating in Bolivia and Peru. Subsequently, the seeds spread throughout Central America. Columbus discovered the pepper in the West Indies that he brought to Europe, Africa and Asia [*http://yolonutrition.ucanr.edu/files/241826.pdf*].

Bell pepper is part of the Solanaceae family, which also includes tomatoes and potatoes. From the botanical point of view, the bell peppers are annual or perennial fruits of *Capsicum annum*, which have increased their popularity due to their bioactive content (ascorbic acid, carotenoid, avonoid and polyphenol). There are almost 2000 varieties of bell peppers, such as green, yellow, orange, red and violet, of different sizes and shapes [*Lucier and Lin, 2001*].

Bell pepper is a warm seasonal crop that grows well beyond fluctuating or freezing temperatures. It grows poorly at temperatures between 5 and 15 ° C [*Bosland and Votava, 1999*]. The optimum temperature for sweet pepper is 20 to 25 ° C [*Anonymous, 2000*].
The peppers are thick fruit, with a smooth, waxy and crisp texture.

3. Theoretical considerations over the technology of puree manufacturing

Changes in modern lifestyle, the incresing of the awareness of health diet and new processing technologies have led to the necessity of consuming the ready-to-eat products, functional foods and the development of high-fiber foods with low fat content [*Phillips and Williams, 2009*].

The consumption of purees has become extremely convenient for the modern consumer who chooses products that can be used without much time to prepare. The use of puree is one of the ways to consume balanced nutritional and mineral foods [*Galoburda et al., 2014*].

The purees are foods defined as shredded to a form that involves a very low mastication degree. The bowl of puree will be easy to send with the tongue to the pharynx, thus favoring swallowing. These products are soft, smooth and semisolid mechanically modified, with or without the addition of thickening agents or liquids in the preparation process [*Sharma et al., 2017*].

The purees are a class of special products created for persons with special food like babies, children in certain developmental periods (dental eruption), the elderly and people with various health problems, especially in the digestive tract. The technology of puree manufacturing is dependent on the raw materials, on their moisture content and their degree of granulation.

3.1. The addition of thickening agents – Hydrocolloids

Hydrocolloids are substances with a big affinity for water. From the chemical point of view, the hydrocolloids are macromolecular hydrophilic substances which have the capacity to form gels used for the microencapsulation or the texture control of foods, drugs, probiotics and cosmetics [*Sugiura et al., 2005; Zimmerman et al., 2005*].

3.1.1. Pectin

Pectin is one of the most known jellification agent. It is extremely widespread in the vegetal tissues, where it actions as an intercellular matrix, both with the cellulose having a constructive role in the cellular walls and central lamella formation.

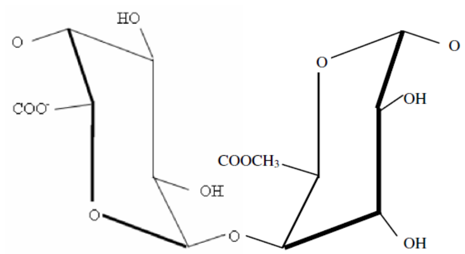

Figure 3.1. Chemical structure of pectin adapted by *www.researchgate.net*

3.1.2. Sodium alginate

Alginate is a derivate of the alginic acid, which has a primer derivate from the brown algae (*Phaeophyceae*). The alginates are linear unbranched polymers which contain derivates of (β-1 → 4) D-mannuronic (M) acid and residues of α-(1→4) L-guluronic (G) acid. The residual sequences M and G varies from the varieties and within the same polymer chain.

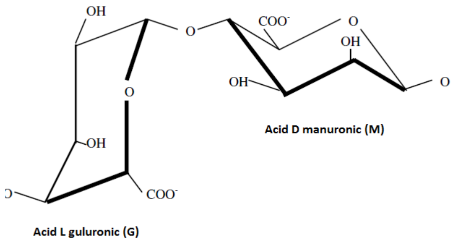

Figure 3.2. Chemical structure of alginate structure adapted by *www.scielo.br*

3.1.3. Starch

Starch represents one of the most used hydrocolloids as thickener agent in food industry. Moreover, it is found in very large quantities in nature, it is easy to extract and does not borrow the taste, smell or non-product color if used in low concentrations (2-5%). It is present in leaves, stems, roots, bulbs, nuts, stems, seeds and basic crops such as rice, corn, wheat, manioc and potatoes [*Sajilata et al., 2006*].

The starch is the main source of carbohydrates from the human diet, is the polysaccharide with the largest herb deposit, and appears in the form of granules in chloroplast of green and amyloplast leaves in seeds and tubers.

In Figure 3.3. are presented the main types of starch granules depending on the source of origin.

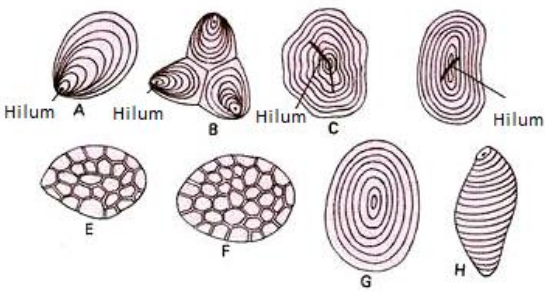

Figure 3.3. Starch granule types adapted by *http://www.biologydiscussion.com*

A., B. Granules from potato, C. granule from maize, D. granule from pea, E. granule from rice, F. granule from oat, G. granule from wheat, H. granule from banana.

3.2. Techniques of thermal processing

Thermal processing means the transformation of fresh foods into preserved state. Food preservation is essential for food innocuity and consumer health. Each heat treatment is uniquely designed, but has as common goal, the delay of perishability from production to consumption.

Most foods are subjected to thermal processes such as cooking, baking, roasting, extruding, pasteurizing or sterilizing. These processes aim to obtaining sensory or textural particularities, microbiological safety and elimination of enzymatic activity [*ftp://ftp.feq.ufu.br/Luis_Claudio/Books/E-books/Food/Thermal_technologies_in_food_processing*].

The processing using the heat is an indispensable technique for food industry. The heating was always the most common method used for preservation, processing, and enzymatic inactivation of the biomaterials [*Kumar et al., 2014*].

3.2.1. Ohmic heating

Similar to other researchers such as *Jaeger et al., 2016; Sakr and Liu, 2014*, recently, the ohmic heating is one of the most known modern technologies of thermal processing. It appeared as a novel technology promising to minimize unwanted changes, thus maintaining the nutritional value of the products, but also their freshness.

Ohmic heating is a modern thermal process by which the electric current directly passes through the product volume, the resulting heat being generated by the ohmic resistance represented by the product by the movement of the molecules under the action of the electric current [*Shynkaryk et al., 2010, Boldaji et al., 2015; Ramaswamy et al., 2014*].

The advantages of the ohmic heating are:

1) the volumetric and uniform heating of foods [*Ruan, 2001*], even those with an increased content of solids particles;
2) quick heating - a short period of processing time (high temperature-short time HTST) or even ultrahigh temperatures (UHT);
3) high efficiency;
4) low maintenance costs due to the absence of the moving parts;
5) the versatility of the process, which can be used as blanching, thawing, drying, concentration or heating;
6) the preservation of the nutritional values.

The electrical, thermo physical and rheological properties play an important role for achieving uniform heating. In addition to product parameters, process parameters such as frequency of current and electrode material, other issues like processing chamber geometry are also relevant [*DFG Senate Commission on Food Safety, 2015*].

4. Dysphagia

The number of elderly people (over 65 years old) presents the fastest rate of growth among all segments of the population. Until 2050, worldwide will exist more than 400 billion of elderly people over 80 years old.

Providing soft, tasty and healthy modified foods for seniors, especially those who have masticatory/swallowing dysfunctions and/or require special nutrition, is a major challenge for the food industry.

Just like adults, children can develop a deglutition problem. Compared to adults, children have a rapid body development, and sometimes even short-term problems.

Dysphagia is a swallowing dysfunction, which involves specific stages of swallowing such as oral, pharyngeal and esophageal passage, which is particularly associated with degenerative diseases such as dementia, Parkinson and Alzheimer, and appears to affect 60% of institutionalized elderly people. The frequent consequences of the malnutrition generated by dysphagia include: confusion, dehydration, ulcer, constipation, infections, and ultimately a decrease in quality of life [*Curran and Groher, 1990*].

EXPERIMENTAL STUDY

5. The conception, characterization and evaluation of courgette and bell pepper puree with pectins addition for people with special diet, which suffer from dysphagia

5.1. General aspects

The courgette of the Crisan variety (2008) is intended for both seedling and field cultivation. This is a type of early-green courgette with an average weight of 150-300 g.

The bell pepper used is of the Mintos F1 variety, which is a hybrid of green pepper recommended for cultivation in greenhouses, solariums and open fields. Fruit Mint F1 is Blocky type, with a medium weight of 250 grams, big, glossy, and with a great commercial appearance. The color gradually changes from light green to yellow, with red at maturity. The Mint F1 pulp is thick.

Although they have an extremely important nutritional potential, both courgettes and bell peppers are scarcely investigated in research. Additional investigations are needed to know the rheological properties of products for patients with dysphagia. These statements support the need for the study below.

5.2. Objectives

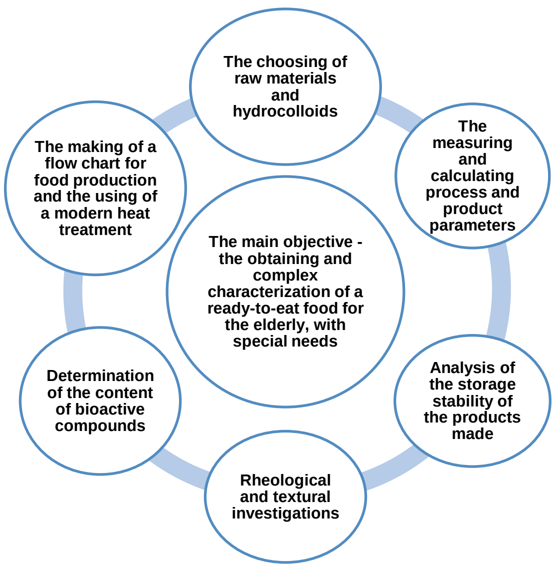

Figure 5.1. Objectives

5.3. Materials and methods

Materials used in the production of vegetables purees (courgettes, peppers) with pectin (apple and citrus):

- Courgette from Crisan variety (2008)
- Bell pepper from Mintos F1 variety
- Apple pectin (Natura Cookta, Budapesta, Ungaria)
- Citrus pectin (Natura Cookta, Budapesta, Ungaria)
- Still water (Aqua Carpatica, Valvis Holding, Vatra Dornei, Suceava, România)

The reagents used are of high analytical purity and have not been purified or processed in the experiment. The courgettes and bell peppers were bought from local producers in July-October 2016.

The manufacturing of vegetal purees: Before being processed, they were washed, peeled off or, as the case may be, the seedbed was removed, cut and then subjected to the grinding operation with a Philips blender.

The grinding was performed at a rate of 1900 rpm for 2 minutes for each type of puree. This operation was applied with the purpose of obtaining purees made from courgettes and peppers.

The increasing of the consistency of vegetable puree: The purees were mixed at a rotational speed of 1900 rpm with apple or citrus pectin in the proposed proportions (0.1%, 0.2% and 0.3%) and the volume of water required to hydrate the pectin for 1 minute.

All samples were made in triplicate.

Tabel 5.1. Encoding of the samples

No.	***Sample encoding***	***Sample name***
1	MD	control courgette sample
2	DPC0.1	courgette puree with 0.1% citrus pectin
3	DPC0.2	courgette puree with 0.2% citrus pectin
4	DPC0.3	courgette puree with 0.3% citrus pectin
5	DPM0.1	courgette puree with 0.1% apple pectin
6	DPM0.2	courgette puree with 0.2% apple pectin
7	DPM0.3	courgette puree with 0.3% apple pectin
8	MA	control bell pepper sample
9	APC0.1	bell pepper puree with 0.1% citrus pectin
10	APC0.2	bell pepper puree with 0.2% citrus pectin
11	APC0.3	bell pepper puree with 0.3% citrus pectin
12	APM0.1	bell pepper puree with 0.1% apple pectin
13	APM0.2	bell pepper puree with 0.2% apple pectin
14	APM0.3	bell pepper puree with 0.3% apple pectin

5.4. Results and discussion

The courgette and bell pepper purees obtained by the method presented in the chapter **Materials and methods** have been subjected to analyze and determinations to characterize special purpose products. The data processed and presented in this chapter represent the average of 3-5 determinations according to the type of parameter or characteristic analyzed.

5.4.1. Results and discussions for the courgette purees treated by OH at 20 V/cm

The establishing of the electrical properties of the courgette purees

The presence of the different components, the volume of each component, their size and shape are among the important factors that generally affect the electrical conductivity of a multiphase food system.

In Figure 5.1. is presented the electrical conductivity evolution depending on the processing temperature by OH at 20 V/cm.

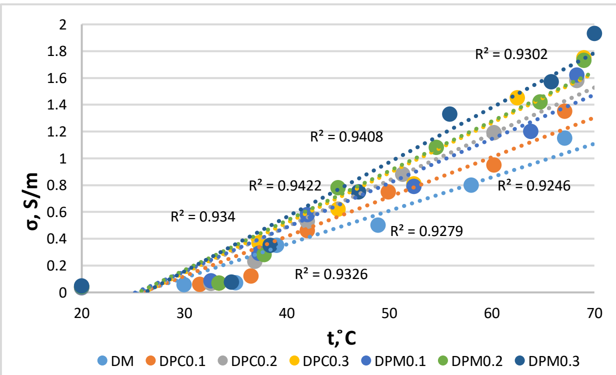

Figure 5.14. Electrical conductivity evolution depending on the processing temperature by OH at 20 V/cm

In Figure 5.14. can be observed the linear variation of the courgette puree, both in the control sample and in the samples with citric and apple pectin. The values obtained for the electrical conductivity are similar with other researchers' findings as *Mitchell* and *de Alwis* in *1989*.

In Figure 5.16. is presented the temperature variations (°C) versus the processing time (s).

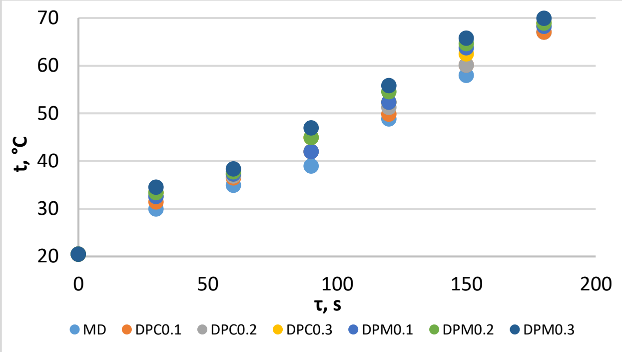

Figure 5.16. Temperature variation versus the OH processing time

In Figure 5.16. is evidenced by the linear evolution of the temperature versus processing time. The processing time is the same (180 s) for all the analysed samples.

It can be observed that the courgette purees processing temperature with 0.3% citrus pectin, respectively apple pectin ($D_{PC0,3}$ and $D_{PM0,3}$) increases faster (69-70°C) compared with the control sample purees (67.1°C) or in the case of puree with a lower pectin addition (DPC0.1 - 67.1, DPC0.2 - 68.3, DPM 0.1-68.3°C). Similar research was also highlighted by *Nistor et al., 2013* on the ohmic heating of apple puree. Firmness values are proportional to the contact area between the plunger and the sample. This is why higher values of firmness have been recorded for Ottawa cells compared to TPA.

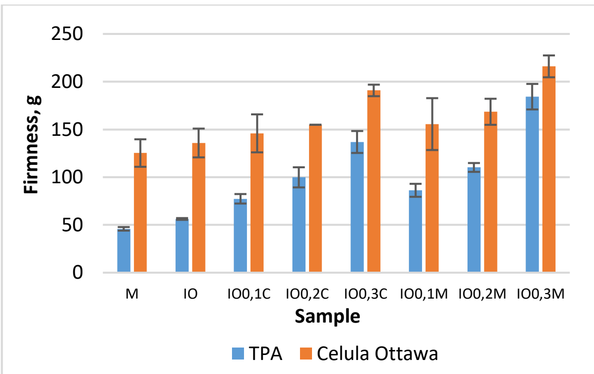

Figure 5.22. The courgette puree firmness (Ottawa cell versus TPA)

FT-IR spectra analysis

The FT-IR analysis method offers considerable advantages comparable to colorimetry as a method of determining the presence of demethoxylated pectins and not only, due to the simplicity, velocity, the high sensitivity of identifying the compounds in the analyzed matrix.

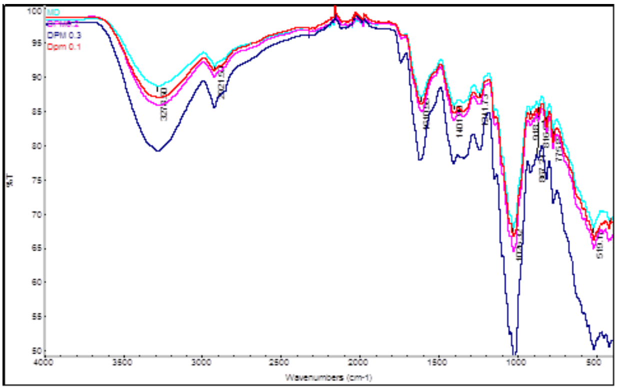

Figure 5.24. FT-IR spectra for courgette purees

In the case of courgette puree, a strip of the fingerprint area is presented in the untreated puree spectrum is observed at 1340 cm^{-1}. In other words, OH does not affect the structure of courgette puree. The addition of pectin, even in a concentration of 0.1%, leads to the disappearance of this new band.

The band reappears at 0.3% pectin additions, but can be attributed to a pure pectin specific band at 1335 cm^{-1}. This statement highlights the fact that courgette is sufficient a 0.1% addition of pectin to improve the puree structure.

5.4.2. Results and discussions for bell pepper purees treated by OH at 20V/cm

The aim of this study is the complex characterization of the bell pepper purees with citrus or apple pectin.

The determination of the electrical properties of bell pepper purees

The electrical properties of vegetal products are extremely important, particularly in order to obtain data that could be used as a basis for other studies where they are processed using electrical techniques. Moreover, studies on the processing of bell peppers are extremely limited. In conclusion, it is important to evaluate the electrical conductivity of bell peppers according to the ohmic heating processing temperature at a voltage gradient of 20V / cm (Figure 5.5).

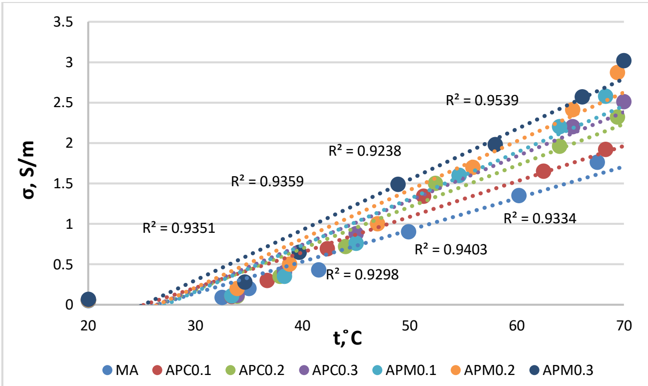

Figure 5.27. Electrical conductivity variation versus temperature for bell pepper puree treated by OH at 20 V/cm

The variation of the electrical conductivity versus temperature is arranged after a linear correlation, which emphasizes the increase of the electrical properties values dependent on the processing temperature. The linear evolution of electrical conductivity depending on the processing temperature is determined by the uniformity between the soluble or insoluble solids in the liquid and liquid phases as *Icier* stated in *2012*. This phenomenon was possible by grinding and mixing the components with the blender.

FT-IR spectra analysis

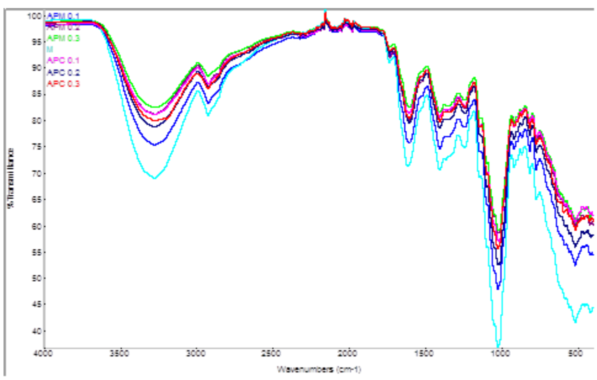

Figure 5.37. FT-IR spectra for the bell pepper purees

The treatment of bell pepper purees by ohmic heating produces changes in the fingerprint area (basically the imprint is associated with pure compounds, which cannot always be identified) (1500-900 cm^{-1}), resulting in the appearance of 4 new bands, at 1049, 1099, 1143 and 1368 cm^{-1}. Adding 0.3% of pectin contributes to the disappearance of these bands. Depending on the degree of methyl esterification of the pectin, C = O carbonyl ester groups may occur within this range due to the presence of carboxyl groups COO-. Thus, in the case of apple pectin of 0.3%, only the bands of 1099 and 1143 cm^{-1} are observed, and in the case of 0.3% citric pectin addition, one single band is retained at 1143 cm^{-1}.

5.5. Partial conclusions

- This chapter has allowed the complex investigation of two types of vegetables (courgettes and bell peppers) and the possibilities of their utilization in the design and creation of special purpose foods;
- Two types of hydrocolloids (pectin from citrus and apple) were chosen, which are suitable for analyzed products;
- The results of the study serve as a database of the effects of ohmic heating on the rheological and textural behavior, electrical and physico-chemical properties of courgette and bell pepper puree supplemented with hydrocolloids (citrus and apple pectin);
- As a result of the analyzes, it is considered that the courgette puree, bell pepper puree with 0.3% apple pectin, is the best technological variant;
- The study presents original elements from the perspective of products chosen for research and their special purpose (for people suffering from dysphagia);
- The data presented may be the basis for the development of *ready-to-eat* products for special nutrition;
- Ohmic heating does not change the rheological behavior of courgette and bell pepper;
- Ohmic heating and pectin addition have improved the textural qualities of courgette purees. The values of all analyzed textural parameters recorded increases proportional to the amount of pectin added.
- From the obtained data, it can be concluded that the courgette and bell pepper puree treated by ohmic heating are suitable for use in the nutrition of the dysphagic persons.

6. The design and characterization of bell pepper or courgette purees with starch or sodium alginate addition for people suffering from dysphagia investigates the using of sodium alginate and corn starch as hidrocolloids

6.1. General aspects

Designing products for special nutrition has always been a challenge, especially since there are no special standards for this type of product in Romania.

In view of the acute need to market of the special foods for people with dysphagia, it is important to evaluate the main characteristics of these products.

Differential nutrition involves the assimilation of nutrients from modified foods in terms of texture and consistency. In order to stimulate appetite and manage to meet the daily needs of the patient, it is important to create new products specific to the symptoms.

To produce the products, courgettes and bell peppers were used as described in subchapter 5.1.

6.2. Objectives

Figure 6.1. Objectives

6.3. Materials and methods

Materials used in the production of vegetables (courgette, bell peppers) with added starch and alginate

- Courgette Crișan (2008) variety
- Bell pepper from Mintos F1 variety
- Corn starch (SanoVita, Valcea, Romania)
- Sodium alginate from several types of brown algae (Fucus, Laminaria, Macrocrystis) (Bos Food, Germany).

The reagents used are of high analytical purity and have not been purified or processed in the experiment. Courgettes and bell peppers were bought from local producers between May and September 2017.

Tabel 6.1. Encoding of the samples

No.	***Sample encoding***	***Sample name***
1	DM	Control sample of courgette puree
2	DAM1	Courgette puree with 1% starch addition
3	DAM2	Courgette puree with 2% starch addition
4	DAM3	Courgette puree with 3% starch addition
5	DAL1	Courgette puree with 1% sodium alginate addition
6	DAL2	Courgette puree with 2% sodium alginate addition
7	DAL3	Courgette puree with 3% sodium alginate addition
8	AM	Control sample of bell pepper puree
9	AAM1	Bell pepper puree with 1% starch addition
10	AAM2	Bell pepper puree with 2% starch addition
11	AAM3	Bell pepper puree with 3% starch addition
12	AAL1	Bell pepper puree with 1% sodium alginate addition
13	AAL2	Bell pepper puree with 2% sodium alginate addition
14	AAL3	Bell pepper puree with 3% sodium alginate addition

6.4. Results and discussions

6.4.1. Results and discussions for the courgette puree treated by OH at 20 V/cm

The determination of the physical properties of courgette purees

Contrarywise to conventional thermal processing techniques, where heat is conducted on the outer surface of the product and from here onwards, in the case of ohmic heating, the heat is distributed throughout the product mass [*Leizerson and Shimoni, 2005a, 2005b; Sarang et al., 2008*].

The degree of ohmic heating is dependent on the heating rate of the system and the electrical conductivity of the food [*Leizerson and Shimoni, 2005a*].

The heat dissipated across the product mass is directly dependent on the applied voltage and the electrical conductivity of the product or of particles in the product under heating (Ohm's Law) [*Varghese et al., 2014*].

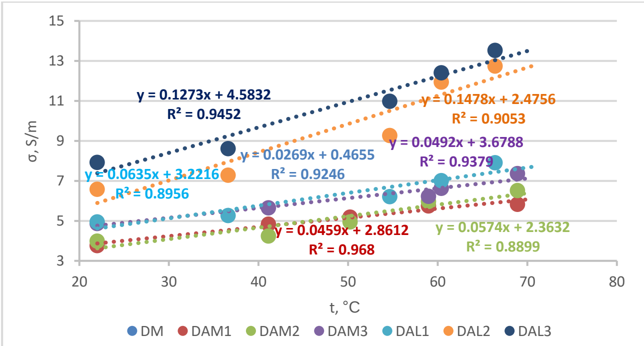

Figure 6.4. Electrical conductivity variation depending on the OH processing temperature

The electrical conductivity values (0.91-7.37 S/m) increase with the increase in the processing temperature. The addition of starch positively influences the increase of the electrical conductivity values of the courgette puree samples. A significant increase in the electrical conductivity values is observed for the addition of alginate (4.94-13.53 S/m).

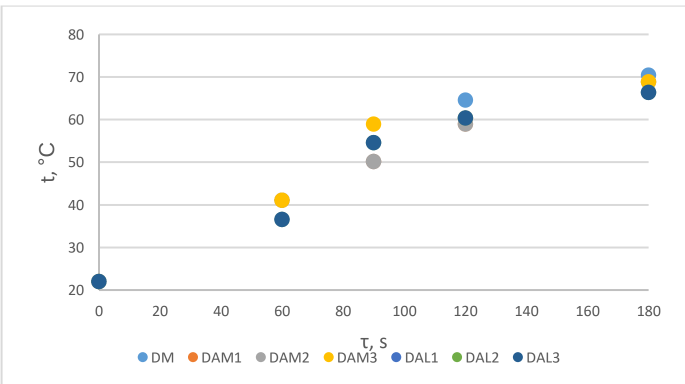

Figure 6.5. *Temperature variation depending on processing time*

Electricity is converted to heat and depends on both temperature gradient and processing time. The temperature of the courgette puree steadily increases during the 180" processing time. It can be seen, that the highest temperature was recorded by the control sample (70.5°C) and the starch-added samples (68.9°C), while the alginate samples (66.4°C) recorded slightly lower temperatures.

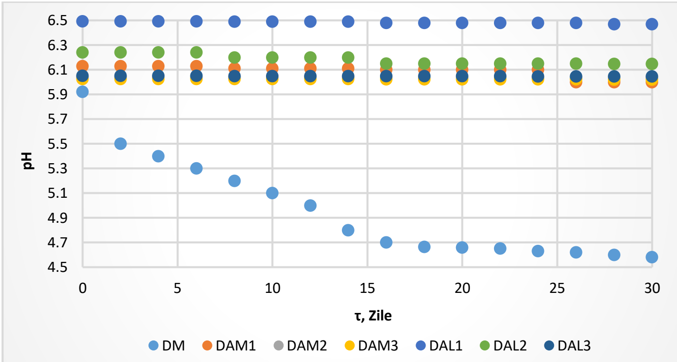

Figure 6.6. pH variation of the courgette purees during storage

The storage stability of the purees was monitored at refrigeration temperatures of 4-5°C for a period of 30 days.

The stability of courgette puree is dependent on the addition of starch or sodium alginate, as the percentage of added starch or alginate increases the storage stability is higher. The decreasing of the pH value is insignificant.

Confocal microscopy with laser scanning analysis

In Figure 6.14. (a) that can be observed perforated (EWP) cells with tubes cut (tubular, long) liberian vessels measuring 57.51 μm in length across a width of 10.45-11.50 μm. Maintaining tissues are made of walls with high fiber content. In the Figure 6.14.(b) can be observed high parenchymal cells (72.59-74.64 μm in lengths and 55.61-71.23 μm wide) with mesidocarp peripheral (pulp) cells with well-differentiated nucleus clearly distinguishable.

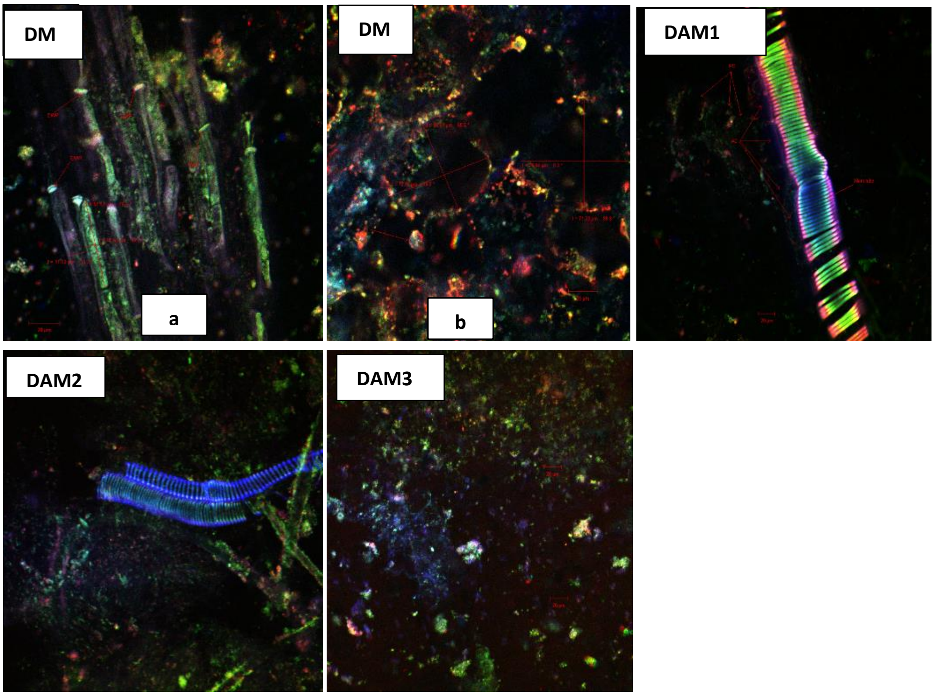

Figure 6.14. Confocal images of the courgette purees with starch addition
DM-control sample of the courgette puree (a-control sample section 1, b- control sample section 2), DAM1-courgette puree with 1% starch addition, DAM2- courgette puree with 2% starch addition, DAM3- courgette puree with 3% starch addition

Sample DAM1 is represented by a xilem with cell wall decorations. Tracheids and starch granules attached thereto are present in the DAM2 sample. Starch granules have a structure specific to maize. Already for the sample with 3% starch addition, no longer whole cells are distinguished, the biologically active compounds are found in conglomerates with relatively homogeneous starch.

All images reveal the presence of cellular tissues or parts or the formation of complexes with biologically active potential, which underlines the importance of using OH as a thermal processing method that has protected some of these characteristics.

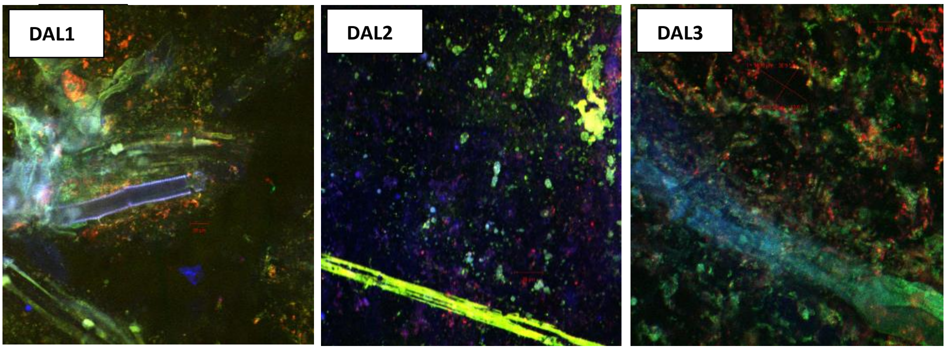

Figure 6.15. Confocal images of the courgette purees with sodium alginate addition

DAL1- courgette puree with 1% sodium alginate addition, DAL2- courgette puree with 2% sodium alginate addition, DAL3- courgette puree with 3% sodium alginate addition

The three pictures for courgette puree samples with 1-3% sodium alginate addition reveal the presence of tracheids - wood-bearing decorative vases with annular decorations of the walls (DAL1), in the image for the second sample (DAL2) agglomerations are present and coalescents of alginate, which explains the formation of gels with a lower consistency than those with starch and supports the results obtained from the rheological and textural analyzes, respectively.

In DAL3, a high proportion of alginate clumps are observed. Larger parenchymal cells are present (length = 36.78 and a width of 25.09 μm).

6.4.2. Results and discussions for bell pepper purees ohmically heated at 20 V/cm

The determination of bell pepper purees physical properties

The heating speed is directly dependent on the electrical conductivity values. The electrical conductivity of the bell pepper puree varies depending on the structure of the product, its constituents, but also the processing time and the induced temperature [*Nistor et al., 2015*].

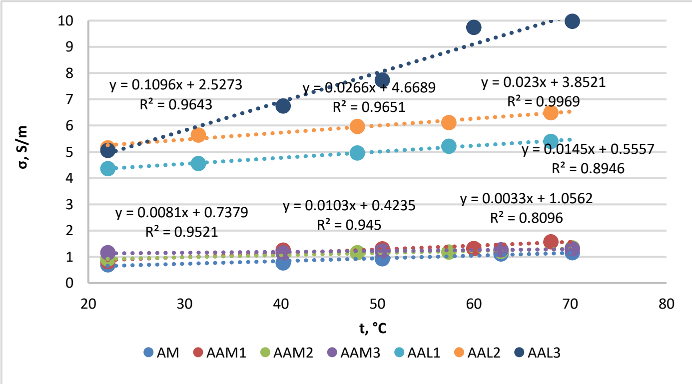

Figure 6.16. Electrical conductivity variation depending on temperature for ohmically heated bell pepper puree

The electrical conductivity values of bell pepper are positively influenced by the addition of starch or sodium alginate. The electrical conductivity values varies with the temperature increase for the control sample (AM = 0.697-1.155 S/m), for the samples with starch (AAM = 0.815-1.307 S/m) and for alginate samples (AAL=4.36-9.98 S/m). Similar values, 1.865 S/m, were reported by *Cho et al.* in *2016* for the red pepper pasta.

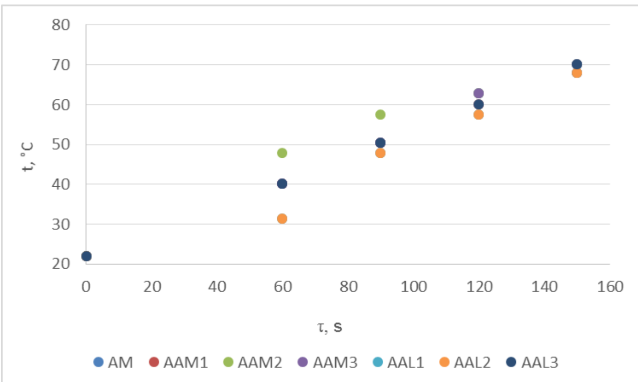

Figure 6.17. The temperature variation versus ohmic heating processing time

It can be observed the linear dependence of the temperature depending on the processing time by OH at 20 V/cm. Moreover, for all the samples the evolution presents a rise threshold from room temperature to the temperature recorded at 60 seconds of processing. After this, the temperature increases constantly with 10-15°C in the interval 60-90 sec.

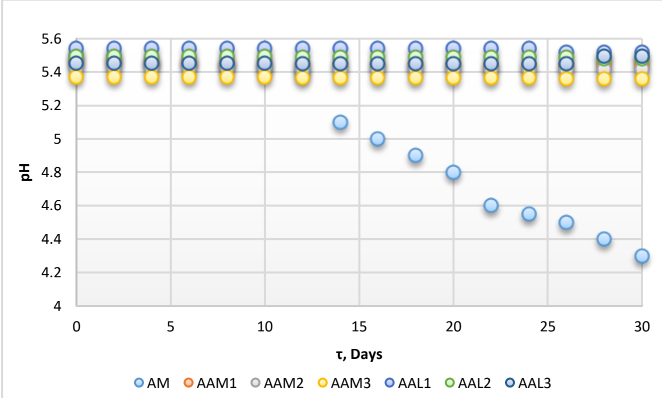

Figure 6.18. pH variation versus storage time

The storage of bell pepper purees was done at refrigeration temperatures for 30 days. An insignificant decrease in pH values can be observed. The only sample that records a more significant decrease is the control sample. The pH values range from 4.3-5.502.

Confocal microscopy of bell pepper puree

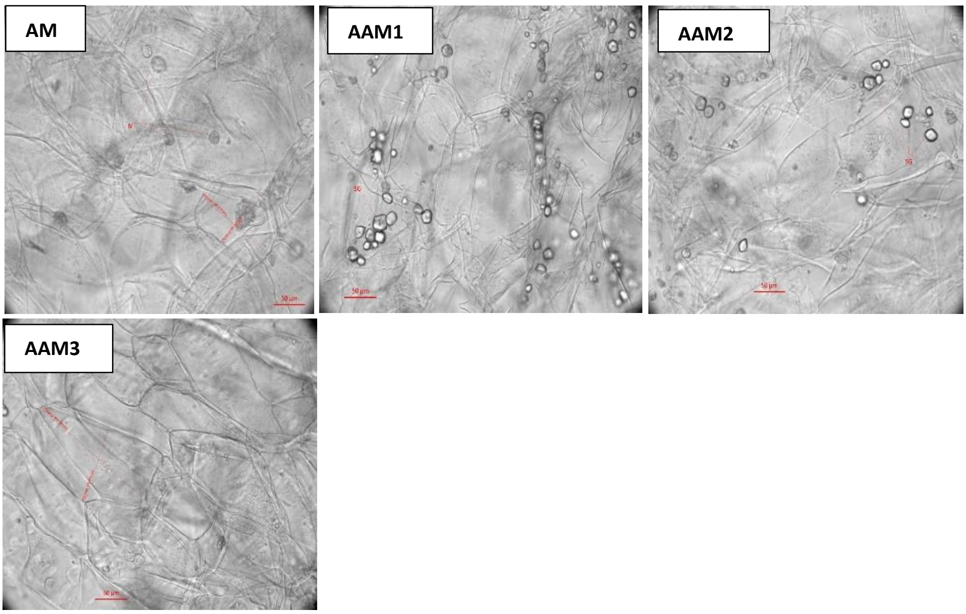

Figure 6.24. Confocal images for bell pepper puree with starch addition

AM-control sample, AAM1- bell pepper puree with 1% starch addition, AAM2- bell pepper puree with 2% starch addition, AAM3- bell pepper puree with 3% starch addition

The confocal microscopy analysis involves evaluating the microstructures originating from the bell pepper purees with or without hydrocolloids, may also reveal possible complexes formed between the biologically active components in the food matrix, or any transformations that may occur as a result of heat treatment.

In the control sample (MA), cell nucleus of large parenchymal cells (length = 130.273 and width = 90.486 μm) with thin walls and cell contents rich in constituents are clearly shown.

For the samples with 1 and 2% starch, it can observe the presence of starch granules (SG), which are better grouped with sample (AAM1) with 1% added and more dissipated in the sample (AAM2) with 2% starch.

Already in the sample (AAM3) with 3% starch can be seen conglomerates created by the biologically active compounds with starch, we can see well-defined cells with large dimensions (length = 206.194 and width = 106.831 μm).

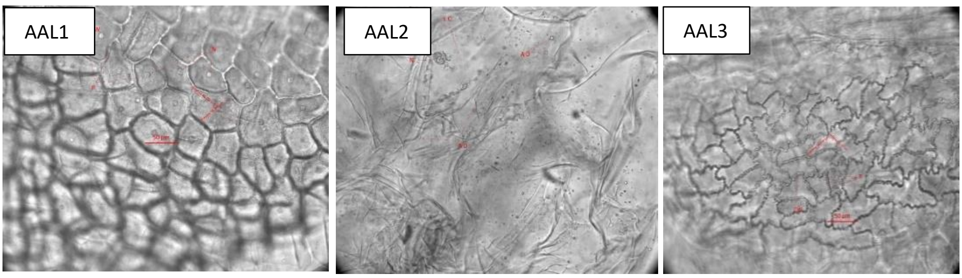

Figure 6.25. Confocal representation for bell puree with sodium alginate

Regarding the samples with alginate addition, the captured images have shown cell structures specific to the investigated vegetal material. Thus, for the bell pepper puree sample with 1% alginate addition (AAL1), are presented thickened (CW) pericarp tissue where there are punctures (pores) through which cells communicate with each other. The representative large size cell (80.251x58.780μm) contains the nucleus. With respect to the AAL2 sample, alginate particles (AD) can be distinguished, the cells begin to break, and the cellular content is homogenized with the thickening agent. A higher density of alginate droplets (AD) appears from place to place next to cell walls and nucleus. AAL3 contains a non-regulated (66.230x18.801 μm) tissue with plasmodesme.

6.5. Partial conclusions

- The original elements of the study are the products chosen for research and their special purpose (for people suffering from dysphagia);
- The optimal concentration of hydrocolloids added to courgettes and bell peppers was determined at 3% for starch;
- The effects of ohmic heating on starch supplemented samples are minimal;
- The results of the study serve as a database on the effects of ohmic heating on the rheological and textural behavior, electrical and physico-chemical properties of courgette and bell pepper purees supplemented with hydrocolloids (starch and sodium alginate);
- The data obtained from the researches carried out could be the basis for the development of industrial scale products;
- Ohmic heating does not change the rheological behavior of courgette and bell pepper purees;
- The thermal treatment by ohmic heating and the addition of starch improved the textural qualities of courgette and bell pepper purees;
- Courgette and bell pepper purees treated by ohmic heating are suitable for use in the alimentation of dysphagic persons;
- The addition of alginate to purees forms gels with a low consistency, which does not recommend it as a possible hydrocolloid used to obtain special purpose products.

7. The modeling and simulation of thermal processing techniques is intended to use the numerical data obtained from the experiments to simulate the proposed process

7.1. Mathematical modeling of voltage and temperature distribution

Mathematical modeling and simulation of thermal behavior can be used in industrial applications when designing ohmic heating systems to optimize pasteurization and sterilization processes using uniform and rapid heating. Choosing an appropriate mathematical model will help predict the thermal energy values achieved during ohmic heating.

Ohmic heating has been intensively researched in recent years at international level due to the advantages it has over conventional heat treatments. The modeling of the ohmic heating process is quite complex, since the conversion of electric energy into heat depends very much on the electrical conductivity of each product.

Locating the coolest spot within the ohmic cell is an important concern for determining the spatial and temporal distribution of temperature in product volume as it provides essential information for plant design, monitoring, and control of thermal processing.

The modeling of thermal processing techniques by ohmic heating has been previously developed and validated experimentally: *de Alwis and Fryer (1990bc)*; *Fryer et al. (1993)* have performed modeling for a single particle in the case of static ohmic heating, and *Sastry and Palaniappan (1992c)*; *Sastry (1992abc); Sastry and Li (1993); Zhang et al. (1992); Zhang and Fryer (1995); Sastry and Salengke (1998); Orangi and Sastry (1998)* have developed simplified models for heterogeneous systems.

For discontinuous ohmic heating, several models were developed that described the thermal behavior of the particles in the liquid, and in which constant thermal characteristics, homogeneous and isotropic particles, absolute thermal conductivity were considered. For particle systems, models were developed for a limited number of particles.

Generally, two main approaches were used to calculate the electric field generated in the volume of the product under ohmic heating: *de Alwis and Fryer (1990bc)* concluded that the determination of the electric field could be solved using the Laplace equation; *Sastry and Palaniappan (1992c)* proposed an analogy with an electrical circuit where it was considered that the ohmic heating system, in the presence of a liquid and the particles, could be equated with a set of electrical resistors. Two parallel electrical resistors were assigned to the heterogeneous mixture and a series resistance for the liquid.

Both methods have shown similar results for samples with a particle content greater than 30% [*Zhang and Fryer, 1995; Sastry and Salengke, 1998*], while some differences were noted for samples with a low solids content in suspension. *de Alwis et al. (1989)* were the first to assess the physical factors that influence the rate of particle heater (eg particle shape, liquid and solid conductivity, electric field orientation relative to solids) under static conditions to eliminate the effects of fluid flow.

De Alwis and Fryer (1990) used modeling using finite element methods because food systems are extremely complex. *Sastry and Palaniappan (1992)* have developed a 3D model for approximating temperatures for liquid and particle mixtures in suspension for discontinuous ohmic heating. Based on the results, they concluded that the particles, having less electrical conductivity than the fluids, have a lower heating rate than the fluids. Paradoxically, the higher the particle concentration, the higher the heating rate of the food systems, even if theoretically the fluids have a higher electrical conductivity. This was attributed to the increased temperature gradient of solids as compared to liquids.

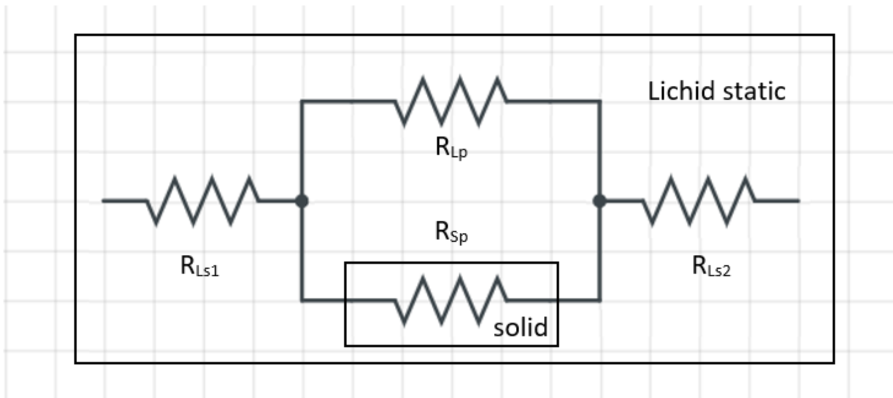

Figura 7.1. Circuit diagram for electric ohmic heating circuit after *Sastry and Salengke (1998)*

Total electrical resistance can be determined by calculation [*Sastry and Salengke, 1998*].

$$R = R_{Ls} + \frac{R_{Lp} \cdot R_{Sp}}{R_{Lp} + R_{Sp}}$$

where:
R – total electrical resistance, (Ω)
R_{Ls} – the serial electric resistance of the liquid (R_{Ls1}+ R_{Ls2}), (Ω)
R_{Lp} – parallel electrical resistance of the liquid, (Ω)
R_{Sp} – parallel electrical resistance of the solid, (Ω)

In the case of ohmic heating, the temperature distribution in the product is uniform as the resulting heat takes place due to the passage of the electric current through a product acting as an electrical resistance, eliminating the need for the use of heat exchangers. The conversion rate of electric energy to thermal energy is close to 100%.

The ohmic heating thermal processing technique can be performed using continuous or alternating current, but usually the alternating current is preferred to avoid the undesirable effects of the electrochemical and electrolytic reactions that may occur in the product.

The operating principle of ohmic heating is given by the ionic conduction in electrolytes with heat generation, conditioned by the presence of ionic constituents. For ionic conduction to occur, a voltage gradient must be applied between the electrodes of the ohmic plant, resulting in heat generation in the product.

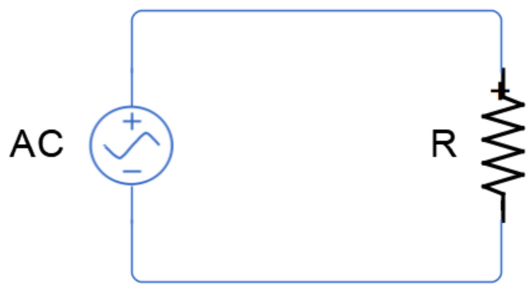

Figura 7.2. The simplified electrical diagram of ohmically heating

R – the resistance of the heat-processed product.
AC – voltage source, alternating current.

7.2. Objectives

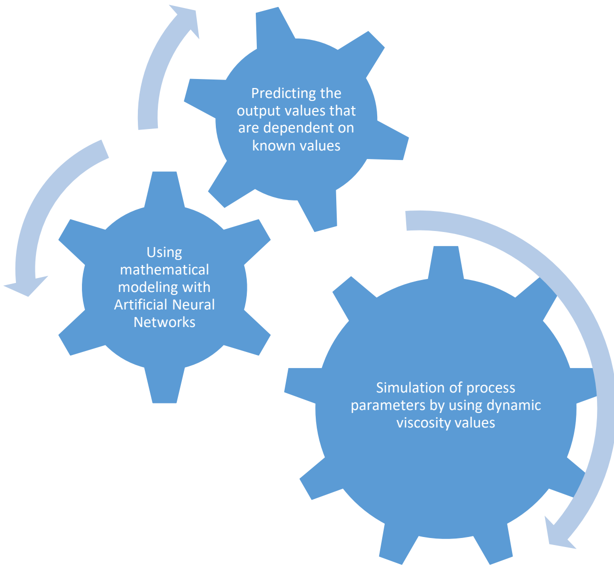

Figure 7.4. Objectives of simulation of thermal processing techniques

7.3. Materials and methods

The data used for prediction were obtained experimentally by testing samples of courgette puree or bell pepper with the addition of hydrocolloids, as follows: apple / citrus pectin in a concentration of 0.1-0.3% or starch or sodium alginate in proportion 1-3%.

In the tables below are presented experimental data used as input in RNA simulation:

Table 7.1. The dynamic viscosity values versus the shear rate for the courgette purees with citrus/apple pectin addition

γ, s^{-1}	M_D	$D_{PC0.1}$	$D_{PC0.2}$	$D_{PC0.3}$	$D_{PM0.1}$	$D_{PM0.2}$	$D_{PM0.3}$
0.00105	19.1	24.2	49.8	49.6	36.66	42.46	61.1
0.00175	15	15.93	26.2	29.36	25.86	32.94	32.66
0.0021	9.83	11.76	22.23	23.76	16.39	19.60	20.33
0.0035	6.4	6.3	13	19.03	9.78	15.68	18.83
0.00525	4.46	4.53	10.4	14.31	6.6	10.09	11.07
0.007	3.66	3.43	7.27	10.81	5	8.03	9.16
0.00875	3.17	2.74	5.86	8.81	4.42	7.48	7.56
0.0105	2.58	2.26	4.79	7.91	3.69	5.58	5.46

0.014	2.06	1.77	3.77	6.36	2.71	4.36	4.31
0.0175	1.68	1.48	3.29	5.35	2.44	3.65	3.56
0.021	1.41	1.19	2.73	4.36	2.15	3.14	3.08
0.035	1	0.72	1.88	2.91	1.306	1.98	2.01
0.042	0.83	0.56	1.50	2.47	1.136	1.622	1.57
0.07	0.60	0.35	0.955	1.53	0.80	1.08	1.01
0.105	0.39	0.219	0.63	1.03	0.533	0.71	0.62
0.175	0.218	0.136	0.38	0.588	0.28	0.338	0.31
0.21	0.15	0.11	0.30	0.465	0.22	0.24	0.26
0.35	0.097	0.074	0.178	0.281	0.131	0.189	0.152
0.35	0.113	0.071	0.219	0.397	0.123	0.131	0.566
0.21	0.156	0.105	0.315	0.451	0.205	0.228	0.23
0.175	0.21	0.11	0.44	0.552	0.22	0.23	0.282
0.105	0.31	0.193	0.655	0.95	0.318	0.342	0.387
0.07	0.45	0.27	0.96	1.42	0.46	0.54	0.565
0.042	0.61	0.41	1.28	2.26	0.78	0.74	0.822
0.035	0.82	0.53	1.81	2.59	0.93	1.77	1.90
0.021	1.11	0.83	2.25	3.95	1.61	2.43	2.53
0.0175	1.32	1.13	2.76	4.77	2.33	2.9	3.04
0.014	1.48	1.463	3.61	5.85	2.67	3.59	4.08
0.0105	1.91	1.77	4.21	6.99	3.47	4.28	5.03
0.00875	2.47	2.23	5.48	8.64	4.28	5.21	7.07
0.007	3.05	2.90	6.76	9.92	4.66	6.72	8.61
0.00525	3.99	3.78	9.75	13.68	6.44	7.79	10.43
0.0035	4.76	5.51	12.16	17.13	9.76	13.14	17.62
0.0021	7	10.58	20.18	21.09	16.06	18.4	19.63
0.00175	8.73	17.26	24	28.64	24.6	23.46	31.69
0.00105	13.16	22.10	45.9	46.13	36.77	46.06	60.03

Table 7.2. Experimental data obtained for dynamic viscosity values versus the shear rate for the courgette purees with starch/sodium alginate addition

ɣ, s-1	**DM**	**DAM1**	**DAM2**	**DAM3**	**DAL1**	**DAL2**	**DAL3**
0.00106	23.25	28.9	32.9	40.9	14.8	29.1	35.2
0.0017	20.8	25.6	28	35.68	10	20.4	29.36
0.00212	19.2	23.02	25.9	29.98	8.53	19.07	25.8
0.0035	15.2	19.07	20.78	23.89	6.64	18.56	17.56
0.0053	11.84	18.87	19.22	21	5.5	13.97	13.63
0.007	9.27	10.27	15.75	17	4.92	13.52	10.12
0.0088	8.32	8.98	10.66	13.97	4.37	10.78	8.72

0.0106	6.08	7.27	9.52	11.83	3.83	9.12	7.8
0.0141	4.4	5.68	7.98	9.36	3.09	7.85	6.62
0.017	3.7	4.84	6.25	8.42	2.67	6.28	5.66
0.021	3	4	5.89	6.56	2.35	5.32	4.92
0.035	2.3	3.89	4.27	5.69	1.63	4.67	3.48
0.0424	1.96	3.1	3.82	4.82	1.45	3.19	3.07
0.0706	1.67	2.98	3.09	4.09	1.006	2.74	2.98
0.106	1.06	2.16	2.86	3.46	0.735	1.9	2.59
0.176	0.89	1.98	2.09	3.12	0.51	1.7	1.9
0.212	0.556	1.56	1.84	2.97	0.442	1.5	1.7
0.35	0.373	1.26	1.53	2.26	0.305	1.3	1.5
0.35	0.23	1.18	1.46	2.14	0.302	1.27	1.45
0.212	0.48	1.56	1.76	2.56	0.434	1.4	1.59
0.176	0.79	1.89	2.08	2.78	0.492	1.67	1.79
0.106	0.99	2.07	2.59	3	0.707	1.88	1.97
0.0706	1.12	2.67	2.79	3.98	0.95	2.55	2.85
0.0424	1.58	2.98	3.09	4.62	1.36	2.85	3.25
0.035	2	3.28	4.01	5.36	1.57	3	3.55
0.021	2.7	4	5.26	6.26	2.24	4.28	4.68
0.017	3.4	4.65	6.1	8.32	2.59	5.98	6.77
0.0141	4	5.94	7.28	9.14	2.98	7.62	8.15
0.0106	5.48	7.07	9.04	11.24	3.53	8.92	9.5
0.0088	6.68	8.28	10	13	3.74	10	11
0.007	7.03	9.56	15.2	16.66	4.06	13	15
0.0053	7.8	10.97	19	20.97	4.56	13.56	15.98
0.0035	8.1	11.27	20.3	22.72	4.88	17.76	19
0.00212	9.04	19.87	25.42	28.72	6	18.68	20.37
0.0017	11.2	21.28	27.08	33.63	7.76	19.8	21.75
0.00106	14.78	25.26	31.99	40	8.9	28.68	30

Table 7.3. Dynamic viscosity values versus the shear rate for the bell pepper purees with citrus/apple pectin addition

ɣ, s^{-1}	**MA**	**$APC_{0.1}$**	**$APC_{0.2}$**	**$APC_{0.3}$**	**$APM_{0.1}$**	**$APM_{0.2}$**	**$APM_{0.3}$**
0.00106	36.83	44.35	59.76	66.8	46.4	53.5	69.7
0.0017	28.90	28.13	44.17	37.36	33.62	40	47.06
0.00212	26.66	23.33	39.79	32.1	23.66	32.20	41.75
0.0035	19.6	18.7	24.65	23.12	18.72	18.69	30.82
0.0053	9.88	10.96	17.41	15.45	9.77	14.76	22.62
0.007	6.98	8.58	12.8	12.96	7.64	12.15	22.15

0.0088	5.25	6.39	10.18	11.31	5.9	9.89	17.82
0.0106	4.55	5.78	9.59	9.845	5.36	7.93	13.25
0.0141	3.52	4.46	7.22	6.925	4.426	6.40	9.36
0.017	2.63	3.71	5.95	5.572	3.44	4.96	7.784
0.021	2.15	3.63	4.911	4.7265	2.83	4.084	6.251
0.035	1.308	2.21	3.01	3.02	1.66	2.970	4.88
0.0424	1.067	1.888	2.521	2.5285	1.418	2.373	3.45
0.0706	0.646	1.39	1.54	1.58	0.86	1.795	2.502
0.106	0.42	0.878	0.99	1.0965	0.57	1.018	1.76
0.176	0.255	0.604	0.59	0.6845	0.331	0.611	1.11
0.212	0.204	0.499333	0.499	0.58	0.276	0.450	0.87
0.35	0.131667	0.347333	0.29	0.361	0.164	0.28	0.71
0.35	0.136	0.396	0.27	0.357	0.158	0.242	0.52
0.212	0.194	0.43	0.49	0.524	0.25	0.46	0.63
0.176	0.27	0.502	0.565	0.6065	0.3	0.548	1.07
0.106	0.333	0.809	0.95	0.9315	0.48	0.87	1.44
0.0706	0.51	1.14	1.47	1.319	0.698	1.308	2.16
0.0424	0.88	1.74	2.27	2.1035	1.082	1.942	3.27
0.035	1.051	1.99	2.62	2.496	1.32	2.41	3.91
0.021	1.61	2.80	4.08	3.8215	2.06	3.50	6.131
0.017	2.04	3.33	4.63	4.522	2.88	4.74	7.272
0.0141	2.86	4.45	6.59	5.25	3.20	4.83	7.78
0.0106	3.76	5.86	7.37	6.88	3.91	5.97	9.31
0.0088	4.97	7.14	9.03	7.815	5.62	7.23	10.65
0.007	6.19	8.7	9.00	11.74	5.98	11.73	13.48
0.0053	7.39	9.93	12.22	13.4	7.66	13.63	15.42
0.0035	9.16	12.31	13.48	18.04	10.5	15.62	23
0.00212	16.82	23.25	31	30.695	16.96	24.26	31.32
0.0017	25.2	27.38	36.02667	35.06	23.78	40.70	40.90
0.00106	33.8	43.70	53.7	65.09	30.97	47.99	67.33

Table 7.4. Dynamic viscosity values versus the shear rate for the bell pepper purees with starch/sodium alginate

ɣ, s-1	**AM**	**AAM1**	**AAM2**	**AAM3**	**AAL1**	**AAL2**	**AAL3**
0.00106	10.5	19.23	24	32	12.9	15.45	18.24
0.0017	10	13.46	21.75	29	11.25	13.05	15.26
0.00212	9.75	12.95	18.25	24.21	10.75	12.15	14.2
0.0035	9.25	12	16	20.18	9.75	11.07	12
0.0053	8.75	11.4	13.23	18.89	9.06	10.56	11.28

0.007	8	10	11.85	14.87	8.65	9.88	10.65
0.0088	6.9	8.25	9.75	12.54	7.94	8.82	9.59
0.0106	5.2	7	8.95	10.43	7	7.69	8.82
0.0141	4.88	6.4	7.52	9.25	6.36	7	8
0.017	4.51	5.88	6.89	8.03	5.82	6.25	7.25
0.021	4	5	6	7.23	5.12	5.79	6.4
0.035	3.55	4.24	5.45	6.48	4.65	5	6
0.0424	3.02	3.3	4	5.25	3.95	4.7	5.26
0.0706	2.45	2.1	3.2	4.35	3.04	4	4.97
0.106	1.35	1.8	2.5	3.78	2.63	3.23	3.81
0.176	0.99	1.2	1.7	2.22	1.23	2.75	3.05
0.212	0.55	0.8	1.1	1.7	0.89	1.25	2
0.35	0.22	0.4	0.8	1	0.53	0.89	1.4
0.35	0.2	0.3	0.6	0.8	0.33	0.7	1
0.212	0.4	0.5	1	1.3	0.68	0.8	1.2
0.176	0.8	1	1.5	2	1	1	1.8
0.106	1	1.5	2.2	3.23	1.65	2.56	2.9
0.0706	1.85	2.3	3	4.02	1.85	3	3.23
0.0424	2.75	3	3.7	4.87	2.08	3.69	4.65
0.035	3.15	4.95	5	5.01	2.56	4	5.05
0.021	3.75	5.83	5.65	5.4	3	4.75	5.86
0.017	5	6.67	6	6.2	3.92	5.26	6.75
0.0141	5.89	7.08	7.02	8	4.87	6	8
0.0106	6.3	7.56	8	10.05	5	6.89	9.17
0.0088	6.9	8.1	8.98	11.45	6.63	7.25	10.26
0.007	7.85	8.69	10.78	14.3	7.12	8.36	11.02
0.0053	7.65	9.531	12.94	16.2	8.02	9.26	11.86
0.0035	8	10.24	15.45	19.06	8.95	10.89	12.43
0.00212	8.75	11.07	17.2	21.4	10	11.69	13.22
0.0017	9.25	12.21	20.4	26.2	10.93	12.85	14.67
0.00106	10	18.74	23	30	12	14.79	16.23

The vegetal material, hydrocolloid concentrations and their nature have been chosen for consumption by people suffering from dysphagia, these products being presented as *ready-to-eat*.

7.4. Results and discussions

The knowledge of the physical properties of food is fundamental in the analysis of unitary operations present in the food industry. The study of these food properties and their responses to process conditions are necessary because they influence the treatment received during processing and also because they are good food quality indicators. Viscosity and its variation depending on different parameters is very important for the food industry in general and especially for plant products because it is necessary to design and optimize several processes or unit operations (eg pumping, evaporation, membrane filtration etc.) [*Rai et al., 2005*].

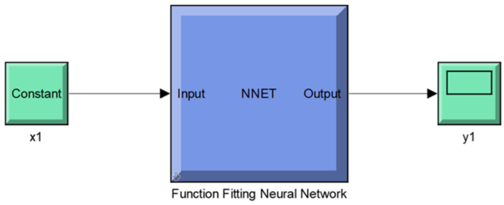

Figure 7.5. Flow chart of RNA

In prediction issues the using of Artificial Neural Networks, it is intended to link incoming data to target data. Using the nftool function, input and target data were created to train an artificial neural network, to evaluate ANN performance using regression analysis and mean squared error (MSE).

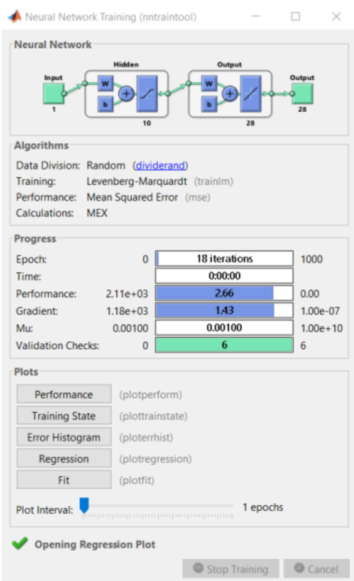

Figure 7.10. The results of network training

The *nntraintool* function provides detailed information about the drive algorithm and network status.

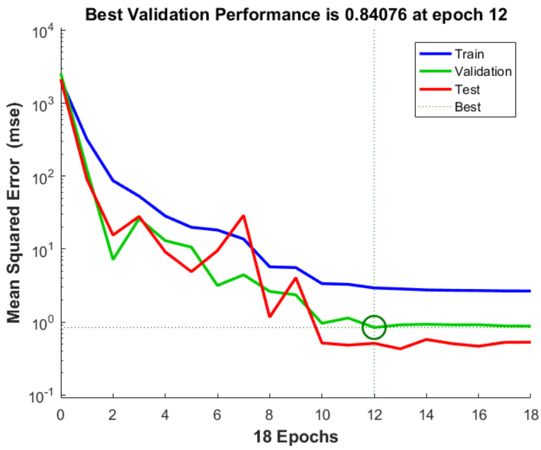

Figure 7.11. The ANN performances

The performance indicator for feed-forward networks is given by the mean square error (MSE) between output data and target data. MSE values drop rapidly as the network learns. The network traction stops when the valid mean square error stops decreasing.

Feed-forward neural networks are the most popular and widely used in many practical applications. They are known by many different names, such as: multi-layer perceptrons. In the feed-forward network the neurons on the first layer send their results to the neurons on the second layer, but do not receive any input back forming the neurons on the second layer [*Rai et al., 2005*].

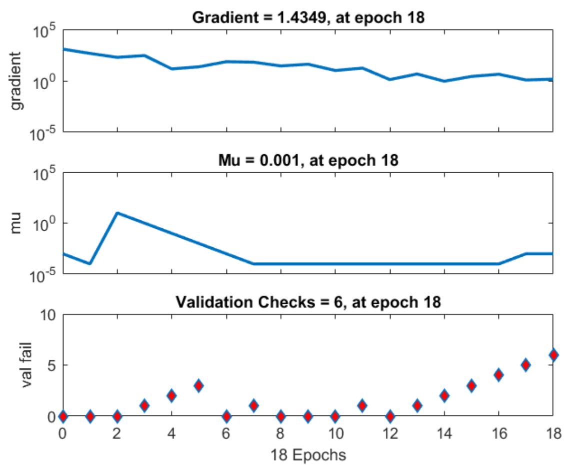

Figure 7.12. Training status

The training status diagram shows how validation was performed. The total number of validation checks was equal to 6 at 18 epochs where the best performance was achieved.

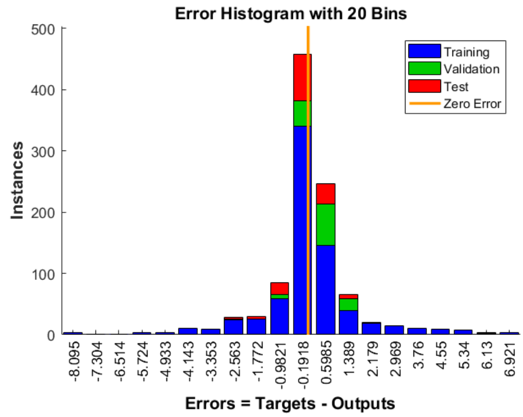

Figure 7.13. Errors histogram

The histogram indicates the errors for the output data. The orange line shows the point where the error is zero. This point can be identified and re-established the network to obtain more accurate output data, ie higher performance.

7.5. Partial conclusions

To model the dynamic viscosity values of courgette and bell pepper purees with apple/citrus pectin or starch/alginate, Artificial Neural Networks were used.

The study highlights the importance of ANN modeling and simulation for such applications. The more modeling data set is larger and more uniform in the range of signal variation, the more accuracy of simulation increases. ANN is an extremely easy solution where mathematical modeling is much more difficult. By means of predicting, the using of ANN was possible to determine the necessary data underlying the swallowing process. Depending on the addition of hydrocolloids, there were approximated the values of the dynamic viscosity, which characterize ready-to-eat products with special destination, for the consumption of people with dysphagia. The results obtained by modeling experimental data can be the basis of future studies and can help estimate the dynamic viscosity values of vegetables or fruits.

8. General conclusions, original contributions and research perspectives

8.1. General conclusions

- Four ready-to-eat products, each presented in 3 variants, were designed for the study.
- Two types of hydrocolloids - pectin from citrus and apple - were of interest for the study presented.
- Initially, experiments aimed at obtaining *ready-to-eat* products with special purpose, characterization and investigation of the impact of ohmic heating on the matrix obtained.
- Courgette and bell pepper purees with citrus/apple pectin 0.3% are the best options from the technologically point of view.
- FT-IR (Fourier Transform Infrared Spectroscopy) spectroscopy has identified the presence of pectin and the fact that the 0.1% minimum added percentage is sufficient to improve the puree structure.
- In the case of the experiments with starch and sodium alginate, which constituted the other two hydrocolloids chosen to be added to the courgette and bell pepper purees, the optimum starch concentration was determined at 3%.
- Ohmic heating does not alter the rheological behavior of courgette and bell pepper purees indifferent to the type of added hydrocolloids.
- The ohmic heating and the addition of hydrocolloids led to the improvement of all the texture attributes of courgette and bell pepper purees.
- FT-IR spectroscopic analysis (Fourier Transform Infrared Spectroscopy) identified new complexes with amylose and amylopectin chains.
- Confocal laser scanning microscopy revealed the presence of cellular structures and intact cellular constituents present in samples, which underlines the fact that ohmic heating is a mild technique of food processing.
- Courgette and bell pepper purees treated by ohmic heating are well suited for use in the nutrition of dysphagic persons.
- Considering the complexity of food matrices, ANN is an easy method of modeling experimentally data.

8.2. Original contributions and research perspectives

- The data obtained from the researches carried out could be the basis for the development of industrial scale products.
- The study presents original elements from the perspective of products chosen for research and their special purpose (for people suffering from dysphagia).
- The data presented may be the basis for the development of ready-to-eat products for special nutrition.
- The results of the study can be used as a database for the effects of ohmic heating on the rheological and textural behavior, electrical and physico-chemical properties of courgette and bell pepper purees supplemented with hydrocolloids (pectin from citrus and apple, starch and sodium alginate).
- Research prospects may be the use of other types of insufficiently exploited vegetables or fruits, and the use of other types of hydrocolloids to produce ready-to-eat products.

LIST OF PAPERS PUBLISHED AND PRESENTED

Abstracts in ISI journals

- Olaru Lucian Daniel, Nistor Oana Viorela, Andronoiu Doina Georgeta, Ghinea Ioana Otilia, Ionita Elena, Botez Elisabeta. 2017. Application of ohmic heating on the bell pepper puree with added apple pectin, Journal of Biotechnology 256S, S17–S43.
- Lucian Daniel Olaru, Oana Viorela Nistor, Doina Georgeta Andronoiu, Vasilica Barbu, Elisabeta Botez, The processing behaviour of starch-based courgettes (Cucurbita pepo var. obloga) purees, Journal of Biotechnology 280S (2018) S32–S91.

BDI Articles

- Oana Viorela Nistor, Lucian Daniel Olaru, Doina Georgeta Andronoiu, Elisabeta Botez, Bell pepper puree especially designed for people with dysphagia, The Volume of the 22nd International Exhibition of Inventics "INVENTICA 2018", June 28th-29th, Iasi, Romania, ISSN 1844-7880.
- Lucian D. Olaru, Oana V. Nistor, Doina G. Andronoiu, Viorica Vasilica Barbu, Ioana Otilia Ghinea, Elisabeta Botez, Evaluation Of Ohmic Heating Effects On Bell Pepper Puree With Added Citrus Pectin, The Annals of the University Dunarea de Jos of Galati, FascicleVI->> FOOD >> TECHNOLOGY 42(2)/2018 – IN PRESS.

ISI Articles

- Lucian Daniel Olaru, Oana-Viorela Nistor, Doina Georgeta Andronoiu, Ioana Otilia Ghinea, Viorica Barbu, Elisabeta Botez, Effect of added hydrocolloids on ready-to-eat courgette (*Cucurbita pepo*) puree ohmically treated, 2018 – In recenzie la Journal of Food Science and Technology.

Papers presentations at international conferences

- Olaru Lucian Daniel, Nistor Oana Viorela, Andronoiu Doina Georgeta, Ghinea Ioana Otilia, Ionita Elena, Botez Elisabeta. Application of ohmic heating on the bell pepper puree with added apple pectin, European Biotechnology Congress, 25-27 May 2017, Dubrovnik, Croatia.
- Olaru Lucian D., Nistor Oana V., Andronoiu Doina G., Barbu Vasilica, Botez Elisabeta. 2017. Evaluation of Ohmic Heating Effects on Bell Pepper Puree with Added Citrus Pectin, 8th International Euroaliment Symposium Mutatis Mutandis in Foods, 7 – 8 September 2017, Galatí, Romania.
- Lucian Daniel Olaru, Oana-Viorela Nistor, Doina Georgeta Andronoiu, Vasilica Barbu, Elisabeta Botez, The processing behavior of starch based

courgettes (*Cucurbita pepo var. obloga*) purees, European Biotechnology Congress, Athens, Greece.

• Oana Viorela Nistor, Lucian Daniel Olaru, Doina Georgeta Andronoiu, Elisabeta Botez, Bell pepper puree especially designed for people with dysphagia, The 22nd International Exhibition of Inventics "INVENTICA 2018", June 28-29, Iași, România.

• Luiza-Andreea Tănase, Lucian Daniel Olaru, Oana – Viorela Nistor, Doina Georgeta Andronoiu, Liliana Ceclu, Elisabeta Botez, Ohmically heated courgettes (*Cucurbita Pepo Var. Obloga*) purees especially designed for dysphagia, International Conference on Microbiological Biotechnology 4th Edition, 11-12 October 2018, Chisinau, Moldova Republic.

Papers presentations at national conferences

• Olaru Lucian Daniel, Nistor Oana-Viorela, Andronoiu Doina Georgeta, Botez Elisabeta. 2017. Effect of ohmic heating processing on the electrical and chemical properties of bell pepper puree with added citrus pectin. SCDS-UDJG 2017, 8-9 June 2017, Galați, Romania.

• Lucian Daniel Olaru, Oana-Viorela Nistor, Doina-Georgeta Andronoiu, Elisabeta Botez, Sodium alginate addition effects on the rheological and textural properties of courgettes purees, SCDS-UDJG 2018, 7-8 June 2018, Galați, Romania.

• Lucian Daniel Olaru, Oana- Viorela Nistor, Elisabeta Botez, 2016, A mini review on thermal processing techniques: scientific and technological aspects, The Fourth Edition of the Scientific Conference of the Doctoral Schools of Dunarea de Jos University, 2-3 iunie, Galați, Romania.

Patent

• Produs vegetal ready-to-eat destinat persoanelor vârstnice OSIM nr. A00188/09.05.2018 (UDJG nr.5596/16.03.2018), Autori: Nistor Oana-Viorela, Olaru Lucian-Daniel, Botez Elisabeta, Andronoiu Doina Georgeta – on-line on OSIM platform.

*Toate publicațiile au derivat din programul de cercetare al tezei de doctorat

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